Benefits to Your Patients

- Boost circulation and lymphatic return
- Decrease edema
- Clear inflammation
- Increase ROM
- Decrease muscle soreness
- Alleviate pain

Benefits to Your Practice

- Improve patient outcomes
- Increase revenue through insurance, cash based services, and retail sales
- Attract new patients
- Increase retention

Interested in finding out more?
Reach out today to Rehab@Hyperice.com

Learn more about the research and science behind Hyperice technology, how other practices are utilizing the products, and discuss the option of receiving a free demo kit to trial in your clinic.
The VASYLI + Howard Dananberg (VHD) orthotic is the world’s first professional orthotic device to enhance 1st Ray Function. The unique removable plugs improves the function pathway of the 1st Ray (great toe) and reduced stressed on the tissues from the feet up to the lower back.

INTERESTED IN EXPLORING VASYLI MEDICAL ORTHOTICS FOR YOUR PATIENTS?
Contact us at medicalsales@vionicgroup.com to secure your sample pair today (Free pair for qualified clinicians only).

www.vasylimedical.com
It’s Time To Try Stopain® Clinical!

To request your FREE Sample Kit, scan the QR code or visit: http://bit.ly/RequestAASPT

Safe & Effective migraine and headache pain relief without any acetaminophen, aspirin, caffeine, dyes, fragrances, opioids or preservatives!

migrainestudy.us

Thomas Jefferson
Clinical Study & Frontiers in Neurology White Paper

Learn more at StopainClinical.com
EDITORIAL BOARD

David Behm, PhD
Memorial University of Newfoundland
St. John's, Newfoundland, Canada

Barton N. Bishop, PT, DPT, SCS, CSCS
Kaizo Clinical Research Institute
Rockville, Maryland, USA

Mario Bizzini, PhD, PT
Schulthess Clinic Human Performance Lab
Zürich, Switzerland

Joe Black, PT, DPT, SCS, ATC
Total Rehabilitation
Maryville, Tennessee, USA

Turner A. "Tab" Blackburn
NASMI
Lanett, AL, USA

Lori Bolgla, PT, PhD, MAcc, ATC
Augusta University
Augusta, Georgia, USA

Matthew Briggs
The Ohio State University
Columbus, OH, USA

Tony Brosky, PT, PhD
Bellarmine University
Louisville, KY, USA

Brian Busconi, MD
UMass Memorial Hospital
Boston, MA, USA

Robert J. Butler, PT, PhD
St. Louis Cardinals
St. Louis, MO, USA

Duane Button, PhD
Memorial University
St. John's, Newfoundland, Canada

J. W. Thomas Byrd, MD
Nashville Sports Medicine and Orthopaedic Center
Nashville, TN, USA

Lyle Cain, MD
Andrews Institute & Sports Medicine Center
Birmingham, AL, USA

Gary Calabrese, PT, DPT
Cleveland Clinic
Cleveland, Ohio, USA

Meredith Chaput, PT, DPT, SCS
Ohio University
Athens, OH, USA

Rita Chorba, PT, DPT, MAT, SCS, ATC, CSCS
United States Army Special Operations Command
Fort Campbell, KY, USA

John Christoferreti, MD
Texas Health
Dallas, TX, USA

Richard Clark, PT, PhD
Tennessee State University
Nashville, TN, USA

Juan Colado, PT, PhD
University of Valencia
Valencia, Spain

Brian Cole, MD
Midwest Orthopaedics at Rush
Chicago, IL, USA

Ann Cools, PT, PhD
Ghent University
Ghent, Belgium

Andrew Contreras, DPT, SCS
Washington, DC, USA

George Davies, PT, DPT, MEd, SCS, ATC, LAT, CSCS, PES, FAPTA
Georgia Southern University
Savannah, Georgia, USA

Pete Draovich, PT
Jacksonville Jaguars Football
Jacksonville, FL, USA

Jeffrey Dugas, MD
Andrews Institute & Sports Medicine Center
Birmingham, AL, USA

Jiri Dvorak, MD
Schulthess Clinic
Zurich, Switzerland

Todd Ellenbecker
Rehab Plus
Phoenix, AZ, USA

Carolyn Emery, PT, PhD
University of Calgary
Calgary, Alberta, Canada

Ernest Esteve Caupena, PT, PhD
University of Girona
Girona, Spain

Sue Falsone, PT, MS, SCS, ATC, CSCS, COMT
Structure and Function Education and
A.T. Still University
Phoenix, Arizona, USA

J. Craig Garrison, PhD, PT, ATC, SCS
Texas Health Sports Medicine
Fort Worth, Texas, USA

Maggie Gebhardt, PT, DPT, OCS, FAOMPT
Fit Core Physical Therapy/Myopain Seminars
Atlanta, GA and Bethesda, MD, USA

Lance Gill, ATC
LG Performance-TPI
Oceanside, CA, USA

Phil Glasgow, PhD, MTh, MRes, MCSP
Sports Institute of Northern Ireland
Belfast, Northern Ireland, UK

Robert S. Gray, MS, AT
Cleveland Clinic Sports Health
Cleveland, Ohio, USA
EDITORIAL BOARD

Jay Greenstein, DC  
Kaizo Health  
Baltimore, MD, USA

Martin Hagglund, PT PhD  
Linkoping University  
Linkoping, Sweden

Allen Hardin, PT, SCS, ATC, CSCS  
University of Texas  
Austin, TX, USA

Richard Hawkins, MD  
Steadman Hawkins Foundation  
Vail, CO, USA

Tim Hewett, PhD  
Hewett Consulting  
Minneapolis, Minnesota, USA

Per Holmich, MD  
Copenhagen University Hospital  
Copenhagen, Denmark

Kara Mae Hughes, PT, DPT, CSCS  
Wolfe PT  
Nashville, TN, USA

Lasse Ishøi, PT, MSc  
Sports Orthopedic Research Center  
Copenhagen University Hospital  
Hvidovre, Denmark

Jon Karlsson, MD  
Sahlgrenska University  
Goteborg, Sweden

Brian Kelly, MD  
Hospital for Special Surgery  
New York, NY, USA

Benjamin R. Kivlan, PhD, PT, OCS, SCS  
Duquesne University  
Pittsburgh, PA, USA

Dave Kohlrieser, PT, DPT, SCS, OCS, CSCS  
Ortho One  
Columbus, OH, USA

Andre Labbe PT, MOPT  
Tulane Institute of Sports Medicine  
New Orleans, LA, USA

Hemning Langberg, PT, PhD  
University of Copenhagen  
Copenhagen, Denmark

Robert LaPrade, MD  
Twin Cities Orthopedics  
Edina, MN, USA

Lace Luedke, PT, DPT  
University of Wisconsin  
Oshkosh, WI, USA

Lenny Macrina, PT, SCS, CSCS, C-PS  
Champion Physical Therapy and Performance  
Boston, MA, USA

Phillip Malloy, PT, PhD  
Arcadia University/Rush University Medical Center  
Glenside, PA and Chicago, IL, USA

Terry Malone, PT, EdD, ATC, FAPTA  
University of Kentucky  
Lexington, KY, USA

Robert Mangine, PT  
University of Cincinnati  
Cincinnati, OH, USA

Eric McCarty, MD  
University of Colorado  
Boulder, CO, USA

Ryan P. McGovern, PhD, LAT, ATC  
Texas Health Sports Medicine Specialists  
Dallas/Fort Worth, Texas, USA

Mal McHugh, PhD  
NISMAT  
New York, NY, USA

Joseph Miller, PT, DSc, OCS, SCS, CSCS  
Pikes Peak Community College  
Colorado Springs, CO, USA

Havard Moksnes, PT PhD  
Oslo Sports Trauma Research Center  
Oslo, Norway

Michael J. Mullaney, PT, SCS  
NISMAT  
Mullaney & Associates Physical Therapy  
New York, NY and Matawan, NJ, USA

Andrew Murray, MD, PhD  
European PGA Tour  
Edinburgh, Scotland, UK

Andrew Naylor, PT, DPT, SCS  
Bellin Health  
Green Bay, WI, USA

Stephen Nicholas, MD  
NISMAT New York  
New York, NY, USA

John O’Donnel, MD  
Royal Melbourne Hospital  
Melbourne, Australia

Russ Paine, PT  
McGovern Medical School  
Houston, TX, USA

Suchal Patel, PT, MSPT, SCD  
HSS Sports Rehabilitation Institute  
New York, NY, USA

Marc Philippon, MD  
Steadman-Hawkins Clinic  
Vail, CO, USA

Nicola Phillips, OBE, PT, PhD, FCSP  
Professor School of Healthcare Sciences  
Cardiff University  
Cardiff, Wales, UK

Kevin Plancher, MD, MPH, FAOS  
Plancher Orthopedics and Sports Medicine  
New York, NY, USA
EDITORIAL BOARD

Marisa Pontillo, PT, PhD, DPT, SCS
University of Pennsylvania Health System
Philadelphia, PA, USA

Matthew Provencher, MD
Steadman Hawkins Clinic
Vail, CO, USA

Charles E. Rainey, PT, DSc, DPT, MS, OCS, SCS, CSCS, FAAOMPT
United States Public Health Service
Springfield, MO, USA

Alexandre Rambaud, PT PhD
Saint-Etienne, France

Carlo Ramponi, PT
Physiotherapist, Kinè Rehabilitation and Orthopaedic Center
Treviso, Italy

Michael Reiman, PT, PhD
Duke University
Durham, NC, USA

Mark F. Reinking, PT, PhD, SCS, ATC
Regis University
Denver, CO, USA

Mike Reinoel, PT, DPT, SCS, ATC, CSCS, C-PS
Champion Physical Therapy and Performance
Boston, MA, USA

Mark Ryan, ATC
Steadman-Hawkins Clinic
Vail, CO, USA

David Sachse, PT, DPT, OCS, SCS
USAF
San Antonio, TX, USA

Marc Safran, MD
Stanford University
Palo Alto, CA, USA

Alanna Salituro, PT, DPT, SCS, CSCS
New York Mets
Port Saint Lucie, FL, USA

Mina Samukawa, PT, PhD, AT (JSPO)
Hokkaido University
Sapporo, Japan

Barbara Sanders, PT, PhD, FAPTA, Board Certified Sports Physical Therapy Emeritus
Professor and Chair, Department of Physical Therapy
Texas State University
Round Rock, TX, USA

Felix “Buddy” Savoie, MD, FAAOS
Tulane Institute of Sport Medicine
New Orleans, LA, USA

Teresa Schuemann, PT, DPT, ATC, CSCS, Board Certified Specialist in Sports Physical Therapy
Evidence in Motion
Fort Collins, CO, USA

Timothy Sell, PhD, PT, FACSM
Atrium Health Musculoskeletal Institute
Charlotte, NC, USA

Andreas Serner, PT PhD
Aspetar Orthopedic and Sports Medicine Hospital
Doha, Qatar

Ellen Shanley, PT, PhD
ATI
Spartanburg, SC, USA

Karin Silbernagel, PT, PhD
University of Delaware
Newark, DE, USA

Holly Silvers, PT, PhD
Velocity Physical Therapy
Los Angeles, CA, USA

Lynn Snyder-Mackler, PT, ScD, FAPTA
STAR University of Delaware
Newark, DE, USA

Alston Stubbs, MD
Wake Forest University
Winston-Salem, NC, USA

Amir Takla, B.Phys, Mast.Physio (Manip), A/Prof Australian Sports Physiotherapy
The University of Melbourne
Melbourne, Australia

Charles Thigpen, PhD, PT, ATC
ATI
Spartanburg, SC, USA

Steven Tippett, PT, PhD, ATC, SCS
Bradley University
Peoria, IL, USA

Tim Tyler, PT, ATC
NISMAT
New York, NY, USA

Timothy Uhl, PT, PhD, ATC
University of Kentucky
Lexington, KY, USA

Bakare Ummukthhom, PT
University of the Witswatersrand
Johannesburg, Gauteng, South Africa

Yuling Leo Wang, PT, PhD
Sun Yat-sen University
Guangzhou, China

Mark D. Weber, PT, PhD, SCS, ATC
Texas Women's University
Dallas, TX, USA

Richard B. Westrick, PT, DPT, DSc, OCS, SCS
US Army Research Institute
Boston, MA, USA

Chris Wolfe, PT, DPT
Belmont University
Nashville, TN, USA

Tobias Wörner, PT, PhD
Lund University
Stockholm, Sweden
IJSPT

INTERNATIONAL JOURNAL OF SPORTS PHYSICAL THERAPY

Founding Sponsors

Arthrex
DOJO Global
Exertools
Hyperice
InReach Health
PT Genie
Stopain Clinical
Tazer
Vasyli

Board of Directors / Business Advisory Board

Turner A Blackburn, PT, ATC President
Mary Wilkinson Director of Operations
Michael Voight Executive Editor and Publisher
Joe Black, PT, DPT, SCS, ATC
Eric Fernandez
Jay Greenstein, DC
Skip Hunter, PT, ATC-Ret
Sean MacNeal
Russ Paine, PT, DPT
Mike Reinold, PT, DPT, SCS, ATC, CSCS, C-PS
Danny Smith, PT, DPT, DHSc, OCS, SCS, ATC
Paul Timko
Tim Tyler, PT, ATC

Sports Legacy Advisory Board

Turner A. Blackburn, PT, ATC
George Davies, PT, DPT, MEd, SCS, ATC, LAT, CSCS, PES, FAPTA
Terry Malone, PT, PhD
Bob Mangine, PT
Barb Sanders, PT, PhD
Tim Tyler, PT, ATC
Kevin Wilk, PT, DPT, FAPTA

IJSPT is a bimonthly publication, with release dates in February, April, June, August, October and December. It is published by the North American Sports Medicine Institute.

ISSN 2159-2896

Contact Information
International Journal of Sports Physical Therapy
6011 Hillsboro Pike
Nashville, TN 37215, US,
http://www.ijspt.org

IJSPT is an official journal of the International Federation of Sports Physical Therapy (IFSPT).
WOULD LIKE TO THANK ITS FOUNDING SPONSORS
# TABLE OF CONTENTS

**VOLUME 16, NUMBER 1**

<table>
<thead>
<tr>
<th>Page</th>
<th>Article Title</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SYSTEMATIC REVIEW/META-ANALYSIS</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>The Comparative Mental Health Responses between Post-musculoskeletal Injury and Post-concussive Injury Among Collegiate Athletes: A Systematic Review. &lt;br&gt; <em>Sabol J, Kane C, Wilhelm MP, Reneker JC, Burrowbridge Donaldson M</em></td>
</tr>
<tr>
<td><strong>ORIGINAL RESEARCH</strong></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Sequencing and Integration of Cervical Manual Therapy and Vestibulo-oculomotor Therapy for Concussion Symptoms: Retrospective Analysis. &lt;br&gt; <em>Wong CK, Ziaks L, Vargas S, DeMattos T, Brown C</em></td>
</tr>
<tr>
<td>21</td>
<td>Determining Near Point of Convergence: Exploring a Component of the Vestibular/Ocular Motor Screen Comparing Varied Target Sizes. &lt;br&gt; <em>Heick JD, Bay C</em></td>
</tr>
<tr>
<td>31</td>
<td>Does the Movement Competency Screen Correlate with Deep Abdominals Activation and Hip Strength for Professional and Pre-professional Dancers? &lt;br&gt; <em>Benoit-Plau J, Morin M, Fortin S, Guptill C, Gaudreault N</em></td>
</tr>
<tr>
<td>41</td>
<td>Normative Parameters of Gastrocnemius Muscle Stiffness and Associations with Patient Characteristics and Function &lt;br&gt; <em>Hoffman LR, Koppenhaver SL, MacDonald CW, Herrera JM, Stradi J, Visco ZL, Wildermuth N, Albin SR</em></td>
</tr>
<tr>
<td>49</td>
<td>Validity of a Sham Dry Needling Technique on a Healthy Population. &lt;br&gt; <em>Cushman DM, Holman A, Skinner L, Cummings K, Haight P, Teramoto M</em></td>
</tr>
<tr>
<td>57</td>
<td>Quantifying the Burden of Shoulder and Hip Pain in Water Polo Players Across Different Playing Levels. &lt;br&gt; <em>Girdwood M, Webster M</em></td>
</tr>
<tr>
<td>64</td>
<td>The Relationship Between Hip Strength and Postural Stability in Collegiate Athletes Who Participate in Lower Extremity Dominant Sports. &lt;br&gt; <em>Olsen B, Freijomil N, Csonka J, Moore T, Killelea C, Faherty MS, Sell TC</em></td>
</tr>
<tr>
<td>72</td>
<td>Risk Factors for Stress Fractures in Female Runners: Results of a Survey. &lt;br&gt; <em>Johnston TE, Jakavick AE, Mancuso CA, Mcgee KC, Wei L, Wright ML, Close J, Shimada A, Leiby BE</em></td>
</tr>
<tr>
<td>96</td>
<td>The Immediate Effects of Expert and Dyad External Focus Feedback on Drop Landing Biomechanics in Female Athletes: An Instrumented Field Study. &lt;br&gt; <em>Leonard KA, Simon JE, Yom J, Grooms DR</em></td>
</tr>
<tr>
<td>106</td>
<td>Differences in Lower Extremity Kinematics Between High School Cross-Country and Young Adult Recreational Runners. &lt;br&gt; <em>Reinking MF, Carson NM, End BM, Miller OK, Munter JD, McPoil TG</em></td>
</tr>
<tr>
<td>114</td>
<td>Differences in Physical and Psychological Parameters in Sub-elite Male Youth Soccer Players with Jumper's Knee Following Physical Therapy Compared to Healthy Controls: A Longitudinal Examination. &lt;br&gt; <em>Niering M, Muehlbauer T</em></td>
</tr>
<tr>
<td>135</td>
<td>Does the Direction of Kinesiology Tape Application Influence Muscle Activation in Asymptomatic Individuals? &lt;br&gt; <em>Dolphin M, Brooks G, Calancie B, Rufa A</em></td>
</tr>
<tr>
<td>145</td>
<td>Quadriceps Strength Influences Patient Function more than Single-leg Forward Hop During Late Stage ACL Rehabilitation. &lt;br&gt; <em>Chaput M, Palimenio M, Farmer B, Katsavelis D, Bagwell JJ, Tierman KA, Wichman C, Grindstaff TL</em></td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS
VOLUME 16, NUMBER 1 (CONTINUED)

Page  | Article Title                                                                                                                                                                                                 |
---    |-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
156    | Prediction of ACL Injuries from Vertical Jump Kinetics in Division I Collegiate Athletes. Ponillo M, Hines SM, Sennett BJ                                                                                       |
169    | Patients Walking Faster After Anterior Cruciate Ligament Reconstruction Have More Gait Asymmetry. Knobel RJ, Ito N, Arhos EK, Capin JJ, Buchanan TS, Snyder-Mackler L |
195    | Descriptive Strength and Range of Motion in Youth Baseball Players. Nakaji RM, Ellenbecker TS, McClenahan KM, Roberts LM, Perez C, Dickenson SB                                                                 |
207    | Comparison of the Effects of Static-Stretching and Tubing Exercises on Acute Shoulder Range of Motion in Collegiate Baseball Players. Busch AM, Broustein J, Ulin R                                               |
216    | Pre-operative Scapular Rehabilitation for Arthroscopic Repair of Traumatic Rotator Cuff Tear: Results of a Randomized Clinical Trial. de Almeida LL, Mendes Junior AF, da Mota Neto J, De Simoni LF, Lopes KHS, Guimarães PC, de Oliveira Valério BI, Sciascia A |

CASE REPORTS


CLINICAL COMMENTARY

270    | Hip and Groin Injury Prevention in Elite Athletes and Team Sport: Current Challenges and Opportunities. Short SM, MacDonald CW, Strack D                                                                                 |

CLINICAL VIEWPOINT

282    | Considerations with Open Kinetic Chain Knee Extension Exercise Following ACL Reconstruction. Wilk KE, Arrigo CA, Bagwell MS, Finck A                                                                                       |

THE IFSP International Perspective

We are honored and thrilled to pen this first editorial for the NEW *International Journal of Sports Physical Therapy*. We wish Dr. Mike Voight, the editorial team and entire staff continued success as this publication moves forward, pressing into the exciting future on the horizon for sports medicine and sports physical therapy.

*Teamwork is not a preference, it’s a necessity.*
- *Coach John Wooden*

There is no cogent argument against the fact that championships at any level are won by a team, not any one individual, regardless of their talent. The three of us have worked together in one form or another for over 40 years now and the only way we have all been as successful as we have is through a combined team approach to the care and rehabilitation of the patients and athletes it has been our distinct privilege to help.

We cannot lay claim to inventing the use of a team concept in sports medicine, that distinction goes to Dr. Frank McCue and Joe Gieck, PT, ATC. They pioneered a team approach as the team physician and head athletic trainer at the University of Virginia. In addition, Dr Jack Hughston and George Mccluskey, PT were creating their own team concept to sports medicine at the Hughston Clinic in Columbus, Georgia. Dr. Andrews learned the benefits of this coordinated approach to patient care from these individuals and started his own team at the Hughston Clinic in Columbus, Georgia with TAB Blackburn, MEd, PT, ATC. Building his team again with Dr. Kevin Wilk in Birmingham, Alabama - a team that has worked side by side for nearly 30 years. Since then, we have leveraged teamwork in every association we have found ourselves in over the years. Bob Mangine, Med, PT, ATC, who cultivated a team approach relationship with Dr. Frank Noyes in Cincinnati, Ohio, chaired the first Sports Physical Therapy Section Team Concept Meeting in 1979 in Houston, Texas. This conference brought orthopaedic surgeons and physical therapists together to share and exchange ideas and knowledge.

There are numerous excellent physician/physical therapy teams that practice this approach: Thomas Byrd, MD, and Mike Voight, PT, DHSc, OCS, SCS, ATC, CSCS, in Nashville, TN. Walt Lowe, MD and Russ Paine, PT in Houston, TX, Steve Nicholas, MD and Tim Tyler, PT, ATC in New York, and many more excellent clinicians that are part of a team approach to sports medicine.

Why does a team concept approach in sports physical therapy work so well? It mirrors the process used by any successful sports organization dedicated to winning championships – the creation of a coordinated effort that puts the right players in place, provides them with the necessary resources, creates an outstanding game plan, and is guided by astute coaching. As Bill Belichick said, “A successful team is a group of many hands and one mind.” One common goal – that is what we strive for – providing the best care possible to every athlete we treat.

We arrive at this goal together through coordinated communication that is bidirectional, open and timely. The physician shares the details of their examination, physical findings and thought process for treatment, and surgical details including pictures, video and necessary information that informs and shapes the rehabilitation process. The physician and therapist learn from one another, developing a common understanding of patient management, treatment approach and a language of effective dialog. This culminates in an interactive relationship of mutual respect that bridges all professional boundaries.
The team approach to sports medicine is often the evening phone call from the surgeon explaining the patient’s surgery and the unique injuries of the patient that you will be seeing in physical therapy the next day. It is the conversation a physician and physical therapist has exchanging thoughts on the pathology and treatment ideas. It is the physical therapist who contacts the sports medicine physician to provide an update, progress summary, discuss a setback, or provide return to play testing results and opinions regarding the readiness of the athlete to resume play. It is assessing patients together in the clinic or sports medicine facility. It is all this and so much more!

The result of this level of teamwork and shared relationship is better patient care. The patient benefits from everyone in the process being on the same page: coordinating care, effectively communicating, timely addressing any issues – the creation of a unified plan that has the athlete’s best interests at heart and places them in the best possible position to return to sport as quickly and safely as possible. This association has professional benefits as well, producing highly skilled clinicians who share their learned knowledge openly with others.

The team approach for the three of us has been a memorable and rewarding journey. It has included thousands of patients, countless post-operative recheck visits, viewing many surgeries, developing a plethora of rehabilitation protocols and programs, participation in teaching conferences all over the world, and speaking together on numerous occasions. None of this, regardless of the talent each of us possesses individually, would have been possible without adopting a team approach to our patient care and athlete management. This team concept approach has worked successfully for us. We encourage every clinician to collaborate with an orthopaedist, creating their own distinct team dedicated to the successful management of patients in an atmosphere of cooperative professionalism. In this environment, we are sure you will find a rewarding professional career and lasting memories from a lifetime dedicated to taking great care of every athlete you treat.

Team concept care makes each day rewarding, enlightening, and exciting, and provides a framework of anticipation for the possibilities you will discover the next day.

We hope you experience the same rewarding professional dynamic that we have found in the team concept approach to sports medicine.

Kevin E. Wilk
Christopher Arrigo
James R. Andrews
The Comparative Mental Health Responses Between Post-Musculoskeletal Injury and Post-Concussive Injury Among Collegiate Athletes: A Systematic Review

Joseph Sabol, PT, DPT, Cecelia Kane, PT, DPT, Mark P Wilhelm, PT, DPT, PhD, Jennifer C Reneker, PT, PhD, Megan Burrowbridge Donaldson, PT, PhD, FAAOMPT

1 Department of Physical Therapy, Walsh University, 2 School of Medicine, Physical Therapy Program, Tufts University, 3 School of Population Health, Department of Population Health Sciences, University of Mississippi Medical Center (UMMC)

Keywords: musculoskeletal injury, movement system, depression, concussion, athletic injuries, anxiety

10.26603/001c.18682

Background

The average annual national estimate of injuries sustained by collegiate athletes is 210,674, which encompasses both those of a musculoskeletal and a concussive nature. Although athletic injuries are sustained through physical means and produce physical symptoms, sports-related injuries may be a stressor among athletes that is related to mental health.

Purpose

The purpose of this systematic review is to summarize existing literature describing mental health responses in collegiate athletes with a concussion compared to those with a musculoskeletal injury.

Study Design

Systematic Review

Methods

Systematic searches of PubMed, CINAHL, Scopus, ProQuest, and SportDiscus were completed. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were utilized. Methodological quality was assessed using the Joanna Briggs Institute (JBI) Critical Appraisal Tool. Data extracted from the included articles included the study design, number of participants, type of injury, sex, age, sport participation, outcome measures, and time to return to play.

Results

A total of six articles were included. Peak depressive symptoms in athletes who sustain a concussion or musculoskeletal injury occur within one-week post-injury. No significant differences between the concussive and musculoskeletal groups anxiety scores were found at baseline or at each follow-up session. Athletes from both groups were found to be returning to their respective sports with anxiety scores representative of clinical anxiety.

Conclusion

Similar trends in depressive and anxiety symptoms at various time points post-injury were observed in athletes with both musculoskeletal and concussive injuries. This study identified that athletes were returning to play before their psychological symptoms had returned to their baseline.

Corresponding author: Megan Burrowbridge Donaldson PT, PhD, FAAOMPT Tufts University School of Medicine; Physical Therapy Program Boston MA, 02111 Megan.Donaldson@tufts.edu
INTRODUCTION

The National Collegiate Athletic Association (NCAA) is composed of 1,117 Colleges and Universities, encompassing 19,750 sports teams, and including nearly half a million college athletes. Of these athletes, the average annual national estimate of injuries is 210,674 encompassing those of a musculoskeletal and a concussive nature. A concussion is an injury that results from the rapid translational or rotational movement of the brain within the skull. This rapid movement can result in damage to or disruption of the functional units of the brain which affects brain metabolism and results in primary physical symptoms including but not limited to headaches, dizziness, sensitivity to light and sound, or loss of balance and coordination. In contrast, a musculoskeletal injury is typically tissue-level or structural damage to the bone, tendon, muscle, ligaments, or a combination of these structures due to supraphysiologic stress that exceeds the intrinsic stability of the musculoskeletal apparatus. These type of injuries result in primary symptoms of pain, weakness, swelling, stiffness, sensory deficits, and disability.

Although athletic injuries are sustained through physical means and produce physical symptoms, sports-related injuries have been shown to be a depression-link ed stressor among collegiate athletes. Psychological responses are a primary symptom in concussed athletes due to damage of the neural structures that contribute to emotional responses in the brain, while they are a secondary symptom in musculoskeletal injuries related to the experience of damage. More specifically, primary cognitive symptoms of a concussion may include memory or concentration deficits along with emotional changes including depression, anxiety, and irritability. These emotional changes are seen in musculoskeletal injuries as well. However, it is the athlete’s perception of the injury, not the injury itself, which results in psychological responses.

A survey by The Association for University and College Counseling Center Directors (AUCCCD) found anxiety (48.2%), followed by depression (34.5%), to be the most frequent mental health experiences among college students. Collegiate athletes represent a subset of this population with additional stressors placed upon them from their respective sports. In terms of depression, symptoms include loss of interest or pleasure in activities once enjoyed, difficulty thinking, concentrating or making decisions, and loss of energy or increased fatigue. For athletes, this could include difficulty making decisions on the field, loss of self-identity, and indifference towards a sport once found enjoyable.

Athletes suffering from post-injury anxiety may experience fear of a return to play, fear of re-injury, and fear of disappointing coaches and peers. Anxiety presents as a feeling of agitation and restlessness in response to certain situations characterized by symptoms of unease, nervousness, or worry about an event. Anxiety can be further subdivided into two components: state and trait anxiety. Trait anxiety is an uninterrupted personality trait, that is, an individual tendency to perceive negative experiences as threatening, which in turn increases the individual’s level of anxiety. Whereas, state anxiety is defined as a transitory emotional state that consists of feelings of apprehension and tension experienced in a particularly stressful situation and characterized by consciously perceived subjective feelings of tension and apprehension. For athletes, state anxiety may be a potential result of an athletic injury. Furthermore, research has found that concussed athletes with pre-injury baseline trait anxiety did not have increased post-concussion depression and state anxiety symptoms, indicating that they are two separate components.

Given the prevalence of depression and anxiety in collegiate students and the potential for athletic injuries to negatively impact mental health, albeit, via potentially different mechanisms, it is important to explore whether there are differences in mental health responses after injury for collegiate athletes, based on the type of injury sustained. Research is limited on the long-term effects of both types of injuries and the subsequent quality of life. Therefore, the purpose of this systematic review is to summarize existing literature describing mental health responses in collegiate athletes with a concussion compared to those with a musculoskeletal injury.

METHODS

STUDY DESIGN

This systematic review was registered with PROSPERO, the international database of prospectively registered systematic reviews in health (CRD42018115296). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were utilized during the search and reporting phase of this systematic review. PRISMA is a 27-item checklist utilized to improve the reporting of systematic reviews and meta-analyses.

SEARCH STRATEGY

Articles were identified through a systematic computerized search of PubMed, CINAHL, Scopus, ProQuest, and SPORTDiscus. Search strategies included MeSH terms, keywords, and text words related to collegiate athletes, concussions, musculoskeletal injuries, and mental health responses. The search strategy was originally optimized for PubMed and adapted for other databases using database specific terminology. No restrictions were placed on the search in terms of date of publication or type of research design. The initial search of published articles was performed on November 1, 2018 and was re-run on August 30, 2019 to include the most recent studies. The full PubMed search strategy can be found in Appendix 1.

ELIGIBILITY CRITERIA

To be eligible for inclusion, articles were required to meet...
the following inclusion criteria: 1) compare mental health responses of collegiate athletes who experienced either a concussive or musculoskeletal injury during their competitive season; 2) include a diagnosis of musculoskeletal injury by a physician, athletic trainer, or therapist; and 3) defined concussive injuries as a diagnosis by a physician and/or on-field signs and symptoms such as observed or reported acceleration or deceleration of the head, any observable alteration in mental status and/or any self-reporting symptoms such as headache, loss of consciousness, nausea, balance problems, or difficulty reading or concentrating. Articles that were written in a non-English language or contained only concussive or only musculoskeletal injuries were excluded.

STUDY SELECTION

Titles and abstracts were reviewed independently by two authors. In situations of disagreement regarding inclusion eligibility, the two authors came to an agreement through discussion. Full-text articles were then reviewed independently by two authors. Disagreements were again discussed between the two authors in order to formulate a final decision. Cohen’s unweighted kappa was calculated to assess inter-rater reliability during the title-abstract and full-text screen. Using this metric, the strength of agreement for a Kappa of 0.0-0.20 was defined as slight, 0.21-0.40 was fair, 0.41-0.60 was moderate, 0.61-0.80 was substantial, and 0.81-1.00 was defined as almost perfect.15

METHODOLOGICAL QUALITY OF INCLUDED STUDIES

The Joanna Briggs Institute (JBI) Critical Appraisal Tools for use in JBI Systematic Reviews: Checklist for Cohort Studies was used to assess the methodological quality of the included studies. This appraisal tool is utilized to determine the extent to which a study has addressed the possibility of bias in its design, conduct, and analysis. The results of this appraisal can then be used to inform synthesis and interpretation of the results of the study.16 The tool consists of 11 questions applicable to cohort designs and is a guide for researchers to determine if a study should be selected based on the stated inclusion criteria. If the critical appraisal tool leads researchers to uncover a large source of bias in a study, it should be excluded. Two authors independently assessed all included articles for methodological quality. Disagreements between the two authors were settled through discussion. Cohen’s unweighted kappa was calculated for the quality assessment process to determine the strength of agreement between the two authors.

RESULTS

STUDY SELECTION

The systematic electronic search yielded 1621 results. After removing duplicates, 1442 titles and abstracts were screened with a reliability of $k = 0.89$ (95%CI, 0.83 to 1.0). Nine articles were included for full-text review, yielding a reliability of $k = 1.0$ (95%CI, 1.0 to 1.0).

After full-text review, six studies met the inclusion criteria for this review. Studies were excluded during the full-text review process for the following reasons: 1) it was a systematic review, literature review, or thesis, 2) the manuscript was not written in the English language, 3) the article was in an inaccessible journal, 4) did not isolate data on collegiate athletes, 4) data were not collected on both concussive and musculoskeletal injuries, and 5) mental health outcomes post-injury were not included. The study screening process is shown in Figure 1.

DATA EXTRACTION

One author extracted data from the included studies using a standardized form. A separate author independently verified all the extracted data to ensure data accuracy. Extracted data included study characteristics such as 1) study design, 2) sample size, 3) sample demographic characteristics, 4) return to play time, 5) outcome measures, and 5) statistical data including the means and standard deviations (SD) for outcome variables of interest. These outcomes of interest included those related to depression and anxiety and were measured by various outcome measures (State-Trait Anxiety Inventory, Centers for Epidemiological Studies Depression Scale, and Profile of Mood States). Statistical values of fear of re-injury and return to play were analyzed.

OUTCOME/SUMMARY MEASURES

The State-Trait Anxiety Inventory is a self-reporting 40-item questionnaire that includes separate measures of state anxiety (20 items) and trait anxiety (20 items). The state anxiety measure assesses how the subject feels in the present moment, whereas the trait anxiety measure assesses how the subject generally feels. Each item is given a weighted score of 1 (low level of anxiety) to 4 (high level of anxiety); with a maximum possible score of 80 for both the state anxiety measure and the trait anxiety measure.17 The Profile of Mood States (POMS) is a 65-item adjective checklist designed to measure the transient emotional states of tension-anxiety, depression-dejection, fatigue-inertia, vigor-activity, confusion-bewilderment, and anger-hostility.18 A modified version of the POMS was developed for sport settings. Two items used to assess depression were deleted and five items designed to assess esteem-related effect were added. The final instrument contained 40 adjectives which referred to seven different mood states: fatigue, anger, vigor, tension, esteem-related affect, confusion, and depression. Responses are made on a 0–4 scale with 0 labeled as “not at all” and 4 labeled “extremely.” It was concluded that this modified form has acceptable psychometric properties.19

The Centers for Epidemiological Studies Depression Scale (CES-D) is a 20-item self-reporting scale designed to measure the depressive symptomology in the general population. Each item is rated on a 4-point, with 0 indicating “rarely or none of the time” and 5 indicating “most or all of the time.” The CES-D has been validated with the collegiate population.20

RISK OF BIAS IN INCLUDED STUDIES

The JBI Critical Appraisal tools for Cohort Studies is as-
sessed out of 11-points. It was determined that one study ranked a quality score of 10, two studies ranked 9, and three studies ranked at an 8. Common themes with the articles include not addressing strategies to deal with confounding factors and an insufficient follow-up time. Agreement between authors for quality assessment of included studies was a kappa score of 0.95 (95%CI, 0.86 to 1.0). Although no studies were excluded based on their quality assessment score, the reader must take caution in over interpreting the results from studies of lower quality. The quality assessment scores of individual studies are shown in Table 1.

**STUDY CHARACTERISTICS**

The total number of injured participants in all included studies is 824, with 652 experiencing a musculoskeletal injury and 192 experiencing a concussive injury. Mean age for athletes with musculoskeletal injury ranged from 19.23 (SD ± 1.45) to 22.54 (SD ±1.73) years of age. Three studies did not report mean age. Further, 559 participants were male, and 265 were female.

Within the six included articles, 21-26 five included football and basketball, 21-25 four included volleyball, 21-24 three included wrestling, 21,22,25 soccer, 21,22,24 and field hockey, 21,22,24 two included softball, 21,22 baseball, 21,22 hockey, 23,24 lacrosse, 23,24 and rugby, 23,24 and one included mountain biking and cheerleading. 26 One study did not report the type of sport injury breakdown. 26 The mean time from the concussive injury until subject’s ability to return to play ranged from eight days to one month. The mean time from the musculoskeletal injury until subject’s ability to return to play ranged from eight days to one year. Five of the studies first measurement of depression and anxiety symptoms were at baseline, meaning prior to an injury occurring. 21-25 One of the studies first measurement of depression and anxiety symptoms was within 72-hours post-injury. 26 A summary of the study characteristics is present in Table 2.

**QUALITATIVE REVIEW OF STUDIES**

**DEPRESSION MEASURES**

**EFFECT OF TIME ON DEPRESSION MEASURES OF CONCUSSED ATHLETES**

Five of the included articles reported on depressive symptoms for post-concusive injuries. 22-26 Depressive symptoms were assessed pre-season prior to any type of injury (baseline) and at varying time periods after an injury was sustained. Four articles agreed that peak depressive symptoms in athletes who sustain a concussion occur within one-week post-injury, which is a significant difference when compared to baseline scores. More specifically, peak depressive symptoms ranged from within 72-hours post-injury, 26 within 96-hours post-injury, 23 four days post-injury, 24 and seven days post-concussive injury. 25 However, Hutchinson et al. reported that peak scores that occurred within 96-hours post-injury are not statistically significantly different from baseline. 25 Guo et al., reported peak depressive symptoms at one month post-concussive injury.
Furthermore, four articles are in agreement that depressive symptoms post-concussive injury steadily decrease after the peak depressive scores. Hutchinson et al. and Mainwaring et al. showed a decrease in depressive scores up to two weeks, while Roiger et al., shows a decrease up until three months. Turner et al. shows a continual decrease in depressive symptoms from within 72-hours post-injury through return to play.

**EFFECT OF TIME ON DEPRESSION MEASURES OF MUSCULOSKELETAL INJURED ATHLETES**

Five of the included articles reported on depressive symptoms for musculoskeletal injuries. Four articles found that depressive symptoms peak within one week of sustaining a musculoskeletal injury while Mainwaring et al. reported peak depressive scores at 11 days post-injury. However, Hutchinson et al. reported that these peak depressive scores are not statistically significantly different from pre-season baseline scores. All articles are in agreement that depressive symptoms gradually decrease over time, however at varying time points reported in each study. Reduction in depression symptoms varied from two weeks post-injury, 23 days post-injury, three months post-injury, and until return to play (which differed for each athlete).

Interestingly, Roiger et al. found that both the post-concussive and post-musculoskeletal injury athletes had peak depressive scores at one week. However, the concussed participants’ scores decreased from one week to one month, while the musculoskeletal injury group remained elevated over baseline at the one month time point before decreasing toward baseline at three months. Hutchinson et al. found neither group to differ from baseline scores, or differ from one another. Guo et al. found that while both musculoskeletal injured and concussive groups scored similar at pre-season baseline and one week post-injury on depressive symptoms, the concussive group scored higher on depressive symptoms at one month after injury than the musculoskeletal group. Mainwaring et al. found that concussed athletes displayed almost three times more depressive symptoms four-days post-injury compared to pre-season baseline measures. Meanwhile, the athletes with musculoskeletal injuries reported over seven times more depression 11 days post-injury than at baseline.
ANXIETY MEASURES

Three of the included articles reported on anxiety symptoms for both post-concussive and post-musculoskeletal injuries.\textsuperscript{21,22,26} Two articles reported trait anxiety symptoms measured at pre-season baseline and state anxiety symptoms for all post-injury follow-ups.\textsuperscript{21,22} One article only reported state anxiety symptoms for all post-injury follow-ups.\textsuperscript{26}

EFFECT OF TIME ON ANXIETY MEASURES OF CONCUSSED INJURED ATHLETES

For concussive injuries, all three articles found that the highest reported anxiety score was the earliest measured score, whether that be baseline or within 72-hours post-injury.\textsuperscript{21,22,26} All three articles also found a decrease in anxiety symptoms from baseline or 72-hours post-injury to one-week post-injury.\textsuperscript{21,22,26} Two articles found an increase in anxiety scores from one-week post-injury to return to play.\textsuperscript{22,26} Turner et al. found that within 72-hours post-injury, 73.3\% of the post-concussive group scored anxiety mean scores that exceeded the state anxiety threshold for clinical anxiety (scores >38).\textsuperscript{26}

EFFECT OF TIME ON ANXIETY MEASURES OF MUSCULOSKELETAL INJURED ATHLETES

For musculoskeletal injuries, all three articles found a decrease in anxiety symptoms from baseline or within 72-hours post-injury to one-week post-injury.\textsuperscript{21,22,26} Guo et al. found decrease in anxiety symptoms from one-week to return to play.\textsuperscript{22} Turner et al. found an increase in anxiety symptoms from one-week to return to play.\textsuperscript{26} Additionally, these authors found that within 72-hours post-injury, 66.7\% of post-musculoskeletal group had anxiety mean scores that exceeded the state anxiety threshold for clinical anxiety.\textsuperscript{26}
<table>
<thead>
<tr>
<th>First Author, Year</th>
<th>Study Design</th>
<th>Participants (n)</th>
<th>Gender</th>
<th>Mean Age (SD)</th>
<th>Sports Involved</th>
<th>Average Return to Play Time (SD)</th>
<th>Outcome Measure(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Covassin, 2014</td>
<td>Cohort Study</td>
<td>MSK (63) CONC (63)</td>
<td>M= 92  F= 34</td>
<td>MSK= 22.84 (1.77) CONC= 22.54 (1.73)</td>
<td>Football, wrestling, softball, soccer, volleyball, basketball, field hockey, baseball</td>
<td>MSK: 8.90 (13.31) days CONC: 8.87 (13.67) days</td>
<td>State-Trait Anxiety Inventory (STAI) Profile of Mood States</td>
</tr>
<tr>
<td>Guo, 2018</td>
<td>Prospective Cohort Study with Repeated Measures</td>
<td>MSK (526) CONC (71)</td>
<td>M= 400  F= 197</td>
<td>MSK= 19.23 (2.34) CONC= 20.05 (1.82)</td>
<td>Football, wrestling, baseball, basketball, soccer, softball, field hockey, volleyball</td>
<td>MSK: 1 week= 311, 1 month= 107, 3 months= 74, 6 months= 27, 12 months= 7 CONC: 1 week= 63.1, 1 month= 8</td>
<td>Centers for Epidemiological Studies Depression Scale (CES-D) State-Trait Anxiety Inventory (STAI)</td>
</tr>
<tr>
<td>Hutchinson, 2009</td>
<td>Prospective Longitudinal Cohort Study</td>
<td>MSK (14) CONC (20)</td>
<td>M= 24  F= 10</td>
<td>MSK= 19.23 (2.34) CONC= 20.05 (1.82)</td>
<td>Basketball, football, hockey, lacrosse, rugby, volleyball</td>
<td>MSK: 8.36 (3.54) days CONC: 12.68 (19.03) days</td>
<td>Profile of Mood States (POMS)</td>
</tr>
<tr>
<td>Mainwaring, 2010</td>
<td>Prospective Mixed Cohort Design with Repeated Measures</td>
<td>MSK (7) CONC (16)</td>
<td>M= 13  F= 10</td>
<td>MSK= 19.23 (2.34) CONC= 20.05 (1.82)</td>
<td>Basketball, field hockey, football, hockey, lacrosse, mountain biking, rugby, soccer, volleyball</td>
<td>CONC: 25 days</td>
<td>Profile of Mood States (POMS)</td>
</tr>
<tr>
<td>Roiger, 2015</td>
<td>Descriptive Epidemiologic Study</td>
<td>MSK (7) CONC (7)</td>
<td>M= 13  F= 1</td>
<td>MSK= 19.23 (2.34) CONC= 20.05 (1.82)</td>
<td>Wrestling, football, basketball</td>
<td>MSK: 12.7 (7.6) days CONC: 16.9 (19.03) days</td>
<td>Centers for Epidemiological Studies Depression Scale (CES-D)</td>
</tr>
<tr>
<td>Turner, 2017</td>
<td>Prospective Cohort Study</td>
<td>MSK (15) CONC (15)</td>
<td>M= 17  F= 13</td>
<td>MSK= 19.95 (1.15) CONC= 19.4 (1.45)</td>
<td>Division I intercollegiate athletics program or cheerleading team</td>
<td>MSK: 10.85 (9.63) days CONC: 13.93 (4.88) days</td>
<td>State-Trait Anxiety Inventory (STAI) Profile of Mood States (POMS)</td>
</tr>
</tbody>
</table>

SD= standard deviation; M= male, F= female, MSK= musculoskeletal, CONC= concussion
EFFECT OF TIME ON ANXIETY MEASURES BETWEEN CONCUSSED AND MUSCULOSKELETAL INJURED ATHLETES

All three articles found no significant differences between the concussive and musculoskeletal groups anxiety scores at baseline or at each follow-up session.21,22,26 Turner et al. found anxiety scores that exceeded the state anxiety threshold for clinical anxiety within 72-hours post-injury and at return to play.26 Turner et al. also found that even though both groups means dropped to lower levels of state anxiety at one week post-injury, over half of the participants in each group (53.3%) still exceeded the state anxiety threshold for clinical anxiety.26

DISCUSSION

This systematic review explored the comparative mental health responses between post-musculoskeletal injury and post-concussive injury among collegiate athletes. The results of the current review illustrate similar depressive patterns in athletes who have sustained a sports-related concussion or musculoskeletal injury from pre-injury measurements to return to play. A distinctive pattern was also shown for anxiety in both injury groups from pre-injury measurements to return to play.

For anxiety, studies reported scores decreasing between the first recorded measurement and one-week post-injury and then increasing from one-week post-injury to return to play for both injury groups. One exception was presented in Guo and colleagues who found athletes reported a continual decrease in anxiety symptoms in the musculoskeletal group from the pre-injury baseline measurement to return to play. This outlier could be due to athletes receiving rehabilitation services and progressing to pre-injury abilities, thereby reducing their anxiety about their injury.

Two interesting findings were observed for depressive symptoms amongst the two groups. First, there was a peak in depressive symptoms at the first measurement post-injury followed by a steady decline in symptoms at subsequent time points for both injury groups.22–25 The elevation in psychological symptoms post-injury could represent a reduction in the hormones that are naturally produced by the body, endogenous opiates, which are generated during exercise.27 These hormones are associated with feelings of comfort, safety, and happiness, which can be interrupted when there is a disruption in the athletes training program, leading to a psychological disturbance.27,28

Alternatively, the second discovery found that with concussive injuries, the lowest peak of depressive symptoms occurred at one-week post-injury, then increased at subsequent time points.22–26 This can be attributed to a higher risk for post-injury depression the longer an athlete faces post-concussive symptoms.21 Additionally, because a concussion is an internal injury rather than external, athletes may have difficulty understanding or reasoning as to their inability to return to play if they cannot see the injury. Resultantly, the mismatch between the patient’s anticipated or expected outcome and their actual ability may alter the course of depression.22 Concussed athletes likely expect to recover in a short period of time and these athletes may not be prepared to cope with any prolongation of that recovery. A prolonged recovery results in increased concern about further sports participation and extent of the injury.29

It has been hypothesized that it may not be the injury itself that triggers a psychological response, but rather the removal from athletic activity participation.30,31 The degree to which an individual identifies with the athlete role is termed athletic identity, which can contribute to an athlete’s sense of self. When there is a disruption in this perception, an athlete may question their self-worth due to a strong connection between their athletic identity and their self-identity.52 Kroshus and colleagues found that athletes with greater athletic identity have an increased likelihood that post-injury symptoms will go under-reported.35 Athletes may fear that time away from the sport will equate to a loss of individuality, and therefore are willing to compete rather than sacrifice their perception of themselves. It is not only their perception of themselves that is at risk but also how others perceive them. Athletes face external pressures from teammates, coaches, and peers, motivating them to hide their injury symptoms because it is more beneficial for the team if the athlete misses the shortest amount of time possible after sustaining an injury.35

Several studies have outlined the benefit of educating athletes on post-injury management in regard to mental health. Athletes will often not report psychological disturbances because they do not realize that such symptoms may be related to injury, which often leads to under-reporting and denial of symptoms.34 It has been shown that education may lead to decreasing the stigma of “sitting out” while concussed; however, some argue the long term efficacy of such education is unremarkable.35,36 Murray et al. argues that it is unlikely that preventative measures will have much impact without a radical change in the perception of injuries within the sports culture.37 Athletes tend to down-play mental or psychological distress due to the expectations of strength, stability, and unwavering “mental toughness” that is ingrained in the sports culture.38 Injuries, and thus secondary effects of injuries, may only be minimized if the aggressive attitude of sports culture is more conscientious of an athlete’s overall well-being.

An additional area of further research may be to determine the long-term effects of injury on quality of life. The included articles did not present data on time points post-return to play. An article by Richmond et al. reports an 18% prevalence of a major depressive disorder, depression not otherwise specified, or persistent depressive disorder one year after even a minor injury.39 It would be of interest to observe if depressive or anxiety symptoms linger after return to play and in what aspects of the athlete’s life are affected and to what extent. Similarly, a study by Montenegro et al. reported cumulative head impacts exposure predicts later-life depression, apathy, executive dysfunction, and cognitive impairment in former high school and college football players.40 More information such as this would be beneficial in minimizing the taboo of optimal self-care after injury, which sports culture does not encourage, and aid in providing long-term physiological and psychological care.

Administering both pre-injury and post-injury patient-centered outcome measures can provide clinicians with important information regarding the extent of an athletic in-
jury. Outcome measures that assess both physical and psychological symptoms should be utilized to ensure the athlete is being treated holistically and allow monitoring of patient progression or regression in an objective manner over time. In addition to outcome measures used within the included studies the Profile of Mood States (POMS), Centers for Epidemiological Studies Depression Scale (CES-D), and State-Trait Anxiety Inventory (STAI); the Anterior Cruciate Ligament-Return of Sport after Injury (ACL-RSI) Scale and Sport Concussion Assessment Tool-5th Edition (SCAT5) can be helpful in screening for an athlete's psychological symptoms specific to their injuries. These tools have been developed to assist coaches and athletes in making the appropriate decision in regards of return to play. The development of these tools helped legitimize the idea that there is a significant emotional response to athletic injury as well as during the subsequent rehabilitation process. The findings of this systematic review indicate that although anxiety symptoms decreased at subsequent time points from baseline, over half of the included athletes had scores that would be considered clinically anxious. Therefore, it is imperative for athletes to become cognizant of their psychological symptoms post-injury, to acknowledge the need to seek professional assistance when necessary.

LIMITATIONS

Limitations exist in the current study that could affect the strength of the results presented. First, only six articles met the inclusion criteria for this systematic review and of these six, four articles included a small sample size of 50 or fewer participants. In addition, the articles included were deficient in quantitative data. For example, four of the six included articles displayed their findings in a line graph rather than presenting specific mean score values in either the manuscript or tables. Furthermore, the articles included were lacking descriptive data within their population, such as disclosing which sports were included along with the number of participants involved in each sport. Lastly, each study provided their own unique definition of "musculoskeletal injury" and did not further subcategorize the group based on severity of injury. This may have attributed to the wide range of return to play times and subsequent reporting of depression and anxiety. Providing the above information could lead to new discoveries and insight on areas in need of further research.

CONCLUSION

Similar patterns in depressive and anxiety symptoms at various time points post-injury were observed in both musculoskeletal and concussive injuries. Although anxiety scores may fluctuate over the course of recovery, a majority of collegiate athletes had scores representative of clinical anxiety throughout subsequent encounters from baseline to return to play. This indicates that athletes were returning to play before their psychological symptoms were back to their baseline. The long-term effects of mental health outcomes secondary to athletic injury as well as information on return to play criteria were not addressed. Further research should focus on an appropriate length of time between injury and return to play, as well as longitudinal data on psychological effects post-athletic injury.

CONFLICTS OF INTEREST

No potential conflict of interests were reported by the authors.

This work was conducted while authors CC, JS, MD, and MW were at Walsh University. JR was at the University of Mississippi Medical Center during the completion of this work.

Submitted: December 11, 2019 CST, Accepted: June 16, 2020 CST
REFERENCES


SUPPLEMENTARY MATERIALS

Appendix 1
Original Research

Sequencing and Integration of Cervical Manual Therapy and Vestibulo-oculomotor Therapy for Concussion Symptoms: Retrospective Analysis

Christopher Kevin Wong, PT, PhD, OCS1, Lauren Ziaks, PT, DPT, ATC2, Samantha Vargas, PT, DPT3, Tessia DeMattos, PT, DPT3, Chelsea Brown, PT, DPT2

1 Department of Rehabilitation & Regenerative Medicine, Columbia University Irving Medical Center, 2 Park City Hospital, Intermountain Healthcare, 3 Vagelos College of Physicians & Surgeons, Columbia University

Keywords: vestibular rehabilitation, vision therapy, manual therapy, cervicogenic headache, concussion

10.26603/001c.18825

International Journal of Sports Physical Therapy
Vol. 16, Issue 1, 2021

Background

After concussion many people have cervicogenic headache, visual dysfunction, and vestibular deficits that can be attributed to brain injury, cervical injury, or both. While clinical practice guidelines outline treatments to address the symptoms that arise from the multiple involved systems, no preferred treatment sequence for post-concussion syndrome has emerged.

Purpose

This study sought to describe the clinical and patient-reported outcomes for people with post-concussion symptoms after a protocol sequenced to address cervical dysfunction and benign paroxysmal positional vertigo within the first three weeks of injury, followed by integrated vision and vestibular therapy.

Study Design

Retrospective longitudinal cohort analysis

Methods

Records from a concussion clinic for 38 patients (25 male 13 female, aged 26.9±19.7 years) with post-concussion symptoms due to sports, falls, assaults, and motor vehicle accident injuries were analyzed. Musculoskeletal, vision, and vestibular system functions were assessed after pragmatic treatment including early cervical manual therapy and canalith repositioning treatment—when indicated—integrated with advanced vision and vestibular rehabilitation. Patient-reported outcomes included the Post-Concussion Symptom Scale (PCSS) for general symptoms; and for specific symptoms, the Dizziness Handicap Index (DHI), Convergence Insufficiency Symptom Scale (CISS), Activities-specific Balance Confidence scale (ABC), and the Brain Injury Vision Symptom Survey (BIVSS). Paired t-tests with Bonferroni correction to minimize familywise error (p<0.05) were used to analyze the clinical and patient-reported outcomes.

Results

After 10.4±4.8 sessions over 57.6±34.0 days, general symptoms improved on the PCSS (p=0.001, 95%CI=12.4-30.6); and specific symptoms on the DHI (p<0.001, 95%CI=14.5-33.2), CISS (p<0.002, 95%CI=7.1-18.3), ABC (p<0.024, 95%CI=.3 - -.1), and BIVSS (p<0.001, 95%CI=13.4-28.0). Clinical measures improved including cervical range-of-motion (55.6% fully restored), benign paroxysmal positional vertigo symptoms (28/28, fully resolved), Brock string visual convergence (p<0.001, 95%CI=3.3-6.3), and score on the Balance Error Scoring System (p<0.001, 95%CI=5.5-11.6).
Conclusion

A rehabilitation approach for post-concussion syndrome that sequenced cervical dysfunction and benign paroxysmal positional vertigo treatment within the first three weeks of injury followed by integrated vision and vestibular therapy improved clinical and patient-reported outcomes.

Level of Evidence: 2b

INTRODUCTION

Sport and recreation-related concussion is a rapidly growing problem, with an estimated 1.6-3.8 million people affected per year.1 Concussion also affects people involved in transportation accidents, fall-related injuries, and other trauma.1 Defined as a mild traumatic brain injury induced by direct or indirect biomechanical forces, concussion may or may not include loss of consciousness.2 While more than 80% of adults recover from sports-related concussions in 7-10 days, concussive symptoms can persist much longer and take weeks or months to resolve after injury.3,4 Symptoms lasting longer than the generally accepted three-week period can be referred to as protracted concussion recovery,5 a particular problem among adolescent athletes.5 After concussion in adolescents, protracted recovery is common with most reporting symptoms lasting more than a month: boys averaging seven weeks and girls an even longer 10 weeks.5

The signs and symptoms observed in protracted concussion recovery cannot always be linked to abnormal brain imaging or neuropathological changes, but rather are often attributed to multiple physiologic systems.6 Typical findings involve the musculoskeletal, visual, vestibular, cardiovascular, and autonomic systems.4 Signs and symptoms after concussion attributed to the musculoskeletal system are commonly localized to the cervical region and include joint and myofascial hypomobility that limits range-of-motion (ROM)7 and cervicogenic headaches.6 Cervicogenic headaches are secondary headaches encompassing neck or facial pain associated with bony, myofascial, and disc disorders of the cervical spine.8 Cervicogenic headaches develop with the onset of cervical disorders, such as biomechanical forces occurring during mild traumatic brain injury, and significantly improve with the resolution of cervical disorders.8 Visual or oculomotor symptoms are not limited to but commonly include blurred vision, double vision, difficulty concentrating, and difficulty with activities such as reading.5 Vestibular system symptoms include dizziness, nausea, fatigue, balance difficulties, and blurry vision with head movements known as oscillopsia.9 In addition, final clinical recovery can be delayed by dysautonomia that can decrease exercise tolerance and limit return to sport;3,4 or cognitive and psychological issues that impair return to learn or work.10

Many post-concussion symptoms can be attributed to brain injury, cervical spine injury, or both,3,4 and can have a long lasting negative impact on function, but can be modified through treatment of the relevant physiologic systems.3 Medical and athletic management of concussions has been delineated in a recent clinical practice guideline.10 In 2020, the American Physical Therapy Association published a clinical practice guideline describing current best practice for physical therapy care of concussion including cervical musculoskeletal, vestibulo-oculomotor, autonomic/exertional tolerance, motor function, and psychological and sociological impairments.11 Manual therapy may provide added value to the benefits of exercise in reducing cervicogenic headache and associated neck pain and dysfunction.12 For instance, treatments including cervical muscle active trigger point release and manipulative therapy can reduce intensity, frequency, and cervicogenic headache symptom duration.13 Visual system impairment can be reduced with vision therapy including oculomotor and vergence training using targets with numbers and letters, and fusion exercises such as stereograms and trianglyphs.14 Vestibular therapy such as vestibulo-ocular reflex movements for adaptation, habituation exercises, and substitution including static and dynamic balance exercises can improve vestibulo-oculomotor symptoms after concusions.9,15 Although multisystem involvement is common, existing treatment protocols typically describe interventions focused on the symptom clusters arising from one system or another.9

Treatment outcomes for post-concussion syndrome can be complicated by the interconnectedness of the vestibular, visual, and musculoskeletal systems.16 For instance, vestibular therapy requires the ability to maintain visual fixation on a point while turning the head.9 Furthermore, deficits in cervical spine and oculomotor coordination can lead to dizziness and blurred vision.17 The function of the cervical spine, visual and vestibular systems are not isolated. Without the ability to have both eyes converge on a point or comfortably rotate the cervical spine, compensations can occur.9 While current clinical practice guidelines outline potential treatments to help address the symptoms that occur in each of the involved systems, no preferred treatment sequence for patients with post-concussion syndrome has emerged.10,11 The purpose of this study was to describe the clinical and patient-reported outcomes for people with post-concussion symptoms after a rehabilitation protocol sequenced to address cervical dysfunction and benign paroxysmal positional vertigo within the first three weeks of injury, followed by integrated vision and vestibular therapy.

METHOD

DESIGN

This study was a retrospective longitudinal cohort analysis of pre-existing data obtained from August 2016 - March 2017 from a single concussion clinic. Deidentified coded data was received for analysis from the participating concussion clinic in accordance with the protocol approved by the
Columbia University Irving Medical Center Institutional Review Board of the participating University Medical Center.

SAMPLE

The records of 59 people with post-concussion symptoms were reviewed. The 38 patients (25 male and 13 female, aged 26.9±19.7 years) who had both evaluation and re-evaluation data—follow-up progress report or discharge assessment—were included for analysis. All patients had been referred for symptoms post-concussion and suspected mild traumatic brain injury with cervicogenic, visual, and/or vestibular symptoms. The average time from injury to initial evaluation was 31.6±50.4 days, with 17 reporting protracted symptoms beyond 21 days. The most common presentation was mixed cervical, vision and vestibular symptoms reported by 24 (63.2%); followed by 10 (26.3%) that had vision and vestibular symptoms; and 4 (10.5%) that reported only cervicogenic symptoms including headache. Concussion etiology was varied with concussions occurring after sport (60.5%), fall (18.4%), motor vehicle accident (13.2%), and assaults (7.9%). A history of prior concussion was reported by 15 (39.5%). Table 1.

ASSESSMENTS

Clinical findings and patient-reported outcomes were obtained by one trained clinician in the participating specialized concussion rehabilitation clinic. To minimize variation among different clinicians for patients who had limited cervical ROM at the initial evaluation, the cervical ROM measure was reduced for analysis in this study to a simple dichotomous outcome. ROM was either normal, denoted in the clinical notes as normal, within normal or within functional limits, or limited, defined as any limitation recorded in degrees, percentage, or qualitative term. Visual system outcome measures included the Brock string score for convergence and divergence distance, the cover-uncover test to screen for malalignment and strabismus that would require neuro-optometry referral, and clinical screening for quality and speed of smooth pursuits and saccades, and near point convergence. Vestibular measures included Dix-Hallpike and Supine Roll Tests for benign paroxysmal positional vertigo (BPPV). Additional vestibular screening assessments included vestibular ocular reflex, visual motion sensitivity and the Balance Error Scoring System (BESS), which has been shown to be a reliable measure in athletes post-concussion.

Patient-reported outcomes included five scales that collectively provide insight on the potential symptoms that stem from deficits in the cervical spine, vestibular and visual systems. The Post-Concussion Symptom Scale (PCSS) assesses general post-concussion symptoms with specific symptom indices for associated sequelae including headache, with variable reliability for the different indices. The Dizziness Handicap Inventory (DHI) assesses the impact of dizziness on functional, emotional, and physical quality of life with excellent reliability and internal consistency. Visual impairment was assessed with the Convergence Insufficiency Symptom Survey (CISS), which has excellent reliability, and the Acquired Traumatic Brain Injury Vision Symptom Questionnaire, since adapted and renamed the Brain Injury Vision Symptom Survey (BIVSS). Finally, the Activities-specific Balance Confidence (ABC) scale assesses individual sense of balance and correlates with cognitive measures after concussion. See Table 2.

INTERVENTIONS

Patients received treatment integrating cervical, vision and vestibular dysfunction as indicated by individual impairment and determined pragmatically by the trained concussion clinic treatment specialist, as previously outlined in a treatment algorithm. Patients evaluated within the three-week post-injury recovery window began treatment for cervical dysfunction and symptoms. Patients evaluated more than three weeks post-injury, consistent with protracted concussion recovery, began with treatment for cervical dysfunction integrated with vision and vestibular therapy. Because resolution of the multiple systems varied, treatments overlapped.

Cervical dysfunction was treated with manual therapy and exercise, followed by canalith repositioning procedure for BPPV when present. Vision therapy included vision exercises for smooth pursuits, saccades, complex motor tasks including divided attention and laterality, and vergences. Vestibular rehabilitation therapy was integrated for substitution (dynamic balance exercises with visual restriction and on compliant surfaces), vestibular ocular reflex training for gaze stability to address adaptation and ex-

<table>
<thead>
<tr>
<th>Table 1: Characteristics of the Patient Cohort</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sex</strong></td>
</tr>
<tr>
<td><strong>Age</strong></td>
</tr>
<tr>
<td><strong>History of Concussion</strong></td>
</tr>
<tr>
<td><strong>Activity at Time of Injury</strong></td>
</tr>
<tr>
<td>Sport</td>
</tr>
<tr>
<td>Fall</td>
</tr>
<tr>
<td>Motor Vehicle Accident</td>
</tr>
<tr>
<td>Assault</td>
</tr>
<tr>
<td><strong>Symptoms</strong></td>
</tr>
<tr>
<td>Vision and Vestibular only</td>
</tr>
<tr>
<td>Musculoskeletal (includes cervicogenic headache) only</td>
</tr>
<tr>
<td>Vision and Vestibular with Musculoskeletal</td>
</tr>
</tbody>
</table>
Sequencing and Integration of Cervical Manual Therapy and Vestibulo-oculomotor Therapy for Concussion Symptoms:...  

Table 2: Clinical and Patient-reported Outcomes

<table>
<thead>
<tr>
<th>System</th>
<th>Assessments</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined</td>
<td>Post-Concussion Symptom Scale</td>
<td>p=0.001, 95% CI 12.4 – 30.6, n=19, d=1.18</td>
</tr>
<tr>
<td>Musculoskeletal</td>
<td>Cervical ROM</td>
<td>55.6% (15/27) regained full ROM</td>
</tr>
<tr>
<td>Vision</td>
<td>Convergence Insufficiency Scale</td>
<td>p=0.002, 95% CI 7.1 – 18.3, n=19, d=-1.04</td>
</tr>
<tr>
<td>Convergence</td>
<td>Brain Injury Vision Symptom Survey</td>
<td>p&lt;0.001, 95% CI 13.4–28.0, n=15, d=1.21</td>
</tr>
<tr>
<td>Saccades</td>
<td>Near-point Brock string score</td>
<td>p=0.001, 95% CI 3.3 – 6.3, n=23, d=1.20</td>
</tr>
<tr>
<td>Vestibular</td>
<td>Dizziness Handicap Index</td>
<td>p=0.001, 95% CI 14.5 – 33.2, n=19, d=1.04</td>
</tr>
<tr>
<td>BPPV</td>
<td>BPPV symptoms</td>
<td>100% (28/28) resolved fully</td>
</tr>
<tr>
<td>Balance-objective</td>
<td>Balance Error Scoring System</td>
<td>p&lt;0.001, 95% CI 14.5 – 33.2, n=19, d=1.04</td>
</tr>
<tr>
<td>Balance-subjective</td>
<td>Activity-specific Balance Confidence</td>
<td>p=0.024, 95% CI 0.3 – 0.1, n=16, d=-0.89</td>
</tr>
</tbody>
</table>

BPPV = Benign Paroxysmal Positional Vertigo  
ROM = Range of Motion  
95%CI = 95% Confidence Interval

Exercises were added for habitation were added on or after the 3rd week of vision therapy. The principles of substitution, adaptation, and habitation were applied to improve balance, postural control, dizziness, oscillopsia, and complaints of motion intolerance. In addition, independent daily light cardiovascular activity for 20 minutes, consistent with the Buffalo Treadmill Test, was recommended for all patients who were greater than three days post-injury.

STATISTICAL METHODS

All statistics were run in Stata for Mac. Descriptive data were calculated including means and standard deviations, with counts presented with percentages. Non-parametric and parametric statistics were used as appropriate after assessment of normal distribution patterns. Effect sizes were calculated with values of Cohen’s d considered large if $d \geq 0.8$, medium if $0.5 \leq d < 0.8$, and small if $0.2 \leq d < 0.5$. Paired t-tests were run using Bonferroni correction to control for familywise error and guard against false positives due to multiple comparisons (p<0.05).

RESULTS

The 38 patients with follow-up data received an average of 10.4±4.8 treatment sessions over 57.6±34.0 days. The average number of sessions addressing cervical dysfunction was 4.0±3.8, vision and vestibular dysfunction 4.8±5.0, and combined symptoms 1.7±0.8.

Significant improvements were observed at post-test for general post-concussion symptoms on the patient-reported PCSS (p=0.001, d=1.18). See Table 2. Musculoskeletal, visual, and vestibular symptom outcome measures improved as indicated on clinical measures and patient reported outcomes. Cervical ROM returned to normal for 15 of the 27 people who had limitations on evaluation (55.6%). Vision function significantly improved for convergence on Brock string score (p=0.001, d=1.20). Subjective vision symptoms assessed with the CISS also improved significantly (p=0.002, d=1.04). Divergence and abnormal saccades did not change significantly (p=0.05). Symptoms of BPPV were fully resolved for all 28/28 (100%) diagnosed with BPPV. Vestibular system impairment represented by clinical measure of balance ability using the BESS improved significantly (p<0.001, d=0.99). The subjective patient-reported outcome ABC scale also improved significantly post treatment (p=0.024, d=−0.89). Vestibulo-oculomotor symptoms improved significantly post-treatment, assessed with the DHI (p=0.001, d=1.04) and BIVSS (p<0.001, d=1.21). See Table 2.

DISCUSSION

The results of this retrospective cohort study showed that patients receiving physical therapy, consisting of manual therapy and exercise for cervical dysfunction and BPPV in the first three weeks post-concussion followed by vision and vestibular rehabilitation therapy beyond three weeks post injury, demonstrated clinical and patient-reported benefits in multiple systems. Improved cervical dysfunction such as limited ROM and headache following head injury, as well as other causes of post-concussion symptoms, can be contributed to by concomitant whiplash injury suffered at the time of the concussion. Changes in neck muscle activity during cervical rotation and cervico-ocular coordination may underlie clinical symptoms reported by people with visual deficits and changes in function, such as postural control, during cervical rotation. Regardless, whether cervicogenic headaches include pain, dizziness, and/or oculomotor dysfunction, restoring cervical ROM may well be one factor affecting multiple systems. Findings in the current study for the musculoskeletal, vision, and vestibular systems were consistent with past literature for select recommendation of the most recent clinical practice guidelines. Reducing musculoskeletal limitation was an important early goal because of the importance of cervical ROM for vision and vestibular assessments and rehabilitation and the impact cervical dysfunction has on headaches, visual and vestibular function. Most subjects regained full cervical ROM by re-evaluation, though data for some patients was missing, the measurement method was unreported, and the definition for full ROM can vary. Direct comparison of the study results with past reports that have shown that manual therapies improve cervical ROM with thrust or mobilization
with movement\textsuperscript{31,32} was not possible because the retrospective data did not include specific manual techniques. Evidence for the efficacy of using manual therapy to reduce cervicogenic headache remains limited by the number of studies and lack of no-treatment control groups.\textsuperscript{8} One randomized controlled trial demonstrated increased ROM after sustained natural apophyseal glides but no significant improvement in dizziness or balance for people with chronic cervicogenic dizziness.\textsuperscript{31} Cervicogenic headache was not analyzed directly in this study, though headache was an item included in the total PCSS scores which improved significantly at re-evaluation. Starting care by addressing cervical dysfunction within the first three-weeks post-injury when indicated may be one among many factors in the improvements seen for cervical dysfunction as well as vision and vestibular outcome measures.

One common vision system dysfunction, convergence insufficiency, has been associated with other neurocognitive impairments and higher PCSS.\textsuperscript{33} After the study treatment, patient-reported symptoms on the PCSS had improved significantly as did clinical Brock string measures for near point convergence consistent with a five subject pilot study\textsuperscript{34} and a case-control study including 15 people with mild traumatic brain injury.\textsuperscript{35} Randomized controlled trials would be the next step to determine effect of vision therapy post-concussion compared to no treatment. Clinical measure of abnormal saccades did not change for patients post-treatment, consistent with past research.\textsuperscript{35} Missing data precluded analysis of other visual deficits common after minor traumatic brain injury such as smooth pursuits, and eye alignment.\textsuperscript{16} Also consistent with previous findings, patient-reported outcomes for vision symptoms improved significantly on the CISS and BIVSS.\textsuperscript{25,34,36} The oculomotor and vestibular systems are highly interconnected with integrated roles in maintaining balance, postural control and gaze stabilization,\textsuperscript{16} and patients exhibited benefits in both systems.

Evidence supports vestibular system rehabilitation for both central and peripheral deficits in concussion management.\textsuperscript{37} Physical therapy for cervical dysfunction has improved both musculoskeletal and vestibular symptoms including dizziness attributed to BPPV.\textsuperscript{37} In the current study, treatment for cervical dysfunction followed by canalith reposition procedures for BPPV was provided when indicated within the 3-week post injury timeframe instead of waiting for the 3-week post injury period when vision and vestibular rehabilitation began. Addressing BPPV before other vestibular deficits was similar to one past study, that aimed to reduce the confounding effect of BPPV on balance outcomes by treating BPPV first before introducing any habitation approaches.\textsuperscript{38} That all patients with BPPV had complete symptom resolution after treatment was comparable to past outcomes for the Epley maneuver summarized in a recent systematic review.\textsuperscript{59} Patient-reported outcome measures including the ABC scale and DHI both improved, consistent with a past retrospective cohort study of vestibular rehabilitation post-concussion.\textsuperscript{30}

The recent clinical practice guidelines for mild traumatic brain injury supports multi-modal rehabilitation\textsuperscript{10,11} and physical therapy models of care for protracted concussion recovery have included cervical dysfunction and vestibular-ocular care and exertional activity without specific intervention sequence.\textsuperscript{40} The results of this study suggest that the intervention sequence\textsuperscript{27} addressing cervical dysfunction and BPPV within the three weeks post-injury before initiating vision and vestibular rehabilitation at more than three weeks post-injury may yield positive outcomes. Early cervical ROM restoration is important because cervical motion can have a confounding impact of cervicogenic headaches, and vision and vestibular function; while BPPV symptoms can confound both vestibular-ocular and vestibular spinal function including balance assessments.\textsuperscript{38} Since post-concussion symptoms resolve spontaneously for 80-90% of adults within 2 weeks, delaying therapeutic vision and vestibular training in the early period of recovery can avoid unnecessary symptom exacerbation.\textsuperscript{5} Within an overall integrated treatment approach, sequencing cervical dysfunction and BPPV treatment before advancing to vision and vestibular rehabilitation acknowledges the role cervical ROM plays in both vision and vestibular function\textsuperscript{16,17,35,40} and may improve the ability to perform functional activities early in the episode of care. Developing exercise tolerance thereafter would precede a return to sport.\textsuperscript{40} In total, the inter-relationships among the musculoskeletal, vision and vestibular systems, with respect to both function and treatment, make screening for and addressing cervical dysfunction a logical first step even before the three-week post-injury timeframe for starting vision and vestibular rehabilitation.

Limitations of this retrospective cohort analysis of de-identified preexisting data included the lack of a control group and inability to obtain follow-up or missing data. Specific sport involvement was not consistently recorded, although at least 10 concussions were due to skiing; and return to sport outcomes were not available. Headache pain, which was incorporated in the PCSS, was also not individually assessed. The small sample size limited ability to analyze sub-groups or perform regression analysis of factors associated with the outcomes. Patients with missing reevaluation data could not be included in the pre-post analysis, thus although effect size changes were large, results should be viewed with caution given unknown outcomes in at least 35.6%. The potential exists for selection bias due to recruitment from a single concussion clinic. However, participation of the one concussion clinic allowed consistent use of the established protocol that sequenced and integrated musculoskeletal, vision and vestibular system care. Finally, the pragmatic treatment approach meant that variation in specific patient treatments was not controlled for, though results suggest that direct comparison of the study approach with a no-treatment control or alternate treatment condition would be warranted.

CONCLUSION

After concussion, symptoms can arise from multiple systems with musculoskeletal, visual, and vestibular dysfunction. Because cervical ROM is a part of both the assessment and treatment of visual and vestibular dysfunction, cervical limitations can confound symptoms in both systems. The results of this study showed that patients with post-concussion symptoms receiving treatment sequenced to address
cervical ROM limitations and BPPV symptoms in the first three weeks, integrated into visual and vestibular rehabilitation improved clinical and patient-reported outcomes for all systems. The interconnectedness of the systems makes sequencing care to address musculoskeletal function before the 3-week post-concussion recovery window in a clinical approach that then integrates vision and vestibular system function a promising approach for concussion recovery.

CONFLICTS OF INTEREST
The authors have no conflicts to disclose.

DISCLOSURES
This study received no funding.

Submitted: February 29, 2020 CST, Accepted: July 24, 2021 CST
REFERENCES


20. Heick JD, Bay C, Valovich McLeod TC. Evaluation of vertical and horizontal saccades using the King-Devick test compared to the Vis 2018;13(5):808-818. doi:10.26603/jispt20180808


Original Research

Determining Near Point of Convergence: Exploring a Component of the Vestibular/Ocular Motor Screen Comparing Varied Target Sizes

John D Heick, PT, PhD, DPT, OCS, NCS, SCS 1, Curt Bay, PhD 2

1 Department of Physical Therapy and Athletic Training, Northern Arizona University, 2 Department of Interdisciplinary Health Sciences, A.T. Still University

Keywords: movement system, oculomotor, concussion assessment

10.26603/001c.18867

International Journal of Sports Physical Therapy
Vol. 16, Issue 1, 2021

Background
Near point of convergence (NPC), a component of the Vestibular Ocular Motor Screening (VOMS) assessment, may be helpful in diagnosing concussion. The VOMS uses a standardized approach to measure NPC; however, methods of screening for NPC are not standardized.

Purpose
The purpose of this study was to determine whether four different methods of measuring NPC yielded different estimates.

Study Design
Descriptive within-subjects laboratory study.

Level of Evidence
Level 3.

Methods
Healthy recreational athletes participated in a comparison of 4 commonly used methods of measuring NPC: a 12-point font target, the VOMS (14-point font target), the tip of a black pen, and the Bernell Vergel™ device (9-point font target). The order of the presentation of the 4 targets was randomized.

Results
Seventy-five participants (59 females, 16 males; mean [SD] age=21.0 [6.12] years) completed 3 trials. The mean (SD) of the 900 NPC measurements was 7.11 (3.67) cm. Measurements for all targets had excellent reliability (r=0.94 to 0.98). In a comparative analysis, participant age was associated with NPC (p<0.01) and was covaried. The NPCs derived from both the 12-point and 14-point font targets were smaller than NPCs from the tip of the black pen and the 9-point font device (p<0.01). Measurements between the tip of the black pen and the 9-point font device (p=0.25) and between the 12-point and 14-point font targets (p=0.84) did not differ.

Conclusions
The method used to measure NPC as a screening test for concussion should be standardized because the estimate differs depending on the technique chosen. The current study supports previous findings that the type of target used to measure NPC should be standardized for concussion assessment.

Clinical Relevance
Screening of NPC should be standardized for concussion assessment to improve the...
INTRODUCTION

Considering that 1.6 to 3.8 million sport- and recreation-related concussions occur annually in the US, and the potential exists for cumulative effects after repeated injuries, sport-related concussion is a public health issue. Further, concussions are one of the most prevalent acquired neurologic conditions in young adults, and disruption to the brain commonly manifests as various deficits in the following three global categories: physical symptoms, cognition, and postural stability. A multifaceted concussion assessment approach must address all three categories because concussion deficits manifest differently in different patients. Vision, one outcome tested for postural stability, uses almost half the pathways in the brain; these anatomical structures are susceptible to injury in a concussed athlete. Visual-motor disruptions include difficulty with saccades, accommodation, smooth pursuit, and fixation. An estimated 65%-90% of concussed patients have ocular motor disruptions, such as convergence insufficiency, slowed saccadic function, and smooth pursuit deficits.

Oculomotor assessment is often used by healthcare professionals to evaluate visual-motor disruptions after a suspected concussion. The Vestibular Ocular Motor Screening (VOMS) assessment, which combines oculomotor and vestibular tests with a concussion symptom scale, has been shown to be useful in identifying concussions. Posttraumatic vision or oculomotor dysfunctions are reported in 30%-65% of concussed patients. Abnormal near point of convergence (NPC), one type of oculomotor dysfunction, is estimated to occur in 46% of athletes after concussion. Convergence occurs when a target is moved toward a patient’s eyes and the eyes converge or move toward the target. The target doubles or presents as diplopia as it approaches the eye. Abnormal NPC has been defined as being unable to see a target clearly at a distance of more than 5 cm from the eye and represents the threshold for NPC. Patients with convergence insufficiency commonly experience diplopia, blurred vision, headaches, or dizziness and nausea.

Near point convergence is a component of the VOMS assessment, and several studies investigating the VOMS reported an abnormal NPC was associated with prolonged concussion symptoms. Although the VOMS uses a standardized approach to measure NPC, different methods of measuring NPC are commonly used. The literature regarding the use of the VOMS instructs clinicians to use a 14-point font size letter on the end of a tongue depressor to measure NPC. The 14-point font size target is moved by the patient from arm’s length toward the tip of the nose, and the examiner uses a ruler to determine the NPC. This method includes subjective and objective approaches to determine NPC; patients are instructed to stop moving the target when they observe two distinct images (diplopia) or when the examiner observes an outward deviation of one eye. Three trials requiring about 30 seconds are performed, and the NPC measurements are averaged to yield an estimate.

Some have proposed measuring NPC with other devices independently of the VOMS. Further, the method of measuring NPC tends to differ across disciplines. For example, Pearce et al. used a standard Gulick tape measure that patients moved from arm’s length to the tip of their nose. The NPC of 78 concussed athletes aged 9-24 years was measured, and a 12-point font size letter was used as the target. The authors correlated NPC measurements with cognitive impairment evaluated by the Immediate Post-Concussion and Cognitive Test (ImPACT) using a standard of more than 5 cm to indicate an abnormal NPC. The athletes repeated three consecutive trials without rest, and the intraclass correlation coefficients (ICCs) across the three trials ranged from 0.95 to 0.98. Athletics with impaired convergence performed worse on the ImPACT for the verbal memory, visual motor speed, and reaction time tests; they also reported higher total symptom scores. Further, 42% of these athletes had impaired convergence one month after their concussion. As with the VOMS assessment, the NPC for this study was determined when the patient saw two distinct images or when the examiner observed outward deviation of one eye.

In another study, Adler et al. investigated NPC using 4 different target sizes, including the tip of a pencil, and found that NPC was significantly different for different target types. The authors used the tip of a pencil because it is a more precise target than a 12-point or 14-point font size letter. The authors also controlled for the speed of the target’s approach by moving it toward the tip of the nose at a rate of approximately 1-2 cm/s.

While these traditional VOMS measures are taken with readily available inexpensive items, there are devices available that specifically measure convergence. The Bernell Vergel™ (Mishawaka, IN) is a battery-operated device that measures convergence by using a 9-point font size target for evaluation. To the authors’ knowledge, the Bernell Vergel has not been investigated rigorously as a test for NPC.

Multiple disciplines are investigating NPC because of its relationship with concussions. Using evidence-based assessment tools such as the VOMS requires a systematic approach. Since multiple disciplines use multiple methods to measure NPC and precision is needed for concussion assessment, it would be helpful for clinicians to use a standardized approach. Therefore, the purpose of the current study was to determine whether four different NPC measurement methods of measuring NPC yielded different estimates.

METHODS

The current study used a prospective within-subjects research design to compare 4 standardized, commonly used methods of measuring NPC: a 12-point font target, the VOMS (14-point font target), the tip of a black pen, and the Bernell Vergel device (9-point font target). The study was conducted from February to December 2018. All experimental procedures were approved by the Northern Arizona University Institutional Review #1195714-1.
PARTICIPANTS

Potential participants were healthy recreational athletes recruited through flyers distributed at a university campus. Participants had to be aged 18-50 years and proficient in speaking and reading English so they could understand directions for testing. Potential participants were excluded if they had a history of head, neck, or face injury in the past year or had any diagnosed neurological or ocular disorder. Participants meeting inclusion criteria were provided information about the nature of the study and completed written informed consent.

PROCEDURES

All testing was conducted at a university research laboratory and was administered by the same researcher. All measurements were collected during a single testing session. Participants who wore glasses or contacts were informed that they could use them if they wished. Instructions were provided before each of the four tests, and participants were offered short rest breaks, as needed, for no more than one minute during testing. To control for order effect of the four tests, the order in which the tests were presented was randomized before each session using a random number generator. All tests were completed in a seated position and at the same location in the laboratory because it provided adequate lighting. Three trials of each test were performed. Distances for NPC were measured using a standard ruler for all tests except the one using the Bernell Vergel device, which does not require a ruler.

INSTRUMENTATION

Instructions for the VOMS tool were modified based on a review of the literature and were consistently used for testing of all participants. The specific modifications included 1: the size of the target; 2: the examiner started the target at arm’s length away from the participant and moved it toward the center of the participant’s eyes at a rate of approximately 1-2 cm/s; and, 3: the examiner was seated to the side of the participant to view the ruler and observe the participant’s eyes. The NPC was established when participants indicated they saw two distinct images or when the examiner observed an outward deviation of one eye. Blurring of the image was ignored because it is a normal reaction.

For the tests with the 12-point and 14-point font targets, the target was an "X" printed in the required font size and placed on the end of a tongue depressor. For the test with the tip of a black pen, the target was the tip of a black BIC (Shelton, CT) pen. The distance between the target and the tip of the participant’s nose for these 3 tests was measured in centimeters with a standard ruler and recorded.

For the Bernell Vergel device test, the target was a 9-point font size "X" located on the Bernell Vergel device. The examiner depressed a button on the device when the participant reported diplopia or the examiner observed outward deviation of one eye. The Bernell Vergel device uses an on-board microprocessor and ultrasonic technology to measure the distance from the participant to the target in cm.

Table 1: Demographic Characteristics of Participants (N=75) of the Current Study

<table>
<thead>
<tr>
<th>Demographic Characteristic</th>
<th>No. (%) or Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>16 (21.3)</td>
</tr>
<tr>
<td>Female</td>
<td>59 (78.7)</td>
</tr>
<tr>
<td>Age, y</td>
<td>21.0 (6.12)</td>
</tr>
<tr>
<td>Glasses/contacts</td>
<td>35 (46.7)</td>
</tr>
</tbody>
</table>

*Age is reported as mean (SD).

A sample size calculation performed using G*Power with an α=0.05, and a power of 0.95 determined 70 participants were required to detect an effect size f=0.15, assuming an average correlation between repeated measures of r=0.60. Generalized estimating equations models were used for analysis to address the repeated measurements within participants, as well as the between-group differences. An exchangeable correlation matrix and log link function best fit the data. Robust estimators were computed. A sequential Bonferroni adjustment was used for follow-up comparisons. Participant age was tested as a covariate, and the use of glasses or contacts was tested as a fixed factor. Reliability analyses were conducted to assess the level of agreement across measurements using a two-way random-effects (consistency) model based on an average measurement. This method allowed bias assessment between mean measurement differences and estimation of an agreement interval, within which 95% of the differences between the two measurements fell. For the ICC estimates, reliability was evaluated as follows: values less than 0.50 were considered poor, 0.50-0.74 were considered moderate, 0.75-0.90 were considered good, and above 0.90 were considered excellent.20 Bland-Altman plots were also constructed based on mean differences.17 In Bland-Altman plots, the y-axis shows the difference between the two paired measurements (A-B), and the x-axis is the average of these measures (A+B/2). Bland and Altman recommended that 95% of the data points should lie within ± 1.96 standard deviations (SD) of the mean difference.17 The average of paired differences is zero if no bias exists between measurements. All analyses were two-tailed, and the criterion level for significance was set a priori at P<0.05. Analyses were performed using SPSS® statistical software version 25 (IBM Corp., Armonk, NY).

RESULTS

Seventy-five participants (59 females, 16 males) completed the study. Demographic characteristics are reported in Table 1. Twelve measurements of NPC were obtained for each participant. The mean (SD) of the 900 NPC measures was 7.11 (3.67) cm. Age was inversely correlated with NPC (p<0.01), so it was retained in the model. The use of glasses or contacts was not significant (p=0.72) and was discarded.
Table 3: Pairwise Comparisons of Near Point of Convergence (NPC) across the 4 Measured Test Targets by Distance (N=75)

<table>
<thead>
<tr>
<th>NPC Test (I)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>NPC Test (J)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Mean Difference (I-J)</th>
<th>Standard Error</th>
<th>Bonferroni-Adjusted &lt;i&gt;P&lt;/i&gt; Value</th>
<th>95% CI for Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bernell Vergel</td>
<td>Tip of black pen</td>
<td>-0.71</td>
<td>0.46</td>
<td>0.25</td>
<td>-1.75 to 0.32</td>
</tr>
<tr>
<td></td>
<td>12-Point font</td>
<td>1.33</td>
<td>0.32</td>
<td>&lt;0.01</td>
<td>0.53 to 2.13</td>
</tr>
<tr>
<td></td>
<td>14-Point font</td>
<td>1.37</td>
<td>0.36</td>
<td>&lt;0.01</td>
<td>0.51 to 2.24</td>
</tr>
<tr>
<td>Tip of black pen</td>
<td>12-Point font</td>
<td>2.04</td>
<td>0.35</td>
<td>&lt;0.01</td>
<td>1.14 to 2.95</td>
</tr>
<tr>
<td></td>
<td>14-Point font</td>
<td>2.09</td>
<td>0.35</td>
<td>&lt;0.01</td>
<td>1.16 to 3.01</td>
</tr>
<tr>
<td>12-Point font</td>
<td>14-Point font</td>
<td>0.04</td>
<td>0.22</td>
<td>0.84</td>
<td>-0.38 to 0.47</td>
</tr>
</tbody>
</table>

<sup>a</sup> NPC results are reported in cm. Abbreviation: CI, confidence interval.

from the model. Table 2 reports the mean and 95% confidence interval (CI) for the three trials of the four NPC measurement tools. Table 3 presents the Bonferroni-corrected results of pairwise comparisons across trials by measurement tool. The NPC for the tip of the black pen was not different from the Bernell Vergel 9-point font device (<i>p</i>=0.25). The NPC for the 12-point and 14-point font targets were not different (<i>p</i>=0.84), but both were smaller than the tip of the black pen and the Bernell Vergel 9-point font device (<i>p</i>&lt;0.01).

The ICCs of the four tests across the three trials were all excellent: 12-point font target (ICC=0.96, 95% CI=0.94-0.97); 14-point font target (ICC=0.98, 95% CI=0.97-0.98); tip of the black pen (ICC=0.95, 95% CI=0.92-0.96); and the Bernell Vergel 9-point font device (ICC=0.95, 95% CI=0.92-0.96).

The Bland-Altman plots for the pairwise measurements across all tests are presented in Figure 1. Pairing of the 12-point and 14-point font targets had the narrowest limits of agreement (Figure 1a), and pairing of the tip of the black pen and the Bernell Vergel 9-point font device had the widest (Figure 1f). The average of paired differences for the 12-point and 14-point font targets was zero (Figure 1a). Bias was limited in measurements across all tests, but 3 of the four measurements outside the limits of agreement for the 12-point and 14-point font targets pairing occurred at mean NPC less than 5 cm. For paired measurements, including the Bernell Vergel 9-point font device (Figures 1b, 1d, 1f), extreme disagreements occurred at larger NPCs.

Sixty-one percent of all NPC measurements exceeded the conventional NPC threshold of 5 cm for concussion screening. The mean NPC measurement by target with a breakdown by percentage of exceeding the 5 cm NPC threshold is as follows: 12-point font target (66.7%); 14-point font target (61.3%); the tip of the black pen (88.4%); and the Bernell Vergel 9-point font device (64.5%).

Table 2: Mean (95% Confidence Interval [CI]) of Near Point of Convergence (NPC) for the 3 Trials of the 4 Measured Tests (N=75)

<table>
<thead>
<tr>
<th>NPC Test&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Mean (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-Point font target</td>
<td>6.25 (5.55-7.04)</td>
</tr>
<tr>
<td>14-Point font target</td>
<td>6.21 (5.57-6.92)</td>
</tr>
<tr>
<td>Tip of a black pen</td>
<td>8.30 (7.62-9.04)</td>
</tr>
<tr>
<td>Bernell Vergel device</td>
<td>7.58 (6.67-8.61)</td>
</tr>
</tbody>
</table>

<sup>a</sup> NPC results are reported in cm.

DISCUSSION

The purpose of this study was to determine whether four different methods of measuring NPC yielded different estimates. These results suggest that NPC screening should be performed using a standardized approach, such as the VOMS because we found differences between the methods. The tip of the black pen and the Bernell Vergel 9-point font device, both small targets, had similar estimates of NPC. The means of these two tests were 7.6 cm and 8.3 cm, respectively, which is larger than the NPC threshold of 5 cm for identifying a concussion, based on the VOMS protocol. The mean NPCs for the 12-point and 14-point font targets were 6.3 cm and 6.2 cm, respectively, and were not statistically different from each other, but they were significantly different from the other, smaller targets. These results were also larger than the NPC threshold for identifying a concussion; however, this threshold has not been endorsed by many disciplines.7,18,21–24

Evaluation of NPC in the clinical environment often uses items of convenience as targets, such as the tip of a pencil or pen, a penlight, or the tip of the index finger.23 Although...
convenient for screening, the items vary in size, and dexterity is required to maintain a standardized approach to assessment.21–25,25–27 These pragmatic measurements of NPC are used across disciplines.7,13,22,23,28,29 For example, Adler et al.18 investigated convenient tools that are used in an optometry clinic, such as the tip of the pen, fingertip,
penlight, and two targets suspended on a ruler that were not 12-or 14-point font size in a population of children. In the current study, targets were similar in clinical usefulness but were centered around investigating the size of the target being moved towards the participant.

Setting a threshold for abnormal NPC can be challenging. For instance, research suggests that approximately 5% of healthy, non-concussed adults routinely have an abnor-
Figure 1e: Bland-Altman Charts for Pairwise Measurements of Pen and 12-Point Font. The blue lines represent upper and lower 95% limits of agreement. The black line represents the mean of differences between the two measurements.

Figure 1f: Bland-Altman Charts for Pairwise Measurements of Bernell device and Pen. The blue lines represent upper and lower 95% limits of agreement. The black line represents the mean of differences between the two measurements.

Some have suggested that the prevalence of abnormal NPC ranges from 1% to 33% in healthy individuals. Optometrists suggest that normal NPC is between 8 cm and 10 cm, which calls into question the 5-cm NPC threshold used in the VOMS. This variability in thresholds has led some to recommend baseline testing of the NPC. A baseline measurement at the beginning of a season could be used as a comparison for athletes with a suspected concussion. Moran et al. suggested that individualized baseline testing could reduce the likelihood of false-
positive assessments after a concussion. In the current study, using the standard 5 cm NPC threshold resulted in 61.3% of participants receiving an abnormal NPC. If the threshold for an abnormal NPC were set at 10 cm for healthy, non-concussed individuals, then 32% of the participants would be classified as abnormal. Thus, if the NPC were not tested at baseline, a large percentage of healthy participants in this study would be incorrectly classified as abnormal. Considering the time required for the sports professional to assess NPC at baseline, the Bernell Vergel may be the most efficient screening tool for preseason baseline measurement. Given these results, a baseline screening is recommended to identify athletes with large NPCs so they are not incorrectly classified as abnormal based on their NPC score.

Although convergence insufficiency has been defined as an abnormal NPC, optometrists and ophthalmologists disagree with this suggestion. Instead, convergence insufficiency should include multiple types of tests and multiple measures to identify NPC. Ophthalmologists perform comprehensive exams that use NPC as one of the measures for assessing convergence insufficiency. In a recent study, Stiebel-Kalish et al. used ocular alignment with distance and near cover testing, Maddox distance heterophoria testing with a Maddox rod, Maddox-Thorington near heterophoria testing with a Thorington card, Randot stereopsis with booklet testing, NPC with a target-specific to the patient’s vision, the amplitude of accommodation with an acuity target, and fusional vergence with targets and prisms. However, these optometric tests should only be performed by ophthalmologists or optometrists who are trained to administer them. Further, other disciplines should not suggest that convergence insufficiency is only identified by a reduced NPC and should not use the term convergence insufficiency even if these disciplines are only screening for NPC. Others should instead refer to a reduced NPC result as an abnormal NPC to decrease confusion across disciplines.

Results of the current study highlight the importance of standardizing NPC screening. The larger targets tended to have higher ICC values across the three trials and narrower limits of agreement. If NPC is used in a serial fashion, for example at baseline and periodically thereafter or as an assessment of progress during rehabilitation from a concussion, it is crucial that the same size target be used. Otherwise, differences in estimated NPC due to measurement variability will obscure any real changes that may be occurring.

The current study had several limitations. For instance, a convenience sample of participants recruited from a local university was used, so results should be generalized with caution. Another limitation is that the details of the participants’ visual history were not obtained. As such, visual dysfunctions, such as stigmatisms or other visual disorders, may have influenced performance on the NPC tests. Participants were asked if they wore glasses or contacts but were not screened for behavioral/psychological disorders such as ADHD or dyslexia that may have affected their test results. Future studies should include a visual history to determine whether this plays a role in NPC.

CONCLUSION

The VOMS, which uses a 14-point font size target for concussion screening, is standardized and practical. Assessment of NPC should be standardized across all disciplines with respect to the target, the speed of the target being moved toward the athlete, and the NPC cut-off score for what is considered abnormal. Results of the current study support previous research that indicates the size of the target used to measure NPC should be consistent across measurements. The authors also recommend that NPC measurements should be conducted pre-season to establish an NPC baseline as a potential comparison if the athlete sustains a concussion.

CONFLICTS OF INTEREST

The authors do not have any conflict of interest.

Submitted: March 02, 2020 CST, Accepted: October 10, 2020 CST
REFERENCES


International Journal of Sports Physical Therapy
Does the Movement Competency Screen Correlate with Deep Abdominals Activation and Hip Strength for Professional and Pre-professional Dancers?

Justine Benoît-Piau, PT, M.Sc¹, Mélanie Morin, PT, PhD¹, Sylvie Fortin, PhD², Christine Guptill, OT, PhD³, Nathaly Gaudreault, PT, PhD¹

¹ School of Rehabilitation, Faculty of Medicine and Health Sciences, Université de Sherbrooke, ² Dance Department, Université du Québec à Montréal (UQAM), ³ School of Rehabilitation, University of Ottawa

Keywords: movement system, transversus abdominis activation, movement competency screen, hip strength, dance

Background
Dancers are a unique category of athletes who are frequently injured and experience pain. The primary cause of dance injuries is overuse, which could potentially be prevented. However, literature is scarce regarding validated methods of evaluating the risk of injury in dancers. The Movement Competency Screen (MCS) could potentially fill this gap.

Hypothesis/Purpose
To investigate the validity of the Movement Competency Screen (MCS) for dancers by 1) examining the correlation between scores on this functional test and the activation of deep abdominals and hip strength; 2) investigating the correlation between MCS scores and those of the Functional Movement Screen (FMS™).

Study Design
Cross-sectional study.

Methods
A total of 77 pre-professional and professional dancers from ballet and contemporary backgrounds were evaluated. The activation of deep abdominals was evaluated using ultrasound imaging and the hip strength was evaluated using a handheld dynamometer. The FMS™, another tool evaluating fundamental movement competency, was also administered.

Results
The dancers’ MCS score was correlated with the activation of the transversus abdominis (r=0.239, p=0.036) and the strength of hip abductors (r=0.295, p=0.010), adductors (r=0.267, p=0.019) and external rotators (r=0.249, p=0.029). The MCS score was also correlated with the FMS™ score (r=0.489, p<0.001).

Conclusion
This study shows that the MCS score is correlated with deep abdominal activation and hip strength in dancers, as well as with the FMS™ score. These findings provide evidence toward the validation of the MCS in dancers.

Levels of Evidence
Level 2B.

Corresponding Author: Nathaly Gaudreault School of rehabilitation, Faculty of medicine and health sciences, University of Sherbrooke, 3001, 12e Avenue Nord, Sherbrooke, J1H 5N4, Canada Phone: 1 819-821-8000, ext. 18613; Fax: 819-820-6864 Nathaly.Gaudreault@usherbrooke.ca
INTRODUCTION

Dancers are a population that needs to combine the qualities and skills of both athletes and artists. To reach a pre-professional or professional level, many years of intensive training are required.¹ The demanding training volume, paired with the repetition of powerful movements at the limit of a dancer’s range of motion, could explain the high injury incidence reported in the literature.¹⁻⁴ Injuries and pain pose a threat to dancers’ physical and mental health, as well as their career.⁵ The musculoskeletal pain and injuries sustained by dancers affect mainly the lower limbs (66-91%) and the lumbar region (8-16%).¹,³,⁴ Most injuries in dancers occur in the ankle, the leg and the foot.¹,³,⁴ The structures injured are predominantly ligaments, muscles, tendons and fascia.¹,³,⁴ These injuries will occur due to overuse in 66-79% of cases.¹,³,⁴,⁶ There is therefore potential for prevention through preseason musculoskeletal screening and functional performance testing.¹⁻⁷ Due to the significant impact and high number of injuries among dancers, screening could be a valuable way of preventing an important portion of injuries.

Few risk factors for musculoskeletal pain and injuries have been identified for dancers in the literature.⁸ A recent systematic review of lower limb strength and injuries among dancers highlighted that strength at the hip and knee could have a protective role, but the heterogeneity of the study designs and low quality scores of the studies included prevented the authors from drawing any valid conclusions. They therefore emphasized that more studies were necessary to identify risk factors for musculoskeletal injuries and to guide the development of preventive strategies.⁹ Activation of the deep abdominal musculature is another potential predicting factor of injury that has raised interest among dance researchers.¹⁰⁻¹¹ Roussel et al. found that dancers who had sustained an injury to the lower back had more difficulties recruiting their transversus abdominis (TrA) compared to dancers without low back pain.¹¹ Thus, the assessment of both hip strength and activation of deep abdominals could be relevant in the prevention of dance injuries. However, focusing on isolated segmental muscle assessment might not be sufficient since dancing requires the body to work in an integrated manner.

Recent authors have highlighted the importance of implementing functional performance tests during preseason preparation.¹²⁻¹⁴ Studies by Cook et al. as well as Bonazza et al. have determined that the Functional Movement Screen (FMS™) has predictive value for injuries in athletes.¹⁵⁻¹⁷ There is an abundance of literature on the FMS™, but its predictive value has been questioned.¹⁵⁻¹⁹ The Movement Competency Screen (MCS) has also been investigated in a study on ballet and modern dancers that yielded predictive results.²⁰ Indeed, Lee et al.²⁰ conducted a prospective study which established a cut-off score of 23 under which dancers were more likely to become injured. It is particularly useful for dancers since it uses movement repetitions and plyometric components which would replicate more adequately the conditions of the sport compared to the constructs that are screened in the FMS™. Even if the MCS is able to evaluate the ability to achieve fundamental movements without compensation in dancers, additional research is needed to establish its validity.

Both the FMS™ and MCS consist of observing movement patterns while considering the mobility and stability continuum to assess whether the athlete is able to complete fundamental movements without pain and compensation. These movements are hypothesized to require the activation of the deep abdominals and strength of the hip muscles. In fact, Hodges et al. suggest that the transversus abdominis (TrA), which is a deep abdominal muscle and an important lumbar stabilizer, should activate prior to the movement of limbs in order to allow performance of a functional task without any compensation, as those required in the MCS.²¹ The importance of the hip muscles in stabilizing the pelvis and lower extremity during functional movement performance is demonstrated by evidence that weakness of these muscles affect the incidence of lower limb and back injuries.²² Asymmetry in hip muscle strength is common among athletes: right handed athletes often exhibit greater strength in the left hip extensor muscles and right hip abductor muscles.²³ These asymmetries impose a greater demand on the weaker hip muscle groups during the execution of fundamental movements that can lead to compensation and/or misalignment observed at the trunk, pelvis or lower limb.²⁴ In other words, trunk stability cannot be achieved without pelvis stability. Although the trunk muscles including the TrA play an important role in lumbar stability during execution of fundamental movements, activation of these muscles alone does not prevent compensatory trunk motions correlated with weak hip muscles. The relationship between the MCS and basic abilities that are necessary to perform movements without compensation, such as the activation of deep abdominals and hip muscle strength, has not been investigated.²⁵ The current study is therefore an early step in improving the quality of literature concerning the MCS.

This study aimed to investigate the validity of the MCS for use in dancers by 1) examining the correlation between the score of this movement screen and the activation of deep abdominals and hip strength (convergent validity) and 2) investigating the correlation between its scores and those of the FMS™ which also evaluates the capacity to perform fundamental movements (criterion validity).

METHODS

STUDY DESIGN

This cross-sectional study is the first step in a larger longitudinal project. The data for the current study were collected during an evaluation session scheduled at the beginning of the dance season in multiple dance schools and companies in two large metropolitan areas. This project was approved by the institutional review boards of the Centre de recherche du CIUSSS de l’Estrie-CHUS and Cégep de St-Laurent. All participants gave written informed consent prior to participation.

PARTICIPANTS

Included participants were ballet or contemporary dancers, aged 16 years or older, enrolled in a pre-professional program or employed by a dance company or a dance program,
and able to read and speak fluently in French or English. They also had to dance for more than 10 hours per week. This threshold was selected to ensure that all dancers achieved a similar baseline for dance exposure. Dancers were excluded if they presented with an injury preventing them from dancing at the time of the evaluation. Women were excluded if they were pregnant, since pregnancy impacts the lumbar-pelvic muscles.

The sample size was calculated in relation to the first objective assessing convergent validity. A total of 19 participants were needed considering an expected correlation coefficient of 0.7 (which characterizes an acceptable correlation), a power of 80% and an alpha of 0.05. Since this study was part of a larger research project requiring 118 participants, sufficient power for the analyses conducted was obtained. The guide established by Akoglu was used to qualify correlations (<0.4=weak, 0.4~0.7=moderate, 0.7~0.9=strong, >0.9=very strong correlation).

RECRUITMENT

Pre-professional schools and professional companies were first approached by a physiotherapist member of the research team to explain the objectives of the study and to seek approval to recruit among their students or employees. Once the organizations agreed, a presentation was then scheduled at each institution to inform professional and pre-professional dancers about the objectives of the project as well as the inclusion and exclusion criteria. Participation in the research study was voluntary. Dancers interested in participating could either schedule the initial evaluation at the end of the presentation or leave their contact information so that the physiotherapist performing the evaluations could contact them. Participants were screened for inclusion and exclusion criteria at the beginning of the first evaluation.

DATA COLLECTION

Each evaluation was conducted individually in a closed room by a physiotherapist who had two years of experience with the evaluation and treatment of dancers. The evaluations took place at the school or company to minimize inconvenience for dancers. They were scheduled in the span of six weeks at the beginning of a season, and lasted between 60 and 90 minutes. Dancers first gave informed consent, filled out a demographic questionnaire including questions about their dance background, and then completed the physical evaluation.

CONVERGENT VALIDITY: TRANSVERSUS ABDOMINIS ACTIVATION AND HIP STRENGTH

In order to evaluate the convergent validity, the activation of the TrA as well as strength in hip muscles were measured on both the dominant and non-dominant side. The TrA is one of the core trunk muscles responsible for maintaining trunk stability by preventing the loss of balance during limb movement, which is necessary to perform the tasks in the MCS. Theoretically, the position and function of the hip muscles contribute to the alignment of the pelvis and lower limb, which is of paramount importance in the performance of the movements in the MCS.

The transversus abdominis activation was evaluated using an ultrasound device (GE LOGIQ E, GE Healthcare, Milwaukee, Wisconsin, 13 MHz linear probe in B-mode). The probe was in a transverse plane and positioned at the mid-distance between the 12th rib and the iliac crest. The physiotherapist started at the linea alba and moved the probe laterally past the rectus abdominis and in between the mamillary and axillary lines until all three abdominal muscle layers, the external and internal oblique and the transversus abdominis, could clearly be seen. A single researcher took all the measurements. The angle of the probe was adjusted to optimize image quality. This non-invasive technology allows the visualization of the changes in thickness of the muscles compressing the abdominal wall when they activate. All participants were assessed in a standardized supine position with knees bent at 90° and were given standardized hollow-in instructions. Images were taken at the end of the expiration for both rest and activation measures. For clinicians with minimal experience in ultrasound imaging of the TrA, it was previously found that the intra-rater reliability ranged from 0.87 to 0.99 and the inter-rater reliability ranged from 0.80 to 0.92. This method was validated to assess the transversus abdominis activation by calculating an activation ratio as seen in Figure 1.

Strength was evaluated for all six muscle groups of the hip, in this order: abductors, adductors, extensors, flexors, external rotators and internal rotators. Each muscle group was tested three times with a 30-second pause between measurements. The average of the three measures was used to calculate correlations. A handheld dynamometer (MicroFET, Hoggan Scientific LLC, Salt Lake City, Utah), and straps were used to provide a fixed resistance for the participant as they exerted a maximal voluntary contraction. The intra and inter-rater reliability of the MicroFET has previously been shown to be excellent for hip muscles. Every muscle group was evaluated in a standardized position as seen in Figure 2. The positions used were those validated by Krause et al.

FUNCTIONAL TESTS

To assess the criterion validity of the MCS, it was investigated whether the dancers’ scores on this test were related to their score on the FMS™. These two functional tests assess the ability to perform fundamental movements without pain and/or compensation. The MCS is composed of five fundamental movements: body weight squat, lunge and twist, push-up, bend and pull, and single-leg squat. Each movement has its own load level, which can range from as-

![Figure 1: Formula for calculation of transversus abdominis activation ratio.](image)
<table>
<thead>
<tr>
<th>Task</th>
<th>Primary criteria</th>
<th>Secondary criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Squat</td>
<td>Shoulders, Lumbar, Hips, Ankle/feet</td>
<td>Head, Knees, Depth, Balance</td>
</tr>
<tr>
<td>Lunge and twist</td>
<td>Balance, Lumbar, Hips, Ankle/feet</td>
<td>Head, Knees, Depth</td>
</tr>
<tr>
<td>Bend and pull</td>
<td>Shoulders, Lumbar, Hips, Depth</td>
<td>Head, Knees, Ankle/feet, Balance</td>
</tr>
<tr>
<td>Push-up</td>
<td>Head, Shoulders, Lumbar, Hips, Depth</td>
<td>Hips, Knees, Ankle/feet, Balance</td>
</tr>
<tr>
<td>Single-leg squat</td>
<td>Depth, Lumbar, Hips, Ankle/feet</td>
<td>Head, Shoulders, Knees, Balance</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Load level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Assisted</td>
<td>2 or more primary regions checked</td>
</tr>
<tr>
<td>2: Bodyweight</td>
<td>1 primary region checked</td>
</tr>
<tr>
<td>3: External load</td>
<td>2 or more secondary regions checked</td>
</tr>
<tr>
<td>4: Eccentric</td>
<td>No primary region checked</td>
</tr>
<tr>
<td>5: Plyometric</td>
<td>1 or more primary and secondary regions failed during explosive MCS</td>
</tr>
</tbody>
</table>

Table 1: MCS tasks, evaluation and load level

This table was adapted from Kritz M. Development, reliability and effectiveness of the Movement Competency Screen (MCS). May 2012.
Table 2: Participants characteristics

<table>
<thead>
<tr>
<th>Sample</th>
<th>N (%) or Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>21.23 ± 4.86</td>
</tr>
<tr>
<td>BMI (kg/m^2)</td>
<td>21.06 ± 2.75</td>
</tr>
<tr>
<td>Dance training per week (hours)</td>
<td>25.82 ± 9.21</td>
</tr>
<tr>
<td>Dance experience (years)</td>
<td>13.40 ± 5.75</td>
</tr>
<tr>
<td>Sustained a pain episode in the last year</td>
<td>63 (82%)</td>
</tr>
<tr>
<td>Women / Men</td>
<td>66 (86%) / 11 (14%)</td>
</tr>
<tr>
<td>Contemporary / Ballet</td>
<td>41 (53%) / 36 (47%)</td>
</tr>
<tr>
<td>Preprofessional / Professional</td>
<td>61 (79%) / 16 (21%)</td>
</tr>
</tbody>
</table>

Table 1 provided a list of primary and secondary body regions to assess for compensations. The primary compensation checkpoints are the most important for a given movement. Compensations for every checkpoint are detailed in the thesis of Kritz\(^{25}\) and the study of Lee et al.\(^{20}\) A lower score indicates poor movement competency and a higher score indicates high movement competency. Movements were evaluated in both the sagittal and frontal planes. This test was validated for the evaluation of movement-related risk factors and has excellent intra (Kappa = 0.93) and inter-rater reliability (79%).\(^{25}\) The final score is calculated by taking the sum of the lowest score out of the two sides for each item.\(^{25}\)

The FMSTM, which has been extensively studied in athletes,\(^{17–19}\) uses seven fundamental movements: squat, hurdle-step, in-line lunge, shoulder mobility, active straight-leg raise, push-up and rotary stability.\(^{15–18}\) Each task is rated on an ordinal scale from 0 to 3, with the highest score indicating that the athlete can achieve the movement without any compensation. All tasks were evaluated in the sagittal and frontal planes. It has an excellent intra (ICC=0.81) and inter-rater reliability (ICC=0.81).\(^{17}\) Despite the identification of a cut-off score for a certain number of studies,\(^{17,34,35}\) not all researchers have been able to support the use of the FMSTM as a predictive tool.\(^{18,36}\)

**STATISTICAL ANALYSIS**

Descriptive analysis was used to characterize the sample for baseline characteristics, deep abdominal activation, hip strength and functional test scores. Since our population was heterogenous, we also conducted t-tests to compare the MCS total score between contemporary and ballet dancers as well as professional and pre-professional dancers. Bivariate correlations and hierarchical regressions were used to explore the correlation between the MCS and FMSTM as well as the correlation between the MCS and the activation of TrA and hip strength (objectives 1 and 2).\(^{26}\) The model used in hierarchical regressions was based on what was obtained in bivariate correlations. If the correlation between the variable and the MCS score was significant (i.e. \(p \leq 0.05\)), the variable was included in the regression.

**RESULTS**

**PARTICIPANTS**

A total of 77 participants were recruited from three companies and six pre-professional schools. There were 41 contemporary dancers and 36 ballet dancers. Dancers were aged 21.25 ± 4.86 years old and had been dancing for an average of 13.40 ± 5.75 years. The sample was composed of 66 women and 11 men. The majority of participants were pre-professional dancers (n=61) compared to professionals (n=16). The participants’ characteristics are presented in Table 2.
Table 3: Functional test scores

<table>
<thead>
<tr>
<th></th>
<th>FMS Mean ± SD</th>
<th>MCS Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Squat</td>
<td>2.00 ± 0.69</td>
<td>2.78 ± 0.45</td>
</tr>
<tr>
<td>Hurdle step</td>
<td>2.65 ± 0.53</td>
<td>NA</td>
</tr>
<tr>
<td>Lunge</td>
<td>2.87 ± 0.47</td>
<td>2.47 ± 0.68</td>
</tr>
<tr>
<td>Lunge &amp; Twist (twist)</td>
<td>NA</td>
<td>2.95 ± 0.22</td>
</tr>
<tr>
<td>Shoulder Mobility</td>
<td>2.99 ± 0.11</td>
<td>NA</td>
</tr>
<tr>
<td>Active straight leg raise</td>
<td>2.96 ± 0.19</td>
<td>NA</td>
</tr>
<tr>
<td>Push-up</td>
<td>1.82 ± 0.91</td>
<td>1.88 ± 0.84</td>
</tr>
<tr>
<td>Rotary Stability</td>
<td>2.77 ± 0.51</td>
<td>NA</td>
</tr>
<tr>
<td>Bend &amp; Pull (bend)</td>
<td>NA</td>
<td>2.88 ± 0.32</td>
</tr>
<tr>
<td>Bend &amp; Pull (pull)</td>
<td>NA</td>
<td>2.88 ± 0.32</td>
</tr>
<tr>
<td>Single leg squat</td>
<td>NA</td>
<td>1.83 ± 1.55</td>
</tr>
<tr>
<td>Total</td>
<td>18.05 ± 1.32</td>
<td>17.68 ± 1.56</td>
</tr>
</tbody>
</table>

**FUNCTIONAL TEST SCORES**

Table 3 depicts the mean total scores (± standard deviation) for the FMS™ and MCS as well as the scores for each item of the tests for the whole sample. Further analyses revealed no differences in the functional test scores between ballet and contemporary dancers, as well as professional and preprofessional dancers.

**RELATIONSHIP BETWEEN THE FMS™ AND MCS**

The scoring of the two functional tests were moderately correlated ($r=0.489, p<0.001$). Since three items from both tests were similar, additional correlations were established for them. The squat items were not correlated ($r=0.085, p=0.460$). The correlation was weak for the lunge items ($r=0.254, p=0.040$) and moderate for the push-up items ($r=0.587, p<0.001$).

**RELATIONSHIP BETWEEN FUNCTIONAL TESTS, TRANSVERSUS ABDOMINIS ACTIVATION AND HIP STRENGTH**

The total score on the MCS was weakly correlated with activation of the TrA. The correlation of TrA activation with the MCS total score was $r=0.239, p=0.036$. Individual items from the MCS were not correlated with the activation of the TrA.

The MCS total score was also weakly and positively correlated with the strength of hip abductors ($r=0.293, p=0.010$), adductors ($r=0.267, p=0.019$) and external rotators ($r=0.249, p=0.029$). The other muscle groups, which included hip flexors, extensors and internal rotators, were not significantly linked to MCS total score.

**EXPLAINING THE VARIANCE OF THE MCS**

Hierarchical regressions, presented in Table 4, showed that the activation of the transversus abdominis and the strength of hip abductors, adductors and external rotators explained 14.1% of the variance of the MCS total score ($F_{4,76}=8.623, p=0.005$). Both the activation of the transversus abdominis and the strength of hip abductors were correlated with the MCS total score ($p<0.028$). The activation of the transversus abdominis explained 3.3% of the MCS total score while the hip strength explained 10.8%.

**DISCUSSION**

This study aimed to develop new knowledge about the validity of the MCS for dancers. It was established that there were weak correlations between the MCS and the activation of deep abdominals and hip strength. It was also found that the MCS and FMS™ scores were moderately correlated.

**RELATIONSHIP BETWEEN MCS, TRA ACTIVATION AND HIP STRENGTH**

A significant (albeit mild) positive correlation was observed between the MCS total score and the TrA activation. It was found that better TrA activation was correlated with a higher score on the MCS. These findings concur with those found in multiple studies conducted by Hodges et al. In healthy, non-injured individuals, trunk muscles including the TrA contribute to the maintenance of trunk stability by making a sequence of postural adjustments before the distal movement to prevent any loss of balance. Since the tasks of the functional tests require trunk stability, a significant correlation between TrA and functional movement performance test was anticipated. It should however be emphasized that the correlation was weak, which may be explained by compensatory movements. For example, some participants may have completed the functional movement tests by activating other muscles such as the rectus abdominis, the internal and external obliques, and the multifidus or gluteal muscles. Others may have successfully activated the TrA but could have had difficulty performing some of the tasks because TrA activation taken in isolation is not the only parameter to consider. Indeed, when perform-
ing a movement, the ability to activate the TrA in a supine position does not guarantee that the dancer will perform a movement in a different position adequately. However, it has been reported that the activation of the TrA in the same participant does not vary according to the assessment position.31 Since the participants were evaluated in a supine position for the TrA activation test and in various positions for the functional tests, this could have contributed to a reduced correlation between tests.37 Similarly to the TrA activation, the measurements for all hip muscle strength tests were performed in different positions than those used for the MCS tasks, which could explain lower correlations.

In order to advance our understanding of the MCS total score, a hierarchical regression was conducted based on the results from the bivariate correlations. The model could significantly explain 14.1% of the variance. While the activation of the TrA explained 3.3% of the variance, the combination of hip abductors, adductors and external rotators strength explained 10.8%. Similarly, Mitchell et al. found that abdominal strength could explain 12% of the variance of the FMS™ score.30 However, this study was conducted in children and did not account for lower limb strength. Moreover, core strength was measured with functional movements such as prone and side planks. In the current study, the assessment was extended to examine whether the activation of deep abdominals, the main stabilizers of the lumbar region, and hip strength, also stabilizers to the lumbo-pelvic region, could indeed affect the MCS score.

RELATIONSHIP BETWEEN FUNCTIONAL TESTS

This is the first study to examine the correlation between the MCS and FMS™, and a moderate correlation (r=0.489, p<0.001) was found between the two tests.27 The current study demonstrates that there is convergence between the two tests, particularly for the push-up and lunge items. The lower level of correlation could be explained by the fact that only three items were similar: the squat, lunge and push-up. The current study also shed light on the relationships between these similar items. No correlation was found between the squat items, indicating that they likely measure somewhat different constructs. The lunge items were poorly correlated and the push-up items were moderately correlated. The low correlations between the squat and lunge items could be explained by the fact that both were evaluated rather differently from one test to the other. The squat item in the FMS™ requires that a dowel held over the head remains in line with the ankles, which was not required in the MCS item. In the same way, the lunge item in the MCS required a twist of the trunk at the end of the movement that is not a part of the FMS™ task.

STUDY LIMITATIONS

A few limitations should be acknowledged. It should be noted that the evaluation, including the tasks from the functional tests, always followed the same order. Therefore, FMS™ and MCS scores could have been influenced by this. Fatigue could have induced a systematic error. There was also a diversity in the dancers who were recruited. However, since no differences were found between ballet and contemporary as well as between professional and pre-professional dancers for the MCS total score, the impact would seem to be minimal on the conclusions drawn for individual groups. Most studies have concentrated solely on pre-professional or professional dancers, often on a single dance style and in one institution. However, the diversification of level, dance style and institution helps strengthen the external validity of the results presented in this study. Future research should focus on longitudinal studies that address whether or not the MCS could be used as a predictive tool of injuries among dancers.

CONCLUSION

This pioneering study is the first to evaluate the convergent validity of the MCS by examining the correlation between the MCS and the activation of deep abdominals and hip strength for dancers. Significant correlations were found between the MCS total score, the activation of the TrA and the strength of hip abductors, adductors and external rotators. Although the correlations varied from weak to mod-

Table 4: Hierarchical linear regression with MCS total score as dependant variable

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Adjusted</th>
<th>Standardized</th>
<th>b</th>
<th>S.E.</th>
<th>p-value</th>
<th>95% C.I.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transversus abdominis activation</td>
<td>0.033</td>
<td>0.241</td>
<td>1.185</td>
<td>0.529</td>
<td>0.028</td>
<td>[0.131, 2.239]</td>
</tr>
<tr>
<td><strong>Step 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip muscle strength</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abductors</td>
<td>0.141</td>
<td>0.338</td>
<td>0.053</td>
<td>0.023</td>
<td>0.024</td>
<td>[0.007, 0.099]</td>
</tr>
<tr>
<td>Adductors</td>
<td></td>
<td>-0.059</td>
<td>-0.007</td>
<td>0.022</td>
<td>0.729</td>
<td>[-0.050, 0.035]</td>
</tr>
<tr>
<td>External rotators</td>
<td></td>
<td>0.135</td>
<td>0.041</td>
<td>0.042</td>
<td>0.336</td>
<td>[-0.043, 0.124]</td>
</tr>
<tr>
<td>Model p=0.005</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
erate, this supports a relationship between the functional movements score, TrA activation and hip strength. The MCS was also found to be significantly correlated with the FMS™, which supports the criterion validity of the MCS in dancers. These results are of great interest given the high proportion of injuries and pain among dancers and the need for screening and prevention. By corroborating the convergent and criterion validity of the MCS in dancers, this study is a step towards its use in preventing injuries in dancers.

CONFLICT OF INTEREST

All authors confirm that no prior or duplicate publication has been released elsewhere concerning this manuscript and that no commercial relationships which may lead to conflict of interest were associated with this work.

FUNDING

Funding from the Institut de recherche Robert-Sauvé en santé et en sécurité du travail was obtained (03SNT007).

Submitted: October 17, 2019 CST, Accepted: October 10, 2020 CST

This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY-NC-ND-4.0). View this license’s legal deed at https://creativecommons.org/licenses/by-nc-nd/4.0 and legal code at https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode for more information.
REFERENCES


Background
Quantifying muscle stiffness may aid in the diagnosis and management of individuals with muscle pathology. Therefore, the primary purpose of this study was to establish normative parameters and variance estimates of muscle stiffness in the gastrocnemius muscle in a resting and contracted state. A secondary aim was to identify demographic, anthropometric, medical history factors, and biomechanical factors related to muscle stiffness.

Methods
Stiffness of the gastrocnemius muscle was measured in both a resting and contracted state in 102 asymptomatic individuals in this cross-sectional study. Differences based on muscle state (resting vs contracted) and sex (female vs male) were assessed using a 2 X 2 analysis of variance (ANOVA). Associations between muscle stiffness and sex, age, BMI, race, exercise frequency, exercise duration, force production, and step length were assessed using correlation analysis.

Results
Gastrocnemius muscle stiffness significantly increased from a resting to a contracted state [mean difference: 217.5 (95% CI: 191.3, 243.8), p < 0.001]. In addition, muscles stiffness was 35% greater for males than females in a resting state and 76% greater in a contracted state. Greater muscle stiffness in a relaxed and contracted state was associated with larger plantarflexion force production ($r = .26$, $p < 0.01$ and $r = .23$, $p < 0.01$ respectively).

Conclusion
Identifying normative parameters and variance estimates of muscle stiffness in asymptomatic individuals may help guide diagnosing and managing individuals with aberrant muscle function.

Level of Evidence
2b Individual Cohort Study

Clinical Relevance
What is known about the subject: Muscle stiffness has been shown to be related to individuals with pathology such as Achilles tendinopathy; however, research is sparse regarding normative values of muscle stiffness. Measuring muscle stiffness may also be a way to potentially predict individuals prone to injury or to monitor the effectiveness of management strategies.

What this study adds to existing knowledge: This study establishes defined estimates of muscle stiffness of the gastrocnemius in both a relaxed and contracted state in healthy
INTRODUCTION

Muscle stiffness is related to both passive muscle tension and muscle contraction, and this relationship suggests that muscle stiffness could be used as a surrogate for other measures to estimate changes in muscle force production. Variances in muscle stiffness have been found to differentiate individuals who have healthy skeletal muscle from individuals who have pathology. Greater muscle stiffness has been observed in individuals with spasticity, and individuals with muscle pathology. Other groups of individuals with pathology demonstrate lower levels of muscle stiffness. Lower levels of muscle stiffness have been observed in individuals with Achilles tendinopathy and individuals who had surgical repair of the Achilles tendon. The measurement of muscle stiffness may provide an opportunity to compare individuals with healthy muscle performance to individuals with pathology and to potentially monitor effectiveness of management strategies for individuals being managed with a muscle pathology.

Muscle stiffness during contraction is modulated by level of voluntary contraction, joint position, and posture. Muscle stiffness increases dramatically between resting state and contracted state. Position of the joint also influences the contribution of muscle stiffness. When positioned in ankle dorsiflexion, there is greater muscle stiffness attributed to spinal reflexes; however, when the ankle is positioned into plantarflexion, the amount of stiffness related to spinal reflexes is significantly less. Further, changing an individual’s posture from a prone to a standing position can impact muscle stiffness. The excitability of spinal reflexes (measured through H-wave/M-wave ratios) are dampened in a standing position compared to a prone position. This difference in positioning demonstrates the value of measuring muscle stiffness in both a resting, prone position, as well as a standing, contracted position.

The primary purpose of this study was to establish normative parameters and variance estimates of muscle stiffness in the gastrocnemius muscle at rest in a prone position and during contraction in a standing posture using the MyotonPRO in a large group of healthy individuals. A secondary aim of this paper is to identify demographic, anthropometric, and medical history factors that are related to muscle stiffness. We hypothesized that lower muscle stiffness would be associated with older age, greater body mass index (BMI), female sex, and the Caucasian race. The third aim of this study was to quantify the relationship between gastrocnemius muscle stiffness and ankle plantarflexion force production and gait parameters. We hypothesized that both resting and contracted muscle stiffness would positively correlate with plantarflexion force, gait velocity, and step length.

METHODS

PARTICIPANTS

A total of 102 participants between the ages of 18 to 50 years-of-age were recruited between August 2018 to December 2019. Participants were excluded if they had been treated with dry needling to the lower extremity within the previous 30 days, had a calf injury within the previous six months, were unable to perform a bilateral heel raise symmetrically, were unable to lie on their stomach, or had a previous fracture of the spine or lower extremity that would affect their gait pattern or strength of the gastrocnemius. This study was approved by the Regis University Institutional Review Board and all participants provided informed consent in accordance with the WORLD Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects.

PROCEDURES

This single-group cross-sectional design involved a baseline examination followed by a single measurement session. All measures were performed by examiners specifically trained in all procedures. After providing informed consent, participants were screened for inclusion and exclusion criteria using demographics, medical history questionnaire, and a brief physical examination. The demographics questionnaire included race, sex, previous injuries of the lower extremity, and exercise participation consisting of frequency (greater than 5 days per week, 5-4 days per week, 1-2 days per week, and no regular exercise), duration of session (greater than 60 minutes, 30-60 minutes, and less than 30 minutes), and mode (walking, jogging, cycling, aerobics, swimming, skiing, rock/ice climbing, and hiking). Participants also completed the Beck Anxiety Inventory. Height and weight were measured, and BMI was calculated.

MYOTONOMETRY

All myotonometry was performed using the MyotonPRO (Myoton AS, Tallinn, Estonia) to assess mechanical stiffness of the medial head of the gastrocnemius muscle. Tissue stiffness (elasticity) is most commonly quantified as Young’s modulus, which is defined as the slope of the stress-strain curve of a material in the elastic deformation region of interest. The MyotonPRO applies a mechanical impulse to the skin which is then transmitted to the underlying soft tissue and muscle (0.58N for 15 milliseconds). This mechanical impulse causes the muscle to respond by a dampened natural oscillation, which is recorded by an accelerometer in the form of an acceleration signal. This acceleration signal is then utilized to calculate Young’s modulus and other viscoelastic parameters. The oscillation of the muscles is recorded by the probe in order to calculate the mechanical stiffness (N/m) of the muscle. A standard site was marked on each participant four fingerbreadths below the popliteal crease in the belly of the medial gastroc-
nemius muscle. All measures were taken at this standardized site. Participants were measured in a resting and contracted state. For resting state measures, participants were positioned in prone with shoes and socks removed and feet unsupported in a resting position off the end of the table and knees in full extension. For contracted state measures, participants stood with a scale under each foot and asked to place equal weight between their right and left feet. They were asked to raise onto their toes (perform a bilateral heel raise) as high as they could and hold the position while the measures were taken (Figure 1). As individuals performed the heel raise position, an assessor made sure equal weight was maintained between the lower extremities as well as consistent heel height between trials.

Three measures were taken in each position and averaged. Reliability of the MytonPRO in a resting state has been shown to be 0.99 to 1.0 and in a contracted state in a standing position within day ICC was 0.94 and between day ICC was 0.99.14

PLANTARFLEXION FORCE PRODUCTION MEASUREMENT

Force production of the gastrocnemius muscles was assessed with a hand-held dynamometer (HHD) (Hoggan Scientific LLC; Salt Lake City, UT, USA). The HHD was anchored to the wall. The participant was strapped to the table (Figure 2) with a strap across the popliteal crease and across the pelvis as previously described by Kelly et al.15 The ankle was positioned to maintain 0 degrees of ankle plantarflexion for the isometric contraction. The dynamometer pad was placed at the first metatarsal head and the participant was asked to push with maximal force. An average of 3 trials was calculated.

GAIT ANALYSIS

Gait analysis was performed using the GAITRite system (CIR Systems, Inc. Sparta, Nj, USA). The 6-meter measurement area of the mat is 61 cm wide and 488 cm long. The sensors are arranged in a grid pattern (48 cm X 384 cm) and placed 1.27 cm from apart. Sampling rate of the system varies between 32.2 and 38.4 Hz. Participants walked across the mat barefoot and an average of 3 trials was used for analysis. All data were automatically uploaded to a computer as the participant walked across the mat. Spatial and temporal characteristics of gait included normalized gait velocity and step length.15

DATA ANALYSIS

All statistical analyses were performed using SPSS 26.0 software (IBM SPSS Inc, Armonk, NY, USA). Descriptive statistics were calculated for all demographic, anthropometric, and medical history variables. Mechanical stiffness of the gastrocnemius muscle was estimated for the cohort and separately for male and female participants. Based on 1,000 bootstrap samples, 95% confidence intervals were estimated. Statistical comparisons of muscle stiffness were made between the muscle condition (resting state and contracted state) and sex (male and female) using a 2 X 2 analysis of variance (ANOVA). Findings were considered statistically significant when p < 0.05.

The associations between muscle stiffness and the following demographic and anthropometric variables were analyzed based on theoretical plausibility: sex, age, BMI, race, exercise frequency, and exercise duration. Bivariate associations between muscle stiffness and each demographic and anthropometric variable were assessed using correlation coefficients (point biserial for dichotomous variables, spearman rho for ordinal variables, and Pearson product moment for continuous variables). Similarly, bivariate associations between muscle stiffness, force production, and gait parameters (normalized velocity and step length) were assessed using Pearson product moment coefficients. All correlation coefficients included 95% confidence intervals estimated based on 1,000 bootstrap samples and all associations were considered statistically significant if p < 0.05.

RESULTS

One hundred and two participants were recruited between August 2018 and December 2019. No participants that were
Table 1: Demographics of Participants

<table>
<thead>
<tr>
<th>Demographics (N=102)</th>
<th>Descriptive Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (Mean, Standard Deviation)</td>
<td>26.00 (4.43)</td>
</tr>
<tr>
<td>Sex - Male (n, %)</td>
<td>44 (42.3%)</td>
</tr>
<tr>
<td>Native American</td>
<td>1 (1%)</td>
</tr>
<tr>
<td>Asian</td>
<td>16 (15.4%)</td>
</tr>
<tr>
<td>African American</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Caucasian</td>
<td>75 (72.1%)</td>
</tr>
<tr>
<td>Hispanic</td>
<td>10 (9.6%)</td>
</tr>
<tr>
<td>Beck Anxiety Inventory (Mean, Standard Deviation)</td>
<td>4.34 (5.11)</td>
</tr>
<tr>
<td>BMI (Mean, Standard Deviation)</td>
<td>23.51 (3.92)</td>
</tr>
</tbody>
</table>

Table 2: Normative Parameters in Muscle Stiffness of the Gastrocnemius for All Participants and By Sex in Newton/Meters

<table>
<thead>
<tr>
<th></th>
<th>Mean (95% CI)</th>
<th>Standard deviation (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All participants (n=102)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting state</td>
<td>300.1 (286.6, 312.3)</td>
<td>68.7 (56.8, 79.2)</td>
</tr>
<tr>
<td>Contracted state</td>
<td>504.6 (461.8, 545.1)</td>
<td>208.4 (179.7, 231.1)</td>
</tr>
<tr>
<td>Female (n=58)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting state</td>
<td>261.95 (250.1, 271.2)</td>
<td>43.4 (34.0, 50.1)</td>
</tr>
<tr>
<td>Contracted state</td>
<td>384.8 (347.5, 408.7)</td>
<td>132.83 (96.2, 145.4)</td>
</tr>
<tr>
<td>Male (n=44)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting state</td>
<td>350.3 (331.9, 370.9)</td>
<td>63.6 (49.9, 76.0)</td>
</tr>
<tr>
<td>Contracted state</td>
<td>662.6 (609.7, 781.7)</td>
<td>183.7 (151.1, 209.9)</td>
</tr>
</tbody>
</table>

screened were excluded due to inclusion/exclusion criteria. Demographic, anthropometric, and medical history characteristics of the participants are summarized in Table 1. There was a significant interaction for sex and muscle condition (p < 0.001); therefore, gastrocnemius muscle stiffness is summarized for both the resting and contracted states as well as separately by sex in Table 2. Muscle stiffness of the gastrocnemius was significantly higher for males than females [183.1 (95% CI: 144.8, 221.4), p < 0.001] and significantly higher in the contracted state than the resting state [217.5 (95% CI: 191.5, 243.5), p < 0.001].

Association between muscle stiffness and demographic, anthropometric, and medical history characteristics are presented in Table 3. There were significant associations for sex and muscle stiffness in both a resting state and contracted state. In a contracted state, muscle stiffness was also associated with anxiety. Sex was associated with muscle stiffness in both states with males exhibiting greater muscle stiffness (see Table 2). A significant negative association was found between muscle stiffness in a contracted state and anxiety suggesting that individuals that reported higher levels of anxiety, as measured by the Beck Anxiety Inventory, had lower levels of muscle stiffness in a contracted state.

Associations between gastrocnemius muscle stiffness in resting and contracted states were significant with muscle force production of the gastoc-soleus complex (see Table 4). The association of muscle stiffness in both a resting and contracted state was positive, indicating that higher muscle stiffness was associated with greater force production. A positive association was also found for step length and muscle stiffness in both states, indicating that individuals with higher muscle stiffness exhibit longer step length. Age, BMI, race, exercise frequency, exercise duration, and normalized gait velocity were not associated with gastrocnemius muscle stiffness in a resting or contracted state.

DISCUSSION

The purpose of this study was to establish normative parameters and variance estimates of muscle stiffness in the gastrocnemius muscle in a resting and contracted state using the myotonometry in a large group of healthy individuals. The confidence intervals for muscle stiffness in a resting and contracted state were small (Table 2), suggesting that the estimates are fairly precise. Muscle stiffness in a resting state was 300.07, whereas it was 504.62 in a con-
trated state, which is 68% higher than the resting state. This likely represents the amount of “stiffening” due to submaximal muscle contraction and is consistent with the findings of other investigators which have also observed greater muscle stiffness in a contracted state.13

Muscle stiffness of the gastrocnemius in both a relaxed and contracted state was significantly higher for males than females. In this study, muscle stiffness, as measured by myotonometry, demonstrated males had 35% higher muscle stiffness than females, and in a contracted state, males had 76% higher muscle stiffness than females. This is consistent with the findings from other researchers who have investigated sex differences in muscle stiffness in lower extremity muscles.16–20

Some investigators have found that sex differences in muscle stiffness are only observed when the muscle is in a tensioned state (such as a position of stretch on the gastrocnemius in a resting dorsiflexed position);19 however, we observed these differences when the muscle was on slack (a resting state in approximately 20 degrees of plantarflexion) and under tension (a contracted state in a plantarflexed position). Interestingly, other investigators have found muscle stiffness (measured using shear wave elastography) was higher in females than males.21,22 Both of these studies investigated stiffness in the biceps muscle. It is possible that muscle stiffness is muscle or region specific. Based on findings from this study, future studies utilizing myotonometry could consider sex as a potential covariate.

A secondary aim of this paper was to identify demographic, anthropometric, and medical history factors related to muscle stiffness. Muscle stiffness was negatively correlated with anxiety. This was not surprising, as the relationship between anxiety and musculoskeletal pain has been documented.23 The relationship between anxiety and muscle stiffness is important to note, as anxiety maybe a confounding variable influencing muscle stiffness during recovery. We also observed increased anxiety in females more than males. Other investigators have also observed that females maybe more vulnerable to anxiety related to musculoskeletal pain.24,25

Interestingly, in this study we did not find significant relationships between gastrocnemius muscle stiffness and age, BMI, ethnicity, exercise frequency, exercise duration, or gait velocity. Other investigators who have only included young and middle-aged adults have also found no correlation between stiffness and age.26 Studies that included older age groups (with an age range of 24–94 years of age) have observed a decrease in muscle stiffness with increasing age.27 In this study, we excluded older individuals (above the age of 65-years-old). The age range in this study was 24–45 years of age.

We did not observe a relationship between BMI and muscle stiffness. Investigations of the relationship between BMI and muscle stiffness in neck muscles only found a correlation in one muscle group out of multiple neck muscles measured.28 Both this study and the investigation by Kuo et al. included only individuals classified as normal or underweight. Future research should include individuals classified in the overweight or obese categories to compare to the muscle stiffness in individuals who are classified as nor-

### Table 3: Association of Gastrocnemius Muscle Stiffness with Demographic, Anthropometric, and History Variables

<table>
<thead>
<tr>
<th></th>
<th>Resting State (95% CI)</th>
<th>Contracted State (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>-.606 (-.719, -.480)**</td>
<td>-.613 (-.757, -.437)**</td>
</tr>
<tr>
<td>Age</td>
<td>-.023 (-.166, .155)</td>
<td>.069 (-.091, .259)</td>
</tr>
<tr>
<td>BMI</td>
<td>-.027 (-.224, .262)</td>
<td>-.102 (-.245, -.110)</td>
</tr>
<tr>
<td>Beck Anxiety Inventory</td>
<td>-.180 (-.312, -.032)</td>
<td>-.223 (-.381, -.027)*</td>
</tr>
<tr>
<td>Race</td>
<td>-.085 (-.274, .132)</td>
<td>-.153 (-.349, .086)</td>
</tr>
<tr>
<td>Exercise Frequency</td>
<td>.076 (.138, .281)</td>
<td>.011 (-.219, .230)</td>
</tr>
<tr>
<td>Exercise Duration</td>
<td>.062 (-.152, .286)</td>
<td>.123 (-.100, .333)</td>
</tr>
</tbody>
</table>

Notes: Sex (female = 1, male = 0); Race (Native-American = 1, Asian = 2, African American = 3, Caucasian = 4, Hispanic = 5).
*p<0.05.
**p<0.01.

### Table 4: Association of Gastrocnemius Muscle Stiffness with Functional Variables

<table>
<thead>
<tr>
<th></th>
<th>Resting State (95% CI)</th>
<th>Contracted State (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plantarflexion Force</td>
<td>.264 (.026, .461)**</td>
<td>.232 (.062, .387)**</td>
</tr>
<tr>
<td>Normalized Gait Velocity</td>
<td>-.066 (-.247, .130)</td>
<td>.050 (-.138, .247)</td>
</tr>
<tr>
<td>Step Length</td>
<td>.230 (.029, .426)*</td>
<td>.288 (.112, .448)**</td>
</tr>
</tbody>
</table>

*p<0.05.
**p<0.01.
We did not observe a relationship between race and muscle stiffness, but it is likely that the lack of diversity in this sample (73.5% being Caucasian) may have influenced this finding. Previous research has indicated that muscle stiffness is greater amongst athletes whom are African American.29

We did not find a significant relationship between muscle stiffness and exercise frequency or duration. This finding was in contrast to previous research. Other investigators have found that exercise is associated with increases in muscle stiffness.30,31 We divided exercise frequency and duration into four different categories. Exercise frequency consisted of the following categories: greater than 5 days per week, 3 to 4 days per week, 1 to 2 days per week, and no regular exercise. We divided exercise duration into the following 3 categories: less than 30 minutes, 30-60 minutes, and greater than 60 minutes. It is possible that the ordinal scale of exercise participation used in this study is not sensitive enough to distinguish differences between groups.

The third aim of this study was to determine if muscle stiffness influences mechanical factors, such as muscle force production and gait parameters. Muscle stiffness in both a relaxed and contracted state was found to be significantly correlated with force production of the gastrosoleus complex and step length during walking. Some investigators have observed a relationship between muscle force production in the tibialis anterior and muscle stiffness (measured with shear wave elastography),32 while others have only found a correlation between rapid force production and muscle stiffness.33 This relationship between muscle performance and muscle stiffness indicates that muscle stiffness could be a valid, alternative measure to examine muscle performance.1

Ankle muscle stiffness varies during walking according to the phase of gait, with greater muscle stiffness occurring during terminal stance and pre-swing phases of gait.34 Therefore, theoretically, individuals with greater muscle stiffness will be able to maintain late stance phases of gait for a longer time and thereby increase step length, as we observed in this study. However, aberrant muscle stiffness, either excessive or insufficient muscle stiffness, may change this relationship. Excessive muscle stiffness (observed in children with spastic cerebral palsy) interferes with the ability to achieve the second and third ankle rockers.34 Alternatively, insufficient muscle stiffness (observed in adults with peripheral neuropathy) could also interfere with efficiency of motion during these late stance phases of gait, leading to reduced gait speed.35 Further supporting this idea, manipulating muscle stiffness through tibial nerve block is associated with a reduction in stride length.36

We did not observe a relationship between gait velocity and muscle stiffness, whereas other investigators have observed a relationship between these two parameters. Increased muscle stiffness has been shown to be related to increased running economy,37 and reduced muscle stiffness has been shown to be a factor influencing reduced gait speed.38 For individuals with peripheral neuropathy, plantarflexor torque explained most of the variance in gait speed, but plantarflexor muscle stiffness also contributed.35 In this study, we excluded individuals with gait deviations, which may explain the lack of a relationship between gait speed and muscle stiffness.

Limitations. This study has several limitations which should be recognized. The homogenous sample may have impacted the results, specifically the lack of a relationship between muscle stiffness and age, race, BMI, gait velocity, and exercise frequency and duration. The ordinal scale designed to measure exercise frequency and duration may not be a valid measure of activity level. Finally, this study excluded individuals with lower extremity injury, which limits the application to individuals with musculoskeletal impairments. Future studies should include a greater diversity of participants, including individuals with musculoskeletal impairments.

CONCLUSION

This study established defined estimates of muscle stiffness of the gastrocnemius in both a relaxed and contracted state in healthy individuals. Myotonometry measures of muscle stiffness demonstrated an increase in stiffness during contraction that varies by sex. Greater gastrocnemius muscle stiffness was associated with increased plantarflexion force production. Establishing estimates of muscle stiffness in healthy individuals may aid in identifying individuals with aberrant muscle stiffness who may be prone to injury, variations in normal muscular function and inform goal setting in rehabilitation.

FINANCIAL DISCLOSURE

We affirm that we have no financial affiliation or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript, except as cited in the manuscript.

CONFLICTS OF INTEREST

All authors state declaration of interest: none.

Submitted: June 06, 2020 CST, Accepted: October 09, 2020 CST
REFERENCES


Original Research

Validity of a Sham Dry Needling Technique on a Healthy Population

Daniel M Cushman, MD, Anna Holman, MD, Lee Skinner, PT, DPT, Keith Cummings, DO, Peter Haight, BS, Masaru Teramoto, PhD, MPH, PStat

1 University of Utah, Division of Physical Medicine & Rehabilitation, Salt Lake City, UT, USA, 2 University of Utah, Department of Family Medicine, Salt Lake City, UT, USA, 3 University of Utah, Department of Physical Therapy, Salt Lake City, UT, USA, 4 University of Utah School of Medicine, Salt Lake City, UT, USA

Keywords: movement system, validation, trigger points, placebos, dry needling, acupuncture

10.26603/001c.18797

International Journal of Sports Physical Therapy
Vol. 16, Issue 1, 2021

Background
Various methods of sham procedures have been used in controlled trials evaluating dry needling efficacy although few have performed validation studies of the sham procedure.

Hypothesis/Purpose
The purpose of this study was to examine the validity of a sham dry needling technique on healthy, active subjects.

Study Design
Validation study

Methods
Runners capable of completing a half-marathon or marathon race and were randomized to receive true (using an introducer and needle) or sham (using an introducer and fixed, blunted needle) dry needling. Blinded subjects were asked to identify if they received sham or true dry needling following the procedure. Proportions of those who correctly identified their needling were also examined on the basis of past experience of receiving dry needling.

Results
Fifty-three participants were included in this study, with 25 receiving the true dry needling procedure and 28 receiving the sham. Of those who had received dry needling in the past (n = 16), 11 (68.8%) correctly identified their respective groups. For those who had not previously received dry needling (n = 37), 13 (35.1%) accurately identified their group. Most importantly, 94.1% of dry needling-naïve participants were unable to identify they received the sham procedure (p < 0.001).

Conclusions
This study shows that a fixed needle in an introducer tube is a simple, inexpensive, effective sham procedure in patients who have never received dry needling before. This technique may be useful for randomized controlled trials in the future.

Levels of Evidence
2

INTRODUCTION

Trigger point dry needling is a procedure in which a thin needle is inserted through the skin into the underlying muscle, directly into trigger points (TrPs), taut bands of muscle assumed to be responsible for pain, muscle dysfunction, and biomechanical alterations. It is becoming more commonly used as a treatment modality for a variety of musculoskeletal conditions including myofascial trigger points.
point pain, migraine, and chronic pain.¹ It has recently gained traction in the sports medicine realm for injury prevention,² strength gains,³,⁴ and sports injury treatment,⁵–⁷ however, the literature to date consists of many case reports and has not demonstrated definitive evidence of its efficacy.

One of the challenges in evaluating TrP dry needling efficacy in controlled trials is establishing an adequate method to account for a subject’s placebo response. Blinding is essential in these studies to accurately determine therapeutic effect and to decrease bias effects on outcomes. Without adequate blinding, therapeutic effect can be overestimated.⁸ Furthermore, the simple insertion of a needle into the skin (often called superficial dry needling) may have an effect.⁹–¹¹ As is the case with several physical interventions such as acupuncture,¹²,¹³ massage (usually use an alternative therapy as placebo¹⁴,¹⁵) and surgery,¹⁶ participants are not easily blinded to intervention with TrP dry needling. Given the nature of the therapy, participants can feel the needle puncture, and may have site soreness or bleeding after TrP dry needling.¹⁷

A valid control is therefore necessary to attempt to establish cause and effect from TrP dry needling. A variety of attempts at providing adequate control conditions have been attempted. Using a contralateral side as a control has been described,¹⁸ but TrP dry needling on one side has been demonstrated to have ipsilateral and contralateral effects.¹⁹–²¹ Others have used “false” dry needling as a control technique, such as needling at the incorrect location or depth,²²–²⁴ but insertion of a needle at any point may carry some form of pain control, likely from descending inhibition²⁵ thus confounding results.²¹,²⁶ To counteract these limitations, several attempts have been made at creating sham dry needles²⁷–³¹ including specialized retractable needles³² and using a blunted needle.²⁸,²⁹,³¹ Other studies have used a tube sheath without a needle as a sham.²⁷,³³ Many dry needling and acupuncture studies have not assessed the validity of the sham intervention,⁵ however of those that did assess validity, a blunted needle was shown to be a reasonable sham intervention.²⁶,³¹ The purpose of this study was to evaluate perception of sham TrP dry needling in healthy subjects both naïve and experienced in TrP dry needling, using a fixed needle as a sham intervention, to evaluate success of blinding of subjects to a TrP dry needling intervention.

METHODS

SUBJECTS

Subjects were recruited as part of a separate study,³⁴ including only marathon and half-marathon runners. Exclusion criteria included runners under 18 years of age, those with acute or chronic skin breakdown in the area of needling (such as abrasions, infection, chafing, etc.), inability to complete the half- or full marathon, and inability or unwillingness to complete questionnaires. Potential participants received email notifications prior to the 2018 Salt Lake City Marathon describing the study. A block randomization schedule was used prior to the study to place each consecutive subject into a real or sham dry needling group, as outlined below.

PERSONNEL AND PROCEDURES

Two practitioners completed the TrP dry needling sessions – one sports medicine physician with five years of dry needling experience and one physical therapist with two years of dry needling experience. This was performed immediately following the aforementioned race, within an hour of completing the race. Subjects were placed in a prone position initially. Alcohol wipes were used on the bilateral calves to sterilize the test area. Based on the subject’s randomization, the practitioner used either the real or sham dry needle on each lateral and medial soleus muscle. The patient was then placed supine on the table, and the process was repeated for the vastus medialis and vastus lateralis muscles. This allowed for a total of eight locations, four on each lower extremity. These sites were chosen due to common clinical complaints seen in the running population. The same treatment group (sham or true TrP dry needling) was used for all muscles on each subject. Subjects were not allowed to watch the procedure (heads remained on the table). Subjects could not see the needles being removed from packaging. All subjects were told that some patients feel a sharp feeling during the procedure. All subjects were also aware that they may receive either real or sham dry needling, but were not told what sham dry needling entailed. Subjects reported on their experience two days after the procedure, which allowed for adequate time for TrP dry needling soreness to set in,³⁵ which is a common side effect of the procedure. They were given three possible responses: “I definitely had the real dry needling,” “I definitely had the sham (placebo) dry needling”, or “I am not sure if I had the real or sham dry needling.” This is in line with the study by Park et al.,³² who reported their findings in a similar manner.

TRUE TRIGGER POINT DRY NEEDLING PROCEDURE

For subjects who underwent true TrP dry needling, the gloved practitioner opened a new package and placed the 0.25 x 4.0 solid-bore filiform (solid, not hollow) needle into the introducer tube. The tube was placed on the patient’s leg and the needle was tapped to insert the needle quickly into the skin; the needle remained, and the tube was removed. The practitioner then moved the needle deeper and aimed for a taut band of muscle, with the goal of elicitating a local twitch response (LTR) in the area. A local twitch response is a complex reflex that has been associated with pain relief.³⁶,³⁷ Repeated passes were made with the needle until a LTR was obtained and repeated until no further LTRs occurred in that area (a "pistoning" technique). If no LTR was obtained after 10 passes, the needle was withdrawn. Only single-use, sterile needles were used. Manual pressure was used if bleeding was noted (which occurs in approximately 16% of patients¹⁷).

SHAM DRY NEEDLING PROCEDURE

A sham needle/introducer was created to allow for an identical-looking needle and introducer, but without inserting the needle (Figure 1). Prior to the study, a single needle was removed, and its sharp point was first cut off around 5
mm proximal to the tip. The shortened needle was blunted for safety and then glued into the introducer with clear glue (cyanoacrylate) so it appeared like a normal dry needle (with the thicker end slightly protruding from the introducer). These sham needles thus had no sharp tip protruding, the needle could not be removed from the introducer, and thus the needle never contacted the skin. The practitioner would hold one of these needles in the same manner they would hold a true dry needle, and would place it on the patient’s skin. They would tap it identically, but as the needle was glued in, no needle would penetrate the skin. Subjects would still feel the introducer pressed hard against their skin however, similar to a prior sham-controlled study.27 The practitioner would then proceed to gently manipulate the introducer/needle apparatus on the skin, in the same location, for approximately thirty seconds at each location, which matched our approximate clinical time for performing this procedure with the true method. In between patients, the sham needles were placed in 70% isopropyl alcohol to ensure sterility.

STATISTICAL METHODS

Initial power analysis was based on similar studies,26,31 estimating approximately 20 subjects in each group. Descriptive statistics were calculated for subjects’ demographics. Proportions of those who correctly identified their needling were compared by past experience of receiving dry needling, using a two-sample test of proportions. Lastly, the effectiveness of sham needling as a placebo was examined by comparing the proportion of subjects in the sham needling group who were unable to identify which needling they received (either identified that they received real dry needling or were not sure if they received real or sham) to a chance occurrence (= 50%), using an exact binomial test. Statistics were performed with Stata/MP 16.0 for Windows (StataCorp LLC, College Station, TX).

RESULTS

A total of 53 subjects were included in this data analysis. Of those, 28 (52.8%) and 25 (47.2%) received the sham and true

<table>
<thead>
<tr>
<th>Variable</th>
<th>Sham (n = 28, 52.8%)</th>
<th>True (n = 25, 47.2%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender [frequency (%)]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>8 (28.6)</td>
<td>12 (48.0)</td>
</tr>
<tr>
<td>Female</td>
<td>20 (71.4)</td>
<td>13 (52.0)</td>
</tr>
<tr>
<td>Race [frequency (%)]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marathon</td>
<td>7 (25.0)</td>
<td>8 (32.0)</td>
</tr>
<tr>
<td>Half-marathon</td>
<td>21 (75.0)</td>
<td>17 (68.0)</td>
</tr>
<tr>
<td>Age</td>
<td>41.9 (12.5)</td>
<td>42.7 (11.8)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>168.4 (6.4)</td>
<td>173.6 (8.8)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>68.9 (13.7)</td>
<td>72.3 (14.1)</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>24.3 (4.6)</td>
<td>23.8 (3.5)</td>
</tr>
</tbody>
</table>

Values are mean (SD) unless specified otherwise

Figure 1: Sham dry needle apparatus. Arrowhead represents tip of needle.

Table 1: Subject demographics.

TrP dry needling, respectively (Table 1).

The results of dry needling identifications by prior experience of dry needling are summarized in Table 2. Of all sub-

International Journal of Sports Physical Therapy
Table 2: Dry needling identifications by prior experience of dry needling.

<table>
<thead>
<tr>
<th>Prior experience of dry needling</th>
<th>Identification</th>
<th>Sham (n = 28, 52.8%)</th>
<th>True (n = 25, 47.2%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes (n = 16)</td>
<td>I am not sure if I had the real or sham.</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>I definitely had the sham dry needling.</td>
<td>7*</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>I definitely had the real dry needling.</td>
<td>0</td>
<td>4*</td>
</tr>
<tr>
<td>No (n = 37)</td>
<td>I am not sure if I had the real or sham.</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>I definitely had the sham dry needling.</td>
<td>1*</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>I definitely had the real dry needling.</td>
<td>1</td>
<td>12*</td>
</tr>
</tbody>
</table>

Values are frequency.

*Correct identification.

Subjects, regardless of group assignment, 28 (52.8%) subjects were unsure which group they were in, 24 (45.3%) identified their group appropriately, and 1 (1.9%) was incorrect. Of those who had received dry needling in the past (n = 16), 11 (68.8%) correctly identified their respective groups. For those who had not previously received dry needling (n = 37), 15 (55.1%) accurately identified their group. The difference in the proportions was statistically significant (z = 2.26, p = 0.024).

Of the 28 subjects in the sham needling group, 11 subjects had received dry needling in the past, while 17 had not. For those who had previously received dry needling, 7 (63.6%) subjects were able to identify that they received the sham needling. The exact binomial test showed that this proportion was not significantly different from 50.0%, a chance occurrence (p = 0.549). Meanwhile, of the dry needling-naïve subjects, only one (5.9%) was able to identify that they received the sham needling. This proportion was significantly lower than 50%, a chance occurrence (5.9% [95% CI, 0 – 17%], p < 0.01). Similarly, one (5.9%) dry needling-naïve subject felt they had received true TrP dry needling.

DISCUSSION

This study examined the validity of a fixed needle as a sham dry needling procedure. Validating a non-penetrating type of sham procedure as an effective placebo treatment is important as this type of sham procedure is likely more inert than a penetrating sham procedure9–11 and thus decreases confounding factors caused by superficial needling or “false” dry needling techniques when evaluating dry needling outcomes.19–21 The sham technique in this study mimicked dry needling in that the participants felt the introducer tube, but the needle did not penetrate the skin. The sham needling was done in the same location, setting, position, and for approximately the same amount of time as the true TrP dry needling procedure. Subjects were not able to see the procedure being done in either the true or sham dry needling group. Mitchell et al.26 performed a similar study with a blunted needle to examine dry needling-naïve subjects’ view on whether a sham needle penetrated the skin. The needling technique in their study did not, however, include “pistoning” as the practitioners did in our study. To the authors’ knowledge, no study has examined this particular type of sham TrP dry needling procedure.12,38 There have been many validation studies examining non-penetrating sham techniques in acupuncture research showing that these can be successful shams, particularly in subjects naïve to acupuncture.23,39–42 Of note, even the non-penetrating sham dry needling procedure may have some limited therapeutic effects as trigger point massage and myofascial release are treatments used for myofascial pain, and pistoning a guide tube over a trigger point, may affect the trigger point to a limited extent.

The main findings from this study demonstrate that this type of sham dry needling is an effective control for subjects naïve to dry needling. It was far less effective in subjects who had previously experienced dry needling; these subjects more reliably determined whether they received the true or sham needle. Of the participants who were naïve to dry needling, only one was able to correctly identify that they underwent true TrP dry needling. This was equal to the number of dry needling-naïve participants (1) who felt they received the true needling when in fact they received the sham. This was likely because the same introducer tube was used as in true TrP dry needling. An introducer tube alone without a needle has been shown to be difficult for participants to distinguish from true needling also using an introducer tube in other comparison trials.26,27,33,43

The subjects who had prior experience with dry needling were more likely to be able to identify their assigned group. One likely reason was that the sham procedure did not cause the same sensation as what they previously received. Some studies have shown that participants are able to detect a difference in the “sharp” sensation of a needle versus a blunted tip,26 whereas other studies show that subjects detect a “sharp” sensation equally with both blunted and true needle;29,31,32 this study did not specifically ask subjects for their definition of the sensation they felt. Some subjects experience secondary symptoms after TrP dry needling such as muscle aches31 and they might not necessarily experience this with a sham procedure. This study allowed for time to elapse for delayed-onset soreness, for which subjects who had previously received dry needling may have recognized. Some of the subjects may have re-
ceived different types of dry needling in the past, perhaps using multiple needles, electrodes or other methods. This sham procedure was meant to mimic dry needling using an introducer tube and repeated passes with the needle to obtain a twitch response. The difference in method alone might have impacted their ability to correctly identify their group. The sham procedure also would not have elicited the twitch response that subjects might have experienced in the past.

This study was primarily limited by the smaller number of participants. Though the study was powered for 20 participants, only 17 naïve subjects were identified. However, it still demonstrated a significant finding. Second, the practitioners could not be blinded to the intervention given the nature of TrP dry needling, which could introduce bias from the practitioners, although blinding practitioners would likely not be feasible in the current study. Third, the technique used by the two practitioners, a physician and a physical therapist, may be different than used by other practitioners and may limit generalizability. For example, this sham method likely will not be usable for practitioners who use electrical stimulation through their needles. This technique used several needle passes, which diminishes electromyographic muscle activity, and also likely contributes to improved clinical pain relief, but may cause increased soreness initially from tissue trauma. Finally, the participants in this study were half-marathon and marathon runners and thus may not be fully generalizable to patients in other settings. The authors chose endurance runners capable of completing a half-marathon given their homogenous nature and their anecdotally high level of relief from myofascial treatments.

Given the aforementioned limitations, this study contains a number of strengths, in that the participants were blinded to the procedure and the study used an easily-reproducible, inexpensive sham needle technique. This study used a non-penetrating sham technique which could potentially decrease confounding effects of other sham techniques.

CONCLUSION

The results of this study indicate that a fixed needle in an introducer tube is a simple, inexpensive, effective sham procedure in patients who have never received dry needling before. These subjects were less able to identify if they received the sham or true TrP dry needling than the subjects who had experienced dry needling.

CONFLICT OF INTEREST

There are no conflicts of interest. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

ETHICAL APPROVAL

Prior to the study, Institutional Review Board approval was obtained through the authors’ home institution (IRB # 108245). All subjects signed written informed consent prior to undergoing study procedures.

Submitted: March 24, 2020 CST, Accepted: July 24, 2020 CST

This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY-NC-ND-4.0). View this license’s legal deed at https://creativecommons.org/licenses/by-nc-nd/4.0 and legal code at https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode for more information.
REFERENCES


Quantifying the Burden of Shoulder and Hip Pain In Water Polo Players Across Different Playing Levels

Michael Girdwood, BHSc, M. Physio Prac 1, Marilyn Webster, Dip. ASc, BEd, M. Sports Physio, DClin Physio2

1 La Trobe Sport & Exercise Medicine Research Centre, La Trobe University, 2 The University of Melbourne

Keywords: water polo, shoulder, overuse, hip, groin

10.26603/001c.18801

Background
Water polo is characterised by unique skills and movements with high demands of both the upper and lower limb. There is growing recognition of the problems of shoulder and hip/groin symptoms in this population.

Purpose
To quantify the prevalence of shoulder and hip/groin pain in water polo players, and to describe how performance and participation were impacted. Secondary aims investigated whether demographic or training variables were associated with levels of symptoms.

Design
In-season, cross-sectional questionnaire study

Methods
An online questionnaire was distributed to all adult levels of the Australian water polo community. Participants were asked about demographic and playing history, and then specific injury history at both the shoulder and hip/groin. Each respondent completed an Oslo Sports Trauma Research Centre (OSTRC) overuse injury questionnaire for the shoulder and hip/groin. Point prevalence and past history were calculated, as well as a morbidity score from OSTRC responses. Risk ratios were used to determine differences between playing levels and sex.

Results
One hundred, fifty-three respondents completed the questionnaire (57% female). High rates of shoulder pain were reported (38.1% current, 81.2% past history), as well as hip/groin pain (33.1% current, 60.4% past history). Current shoulder pain was a risk factor for hip/groin pain (RR 1.99 [95%CI 1.27-3.12], and hip/groin pain was a risk factor for shoulder pain (RR 1.70 [95%CI 1.23-2.35]). Elite-level athletes had higher prevalence (RR 1.87 [95%CI 1.01-3.46]) and past history of hip/groin pain (RR 1.76 [95%CI 1.32-2.36]).

Conclusions
This is the first study to quantify high self-reported levels of hip/groin pain in water polo athletes. Such high levels may be explained by high amounts of eggbeater kick, especially during skeletal development in adolescence. Shoulder pain continues to be the most common source of injury burden in water polo. Future research should determine whether any modifiable risk factors exist that may reduce the burden of injury in this population.

Level of Evidence
2b
INTRODUCTION

Water polo combines technical ball skills and powerful throwing, with agile swimming and explosive speed. The sport is made up of a unique set of movements, including the eggbeater kick, which forms the platform for many skills and techniques in water polo. Because of these unique movement patterns, it has an injury profile different from swimming, and one that has not been extensively researched. A high prevalence of shoulder pain is generally accepted amongst players and coaches; however, other injuries including hip and groin issues are under-appreciated.

There is a growing recognition of the impact of hip and groin pain in water polo players, as well as greater understanding of these conditions in musculoskeletal research in general. Despite this, no studies have attempted to quantify prevalence or burden of hip/groin pain in water polo players. It is also unclear whether presentations in water polo players are different from athletes of other sports with high rates of hip and groin injuries, such as football or ice hockey. It is theorized that the high amount of time spent eggbeater kicking may be implicated in development of symptoms. The eggbeater kick involves rapid cyclical revolutions of the feet, with the movement creating an inward rotation cycle. This results in repetitive internal and external rotation at the hip, in combination with hip flexion and abduction. Water polo players spend large amounts of time in games and training performing the eggbeater kick, as it is a crucial determinate of performance, akin to jump-height in a volleyball player.

Two systematic reviews have investigated shoulder injuries in water polo players. Shoulder pain is the most common injury afflicting water polo players with a prevalence reported between 24–80%. A number of authors have proposed mechanisms behind shoulder pain, including range of motion restrictions, strength or strength ratio deficits, and workload issues (specifically shooting loads), which is in line with other overhead or throwing sports. Unfortunately, most research in this area is of low quality, and limited to small observational studies. Also, many studies have been confined to elite levels or national teams, which may make generalizing findings less reliable to recreational populations. Larger scale studies of water polo players, such as those summarizing injuries at major championships or Olympics do not take into account injuries that do not result in time loss. This may underestimate the burden, particularly as anecdotaly many players report "pushing through" symptoms. Performance impacts of pain also have not been captured, which represents an area from which teams could gain significant benefit. While screening for injury remains a controversial topic in sports medicine, maximizing player performance remains the cornerstone of the profession. The first step to mitigating injuries is understanding the nature of the burden.

The aims of this study were to quantify the levels of shoulder and hip/groin pain in water polo athletes across different levels of participation, and to describe how performance and participation were impacted. A secondary aim was to investigate whether demographic or training variables were associated with levels of symptoms.

METHODS

For this in-season cross sectional study, participants were invited to complete an online questionnaire (Google Forms, Google, USA). The questionnaire was advertised through a variety of channels to ensure a wide and representative range of athletes were captured. All national and state water polo bodies were contacted with promotional material to share via social media, email newsletters, and website advertisements. Two follow up emails were sent to ensure all community members were aware of the study. Word of mouth and local player networks were also utilized. The data collection period was from November 2016- March 2017, in order to capture as many responders as possible while still being in-season, as different States in Australia have slightly different seasonal periods. In 2016/17 there were 6437 senior (>18) registered members of Water Polo Australia (WPA). Participants were required to be over the age of 18, and be an active water polo player in Australia - defined as having played water polo within the prior three months. Informed consent was gained before participants could complete answers to the questionnaire. The study was approved by The University of Melbourne Human Research Ethics (ID: 1648247).

Responders who consented and were within the inclusion criteria were asked to complete the questionnaire, which took around 5-10 minutes. The form was broken into two sections: demographics and playing history, followed by injury history.

Participants were asked to describe their current (prior three months) and previous highest playing level, from a selection of five categories:

- International/Olympic level
- International league
- Junior international level (such as Junior World Championships)
- Australian National water polo league (national competition in Australia)
- Local/regional level – state or lower-level competitions in Australia

For each of these, examples were provided for each competition to ensure players understood what each level corresponded to. It was possible to select multiple responses for the current playing level question, though only the highest level was used for analysis. In addition to this, responders were asked to answer how many years they had been playing water polo (regardless of level).

Responders were then asked to complete a section on training loads;

- Water polo load: Current average number of water polo sessions completed per week (including training and games) – as a numerical value
- Current average hours of water polo, both training and games, completed per week – as a selection of six categories for convenience, ranging from 2 hours or less to 15 hours or more
- What other forms of physical activity they engaged in weekly (if any) – descriptive form
- Other exercise load: How many hours they spent com-
Table 1: Demographic characteristics of sample, broken down by playing level. All values are median (IQR) unless denoted so.

<table>
<thead>
<tr>
<th></th>
<th>Local/Regional n=83</th>
<th>National n=51</th>
<th>International n=20</th>
<th>Total n=154</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Female</td>
<td>52% (n=43)</td>
<td>63% (n=32)</td>
<td>65% (n=13)</td>
<td>57% (n=88)</td>
</tr>
<tr>
<td>Age</td>
<td>28 (19)</td>
<td>20 (6)</td>
<td>22.5 (8)</td>
<td>23 (12)</td>
</tr>
<tr>
<td>Years played</td>
<td>10 (13)</td>
<td>9 (7)</td>
<td>11.5 (7)</td>
<td>10 (9)</td>
</tr>
<tr>
<td>Water polo sessions / week</td>
<td>3 (2)</td>
<td>6 (3)</td>
<td>7 (5)</td>
<td>4 (3)</td>
</tr>
</tbody>
</table>

Completing this other physical activity each week – selection of six categories for convenience, ranging from 0 hours, to 10 or more hours.

Following this, participants were asked specific injury history questions relating to shoulder pain, and also hip/groin pain. Participants were asked about whether they currently had any shoulder pain relating to water polo in the past week (Yes/No), and whether they had ever had shoulder pain previously in their career related to water polo (Yes/No). The same questions were repeated, but instead for hip/groin pain. The terminology 'hip/groin', was deliberately used to ensure all presentations were captured, as specific diagnoses or subgroups were not of interest. This aimed to determine what level dysfunction in the hip/groin region is present in water polo athletes. Participants were dichotomised based on these answers as having current pain, or a past history of pain for both body regions.

Following this, responders completed an Oslo Sports Trauma Research Centre (OSTRC) overuse injury questionnaire for both the shoulder and hip/groin. The OSTRC is a valid and reliable method for capturing overuse injuries, as it does not rely on a time-loss definition of injury. It instead employs four categorical questions around: (1) difficulty participating, (2) reduced training volumes, (3) performance, and (4) pain. Responses total a maximum of 100, with 0 indicating the optimal score of no symptoms or affected performance, and 100 being the worst possible score.

Finally, participants were asked to briefly describe whether they were currently seeking help from a medical professional for a water polo related injury, and whether they had ever completed an injury prevention program designed specifically for water polo players.

Responses from the questionnaire were automatically compiled into a spreadsheet by Google Forms. Once the data collection period was complete, the spreadsheet was downloaded and worded responses were coded where required to allow for statistical analysis. Information from the questions relating to playing level were transcoded into three categories for analysis: (1) International level (international competition, international league and junior international), (2) National level (national water polo league); and (3) local level (local/regional competitions). All analysis was completed in SPSS (v24.0.0, IBM, Somers, New York). The alpha level was set at 0.05 for all testing.

A score for injury morbidity was calculated by totalling the response of the four OSTRC questions (separately for both shoulder and hip/groin). Point prevalence and past history were calculated based on dichotomous questions in the injury history section of the questionnaire. These were conducted for each playing level group, and risk ratios (RR) were calculated to compare differences between groups. A substantial injury was defined from Questions 2 & 3 of the OSTRC - by selecting moderate or severe loss of performance or complete inability to participate in sport. Responders were also classified as having performance impacted, if their response to OSTRC Question 3 (detailing performance) was greater than 0.

To investigate associations between the continuous variables of age, playing history (years), sessions/week and the prevalence of pain, a point-biserial correlation was conducted. For categorical variables of current and past playing level, water polo load, and other exercise load, a rank-biserial correlation was used. Risk ratios were calculated for shoulder pain as a risk factor for hip/groin pain and vice versa. No analysis was conducted using morbidity scores for the shoulder and hip/groin, as the OSTRC cannot be interpreted as a continuous score.

RESULTS

One hundred and fifty-three participants completed the questionnaire, with 57.1% (n=88) being women. Eighty-three local/regional level athletes, 51 national level athletes, and 20 international level athletes completed the questionnaire. Demographic characteristics are presented in Table 1. The median age of responders was 23 (IQR 12), with median years played 10 (IQR 9), and median water polo sessions per week of 4 (IQR 3).

High rates of shoulder and hip/groin pain were reported (Figure 1), with 38.1% of responders reporting current shoulder pain, and 81.2% a past history of shoulder pain. Hip/groin pain rates were slightly lower – 33.1% currently, and 60.4% reporting a past history. Differences were seen between men and women for hip/groin prevalence and past history (Table 2); however, risk ratios were not significantly different (p=0.33 and 0.12 respectively). Analysis of differences between prevalence and past history across playing levels is presented in Figure 2. Significant differences in prevalence and past history of hip/groin pain were seen for more elite levels compared to local/regional level athletes.

The median OSTRC for athletes reporting shoulder pain was 28 (IQR 22) and for hip/groin pain was 28 (IQR 22). Twenty-four respondents (15%) reported a substantial shoulder condition, while 19 (12%) a substantial hip condi-

International Journal of Sports Physical Therapy
Table 2: Point prevalence and past history of shoulder and hip/groin pain, across men and women.

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th>Women</th>
<th>Risk Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prevalence</td>
<td>39.4% (n=26)</td>
<td>37.5% (n=33)</td>
<td>0.95 (0.63-1.42)</td>
</tr>
<tr>
<td>Past History</td>
<td>78.8% (n=52)</td>
<td>83.0% (n=73)</td>
<td>1.05 (0.90-1.23)</td>
</tr>
<tr>
<td>Hip/groin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prevalence</td>
<td>28.8% (n=19)</td>
<td>36.4% (n=32)</td>
<td>1.26 (0.79-2.02)</td>
</tr>
<tr>
<td>Past History</td>
<td>53.0% (n=35)</td>
<td>65.9% (n=58)</td>
<td>1.24 (0.95-1.63)</td>
</tr>
</tbody>
</table>

tion. Thirty-five players (22.7%) reported concurrent shoulder and hip/groin pain. The presence of shoulder pain was a risk factor for the presence of hip/groin pain (RR 1.99 [95%CI 1.27-3.12]). Current hip pain was also a risk factor for current shoulder pain (RR 1.70 [95%CI 1.25-2.35]).

No association was found between current shoulder pain and age (r=0.08, p=0.35), years played (r=0.06, p=0.46), or levels of other physical activity (r=-0.10, p=0.18). No association was found between current shoulder pain and water polo sessions per week (r=0.08, p=0.30) or hours of water polo training per week (r=0.10, p=0.24).

For hip/groin pain there was no association between presence of pain and age (r=0.02, p=0.80), years played (r=-0.05, p=0.50) or levels of other physical activity (r=0.11, p=0.17). Number of water polo sessions per week showed weak association to presence of hip/groin pain (r=0.20 [95%CI 0.04-0.35], p=0.01); however, hours per week was not significantly associated. (r=0.13, p=0.96).

DISCUSSION

This is the first study to investigate self-reported hip/groin and shoulder pain across different playing levels in water polo players. The results of the current study indicate high rates of both self-reported shoulder and hip/groin pain, with significant impact on performance. While no associations were found between demographic variables, playing level or training load with shoulder pain, playing at more elite levels was associated with increased rates of hip/groin pain, and number of sessions per week was also weakly associated. These results also show water polo as one of the first sports with equal or higher prevalence of hip/groin pain in women compared to men.

Research is increasing regarding the pathoetiology and management of hip/groin pain in athletes and this is the first time the prevalence of pain has been quantified in water polo players. The eggbeater kick may expose the hip joint to high repetitive shearing loads, which could lead to the development of hip joint related symptoms. The strong adduction forces in outer ranges required to elevate the body out of the water while using a breaststroke kick may also predispose these athletes to adductor related groin pain. Additionally, the influence of playing in a non-weight bearing environment may also influence muscle and strength development, which may in turn be a factor in symptom onset. Differences have been described in the gluteal muscles of swimmers compared to land athletes, but how this could link to development of pain is not yet understood, and may in fact be considered adaptive to environmental factors. Given players at more elite levels had higher prevalence of symptoms, as well as a weak association between number of sessions per week and pain, internal loading may also be a significant factor in this population. Water polo competitions are often in a tournament format, which may expose players to fluctuations in workload. Also training camp environments may result in more eggbeater kick time than in a competition setting, where loads may be more intermittent in a game.

Another explanation for elite players having higher rates of pain may be high amounts of training and play during adolescence. It is reasonable to assume that the reason such players are at the elite level is due to the significant amount of time and practice committed to their development at a younger age. While in this study, history of years played was not significantly associated with symptoms, sub-group analysis in different playing levels was not conducted due
to small sample size. High loads and lack of movement variability (early sport specialization) may cause alterations in developmental morphology of the hip joint, which may be implicated in symptom development. This would be similar to research in other sports such as soccer and ice hockey, where higher loads during the adolescence are linked to development of altered hip morphology. However, it is also possible that morphological changes are in fact a normal positive adaptation, and biomechanical structure is a poor predictor of musculoskeletal pain in a number of body regions.

Shoulder pain continues to be the most common complaint affecting water polo players, and the results of this study support previous anecdotal reporting and smaller scale studies in water polo players. Combining an overhead throwing sport, with high swimming loads as well as the mechanical disadvantage of being immersed in water places elevated demands on the shoulder complex. Other overhead sports generate significant power from the lower limbs, and while this has not been investigated formally in water polo players, most of the generated energy by the lower limb is used to elevate the body out of the water, and has less influence on forward propulsion of the ball compared to a tennis serve or handball shot. Shoulder pain in these players should not be considered the same as that seen in swimmers, as water polo athletes are likely to have many characteristics of ‘throwing shoulders’ including adaptive responses such as humeral retroversion and muscular and movement imbalances.

No other associations were found between variables measured and rates of pain in this population. Factors not considered in this study include shooting load (number of shots), which result in both high shoulder loads, but also significant force generation at the hip to elevate the body high out of the water using the eggbeater kick. Previous authors have shown number of shots per session to be associated with increased levels of shoulder pain, however hip and groin symptoms were not evaluated. Information about player position was also not included in this study. There is likely significant variability between athletes for the number of shots taken per session, which may explain why session duration or frequency did not show any associations with shoulder pain. This would be similar to high variability in jump loads seen between volleyball players. While the hip and groin complex may also be affected by varying shooting loads, the eggbeater kick is also used for a number of other skills such as ball passing and in defensive situations, and this might explain why sessions per week was only weakly associated with hip/groin symptoms.

An important finding from this survey research is the high presence of concomitant shoulder and hip/groin symptoms. Kinetic chain assessment is often advocated in throwing athletes, and should not be neglected despite a different lower limb "platform" in water polo players. The ability to elevate out of the water or ‘jump height’ is linked with throwing power, hence a reduction in lower limb force production may result in associated force changes at the shoulder, which may lead to development of symptoms. It is also possible, that athletes suffering from both were in high workload periods, and not as a result of one injury leading to the other. Emerging research shows the sequential influence of injury in seemingly distant body regions; however, temporality related to symptoms cannot be determined from this paper. As water polo is predominantly an amateur sport in Australia, unique factors related to the professionalism of the sport may influence findings also, such as lack of time to maximise injury reduction or recovery efforts, as well as improper training techniques.

These novel findings suggest an important area of impact for elite players and clubs to take advantage of to maximize results and performance. Results from this study suggest that at least five to six players per playing roster (of 13-15) could be suffering from pain, with some of this leading to performance deficits. As such, understanding what pathology or patterns of pain are present may allow for programs or treatments to be implemented in order to reduce the burden of pain. While strength and range of motion are often cited as a risk factor for musculoskeletal conditions, further work is required to confirm this in water polo players. It is plausible that physical capacity must be sufficient to tolerate the high forces around the shoulder and high cumulative movement around the hip. However, given elite players, who could be assumed to be stronger and fitter than their recreational counterparts, seem afflicted more by hip/groin symptoms, other variables may be more important to consider.
CONCLUSION
Australian water polo players across competitive levels reported high rates of shoulder and hip/groin pain. Players at the elite level had higher prevalence and past history of hip/groin pain. Hip and groin symptoms may present as a result of eggbeater kick loading during skeletal development or as a result of load related factors, however further investigation is required to understand specific pathoetiolog in this population. No associations were found between demographic or training variables and shoulder pain, suggesting more subtle factors such as shooting loads may explain high amounts of pain. Clinicians involved in water polo should assess the entire kinetic chain when investigating any injury, and should ask about concomitant hip/groin issues in athletes presenting with shoulder pain.

FUNDING
No external financial support

CONFLICTS OF INTEREST
None declared

ETHICAL APPROVAL
The University of Melbourne Human Research Ethics ID: 1648247
Submitted: March 01, 2020 CST, Accepted: July 24, 2020 CST

This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY-NC-ND-4.0). View this license's legal deed at https://creativecommons.org/licenses/by-nc-nd/4.0 and legal code at https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode for more information.
REFERENCES


The Relationship Between Hip Strength and Postural Stability in Collegiate Athletes Who Participate in Lower Extremity Dominant Sports

Bryce Olsen, Nicholas Freijomil, Jennifer Csonka, MS, LAT, ATC, Tara Moore, MS, LAT, ATC, Carolyn Killelea, PhD, Mallory S Faherty, PhD, LAT, ATC, Timothy C Sell, PhD, PT

1 Division of Physical Therapy, Department of Orthopedics, Duke University, 2 Department of Athletics, University of Pittsburgh, 3 Department of Athletic Medicine, Duke University, 4 Michael W. Krzyzewski Human Performance Laboratory, Department of Orthopaedic Surgery, Duke University

Keywords: rehabilitation, postural stability, physical therapy, movement system, injury prevention, hip strength, balance

Background
Lower extremity (LE) injuries are common across many sports. Both core strength (including hip strength) deficits and poor postural stability have been linked to lower extremity (LE) injury. The relationship between these two characteristics is unknown.

Purpose
To explore the relationships between hip strength, static postural stability, and dynamic postural stability.

Study Design
Descriptive Cross-Sectional Study

Methods
162 Division I student-athletes (111 males and 51 females) participated in this study. Isometric hip strength was measured using a hand-held dynamometer and both single-leg static (eyes open EO and eyes closed EC) and dynamic postural stability were assessed with a force plate. Pairwise correlations were calculated to examine the relationship between the hip strength variables and the postural stability scores for all subjects and separately for males and females.

Results
There were no significant correlations between hip strength and dynamic postural stability for any of the pairwise correlations. Significant, albeit minimal, correlations between EO and EC static postural stability and each of the hip strength variables for all subjects and male subjects (correlation coefficients ranged from -0.19 to -0.34). However, there were only two significant correlations between hip strength and EC static postural stability (hip internal/external rotation) and one for hip strength and EO postural stability (hip internal rotation) found for female subjects (correlation coefficients ranged from -0.28 to -0.31).

Conclusion
There was no relationship between isometric hip strength and dynamic postural stability; whereas, there were some relationships between the strength measures and static postural stability. These significant, but minimal correlations were observed in more of the comparisons within the male cohort potentially demonstrating a sex difference.

Level of Evidence
3b
INTRODUCTION

A musculoskeletal injury is a common occurrence for nearly all NCAA student-athletes at some point during their collegiate career. NCAA injury surveillance data has reported the likelihood of an injury occurring to be as high as one injury every two games for a team of 50 participants. Injuries negatively affect the player including missed participation in sport, decreased level of performance upon return, and potential long-term health issues. Lower extremity (LE) injuries make up over half of all injuries experienced by NCAA athletes, with a majority of LE injuries involving the knee and ankle. A better understanding of the factors that lead to LE injuries will help guide and refine injury prevention programs for NCAA athletes.

In addition to previous injury, there are several other examples of identified risk factors for common lower extremity injuries in student-athlete populations. Reduced muscular strength and decreased neuromuscular control in the lower extremity have been identified as risk factors for knee injury. Increased tibial varus and calcaneal eversion in women and increased talar tilt in men have been shown to be predictive of ankle injury. Two measures that are increasingly being researched in connection with LE injury risk are postural stability and core strength.

Postural stability is the ability to integrate sensory, motor, and vestibular input within the execution of motor commands in order to maintain stability and equilibrium in the midst of a variety of perturbations. Static and dynamic postural stability, as demonstrated through various tests of postural sway, were shown to be predictive of ankle injury. Core musculature refers to the abdominals, paraspinals, and the musculature surrounding the hip complex. Theories have pointed to deficits in core strength increasing the risk for LE injury potentially due to the inability to transfer energy through the core and thereby putting greater stress on the LE. For example, both decreased hip external rotation strength and poor core-muscle endurance have been proposed as risk factors for LE injury.

Student-athletes frequently suffer lower extremity injuries demonstrating a continued need to develop injury prevention strategies to reduce their risk of injury. Core strength, including hip strength, and postural stability have both been linked to lower extremity injury however, the relationship between hip strength and postural stability measures, especially dynamic postural stability, are not well known. The purpose of this study was to examine the relationship between hip strength and both static and dynamic postural stability. It was hypothesized that there would be significant correlations between isometric hip strength and dynamic postural stability and no significant correlations between isometric hip strength and static postural stability. The results of this study may guide future injury prevention programs and research examining injury prevention protocols for student-athletes.

METHODS

EXPERIMENTAL DESIGN

This study utilized a prospective cohort design. A descriptive cohort design was chosen in order to determine the association between hip strength and both static and dynamic postural stability in NCAA Division I male and female athletes.

SUBJECTS

A total of 162 Division I student-athletes (soccer, basketball, and football) from two different universities volunteered for the study. Subjects consisted of 111 males and 51 females. Demographic information for the subjects is presented in Table 1. All subjects voluntarily consented to participate in the study and signed an informed consent approved by their university’s Institutional Review Board. All subjects were currently cleared for full participation in their team’s activities.

INSTRUMENTATION

A handheld dynamometer was utilized to assess isometric muscle strength (Lafayette Instrument Co., Lafayette, IN). For all measures, peak force was measured to the nearest 0.1 kilogram. A Kistler force plate (Kistler 9286A, Amherst, NY) was utilized to collect ground reaction force data in order to assess static and dynamic postural stability. The force plate was calibrated according to manufacturer’s recommendations prior to the initiation of any testing procedures. A sampling frequency of 200Hz and 1200Hz was utilized for static postural stability and dynamic postural stability, respectively. All force plate data was passed through an amplifier followed by an analogy digital board and lastly stored on a personal computer. A custom MATLAB (Math-Wroks, v7.0.4, Natick, MA) script was utilized to process all ground reaction force data.

PROCEDURES

Dynamic postural stability was assessed during a single leg
jump test. This protocol has been previously demonstrated to be reliable.\textsuperscript{15} Jump distance was normalized to body height (40%). Subjects were required to complete a jump in the anterior direction over a 30 cm hurdle that was placed midway between the starting point and the front edge of the force plate. Subjects began the jump with a two-footed take-off over the hurdle and were instructed to land on the force plate on the tested leg, stabilize as quickly as possible, place hands on hips, and balance for five seconds while looking straight ahead. Trials were discarded and repeated if subjects failed to jump over or came in contact with the hurdle, hopped on the test leg after landing, the non-weight-bearing leg touched down, or if subjects removed their hands from hips for longer than three seconds. Subjects were provided with three practice trials prior to testing with a one-minute rest period between the practice and test trials. Testing was performed bilaterally. Five successful trials were collected and averaged on both lower extremities; however, data were only used from the dominant leg. Dominant leg was determined by asking participant which leg they would kick a ball with.

Single-leg static postural stability was assessed during a single-leg stance test. The test was performed barefooted under eyes-open and eyes-closed conditions. Subjects performed three trials lasting 10 seconds each for each condition. During testing, the subject was asked to keep the non-test lower extremity foot raised to mid-tibia of the tested lower extremity without touching the tested limb, while maintaining hands on hips. If the subject touched legs or touched down outside the force plate at any time, the trial was discarded and recollected. Data analysis was completed via the standard deviation of ground reaction forces as described later. This protocol has been previously demonstrated to be reliable.\textsuperscript{14} Subjects were provided one complete practice trial for each condition for each leg.

Isometric strength was tested using a handheld dynamometer. Peak force was measured with the dynamometer to the nearest 0.1 kg on both the dominant and the non-dominant lower extremity. This assessment of strength was a "make test", as the subject was asked to exert as much force as possible against an unmoving resistance (a researcher). A practice trial at 50\% of maximum effort was provided for each testing position in order to ensure proper performance. Subjects rested for 30 seconds between each trial in order to avoid fatigue. Three trials were measured, and the results were averaged. Hip abduction, adduction, internal rotation, and external rotation were tested according to standard strength testing positioning, as described below.\textsuperscript{15}

Hip abduction strength was tested with the subject positioned side lying with the leg to be tested on top. The test leg was positioned by a pillow under the lower limb in order to support a neutral spine throughout the duration of the test. The bottom leg was positioned in 90 degrees of knee flexion. The handheld dynamometer was placed just distal to the medial malleolus. The subject was instructed to exert a maximal force against the handheld dynamometer while the examiner maintained a stationary position with the handheld dynamometer.

Hip adduction strength was tested with the subject positioned side lying with the leg to be tested on the bottom. The top leg was positioned in 90 degrees of knee flexion with a pillow at the knee in order to support a neutral spine throughout the duration of the test. The handheld dynamometer was placed just superior to the medial malleolus. The subject was instructed to exert a maximal force against the handheld dynamometer while the examiner maintained a stationary position with the handheld dynamometer.

Hip internal rotation strength was tested with the subject positioned prone on a treatment table with the knee of the test leg flexed to 90 degrees. The examiner passively positioned the test leg into a neutral hip internal-external rotation prior to the initiation of the test. The handheld dynamometer was placed just distal to the lateral malleolus. The subject was instructed to exert a maximal force against the handheld dynamometer while the examiner maintained a stationary position with the handheld dynamometer.

Hip external rotation strength was tested with the subject positioned prone on a treatment table with the knee of the test leg flexed to 90 degrees. The examiner passively positioned the test leg into a neutral hip internal-external rotation prior to the initiation of the test. The handheld dynamometer was placed just distal to the medial malleolus. The subject was instructed to exert a maximal force against the handheld dynamometer while the examiner maintained a stationary position with the handheld dynamometer.

**Statistical Methods**

Data analysis was completed using the standard deviation of ground reaction forces in three planes (anterior/posterior, medial/lateral, and vertical) and the center of pressure in two planes (anterior/posterior and medial/lateral) during the 10-second trial.

For all measures of isometric strength, peak force was averaged across three successful trials was captured in kilograms and normalized to body weight for comparison across subjects (%BW = (average (kg)/subject body weight (kg))*100). Isometric strength measurements normalized to body weight was utilized to calculate strength ratios between each subject’s dominant and non-dominant lower extremity. Isometric strength measurements normalized to body weight was also utilized to calculate strength ratios between opposing muscle groups on each subject’s dominant and non-dominant lower extremity which included hip adduction/abduction and hip external/internal rotation.

Static postural stability is expressed as the standard deviation of ground reaction forces. Following the completion of data collection, a custom Matlab (MathWorks, v7.0.4, Natick, MA) script was used to process and filter the data. All ground reaction force data were passed through a low-pass Butterworth filter with a cut off frequency of 20 Hz. The ground reaction forces from each successful trial were normalized to body weight (%BW). The standard deviation of the ground reaction forces in the anterior/posterior, medial/lateral, and vertical directions, as well as center of pressure in the anterior/posterior and medial/lateral directions were calculated across three successful trials for all conditions. An average of the ground reaction forces in each direction for each condition was calculated in order to explain the subject’s overall static proprioception under each...
Table 2: Hip Strength, Static Postural Stability*, and Dynamic Postural Stability**

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ±SD min  max</td>
<td>Mean ±SD min  max</td>
</tr>
<tr>
<td>Hip Abduction (% Bodyweight)</td>
<td>19.3 ± 5.2 10.5 37.2</td>
<td>20.03 ± 4.9 10 33.3</td>
</tr>
<tr>
<td>Hip Adduction (% Bodyweight)</td>
<td>20.5 ± 5.1 11.6 38.4</td>
<td>20.2 ± 4.3 11.1 29.9</td>
</tr>
<tr>
<td>Hip Internal Rotation (% Bodyweight)</td>
<td>17.03 ± 4.2 8.8 30.1</td>
<td>17.5 ± 3.9 6.8 27.9</td>
</tr>
<tr>
<td>Hip External Rotation (% Bodyweight)</td>
<td>19.1 ± 4.6 10.1 33.5</td>
<td>18.1 ± 4.4 8.5 27.2</td>
</tr>
<tr>
<td>Static Postural Stability (EO) (N)</td>
<td>7.9 ± 3.5 3.8 26.2</td>
<td>6.5 ± 4.6 2.9 27.7</td>
</tr>
<tr>
<td>Static Postural Stability Eyes (EC)(N)</td>
<td>20.4 ± 9.2 7.6 75.5</td>
<td>14.6 ± 6.6 4.7 33.5</td>
</tr>
<tr>
<td>Dynamic Postural Stability</td>
<td>0.342 ± 0.04 0.24 0.472</td>
<td>0.35 ± 0.03 0.287 0.419</td>
</tr>
</tbody>
</table>

EO= eyes open; EC= eyes closed
*Reported standard deviation of ground reaction forces in Newtons; **reported as the dynamic postural stability index, a unitless measure.

condition. For this protocol and data analysis, increased variability in movement on the force plates demonstrates decreased postural stability and a decreased ability to stick the landing at initial contact. Composite scores were calculated for static postural stability and averaged across three trials. In prior laboratory piloting and testing, three trials were demonstrated to be highly reliable for the static balance tasks (ICC = 0.759 – 0.879; SEM = 0.187 – 1.616).16

Dynamic postural stability is expressed through the use of the Dynamic Postural Stability Index. The Dynamic Postural Stability Index calculation creates a stability index for each anatomical direction as well as a composite of all three directions utilizing the first three seconds of ground reaction force data following initial contact with the force plate. For the purposes of this study, initial contact is defined as the point in which the vertical ground reaction force exceeds five percent of the subject’s body weight. Following the completion of data collection, a custom Matlab (MathWorks, v7.0.4, Natick, MA) script processes and filters the data. All ground reaction force data was passed through a low-pass Butterworth filter with a cut off frequency of 20 Hz. An individual Dynamic Postural Stability Index score was calculated for each of the five successful trials. An average of the Dynamic Postural Stability Index scores from the five successful trials was calculated in order to explain a subject’s overall dynamic postural stability. The primary variable for the AP jump and ML jump was the Dynamic Postural Stability Index (DPSI). As described in regard to the static postural stability tasks, a higher DPSI also represents worse postural stability. Intersession reliability and standard errors of measurement were calculated for the primary measures during both postural stability tasks. An intraclass correlation (ICC) using the model described by Shrout and Fleiss was employed to determine the intersession reliability.17

\[
\text{DPSI} = \frac{(\sqrt{\Sigma (0 - x)^2 + \Sigma (0 - y)^2 + (\text{Body Weight} - z)^2})}{\text{Number of Data Points}} \div \text{Body Weight}
\]

Statistical analysis was performed for all subjects and then again separately for males and females. An alpha level of 0.05 was set a priori to determine significance for all statistical analyses. A series of 12 bivariate correlations (Pearson’s r) were computed to determine if a relationship existed between the static and dynamic postural stability measures and the strength measures.

RESULTS

Mean, standard deviation, min, and max values for hip strength and postural stability are listed in Table 2 broken down by males and females. Pairwise correlations, including r coefficients and p values, between hip strength and postural stability measures are listed in Tables 3, 4, and 5 representing all subjects, male subjects, and female subjects, respectively. Among all subjects, significant, albeit weak, correlations were found between all hip strength measures (adduction, abduction, IR, ER) and static postural stability in both the eyes open and eyes closed conditions (correlation coefficients ranged from -0.19 to -0.29). Among male subjects, significant but weak correlations were found between all hip strength measures and static postural stability in both the eyes open and eyes closed conditions (correlation coefficients ranged from -0.21 to -0.34). Among female subjects, static postural stability with eyes open condition found significant but weak correlations with internal and external rotation strength and static postural stability with eyes open condition found a significant correlation with internal rotation strength (correlation coefficients ranged from -0.28 to -0.31). All other static postural stability and hip strength correlations among females were not significant. Among all subjects, males, and females there were no significant correlations between dynamic postural stability and hip strength measures.

DISCUSSION

The main finding of this study was the presence of significant, albeit weak, correlations between isometric hip strength and static postural stability measures, and no correlation between isometric hip strength and dynamic postural stability measures. These findings refuted the original hypothesis of a correlation between dynamic postural stability measures and core strength and no correlation between static postural stability measures and core strength. The findings also revealed a sex difference which could be
### Table 3: Correlation Matrix- All Subjects

<table>
<thead>
<tr>
<th></th>
<th>Static Postural Stability Eyes Open</th>
<th>Static Postural Stability Eyes Closed</th>
<th>Dynamic Postural Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip Abduction</td>
<td>-0.21 (0.008)</td>
<td>-0.26 (&lt;0.001)</td>
<td>-0.10 (0.189)</td>
</tr>
<tr>
<td>Hip Adduction</td>
<td>-0.23 (0.004)</td>
<td>-0.28 (&lt;0.001)</td>
<td>-0.09 (0.265)</td>
</tr>
<tr>
<td>Hip Internal Rotation</td>
<td>-0.29 (&lt;0.001)</td>
<td>-0.28 (&lt;0.001)</td>
<td>-0.07 (0.354)</td>
</tr>
<tr>
<td>Hip External Rotation</td>
<td>-0.19 (0.014)</td>
<td>-0.20 (0.012)</td>
<td>-0.08 (0.286)</td>
</tr>
</tbody>
</table>

### Table 4: Correlation Matrix- Male Subjects

<table>
<thead>
<tr>
<th></th>
<th>Static Postural Stability Eyes Open</th>
<th>Static Postural Stability Eyes Closed</th>
<th>Dynamic Postural Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip Abduction</td>
<td>-0.30 (0.001)</td>
<td>-0.26 (0.005)</td>
<td>-0.16 (0.097)</td>
</tr>
<tr>
<td>Hip Adduction</td>
<td>-0.34 (&lt;0.001)</td>
<td>-0.33 (&lt;0.001)</td>
<td>-0.10 (0.292)</td>
</tr>
<tr>
<td>Hip Internal Rotation</td>
<td>-0.29 (0.002)</td>
<td>-0.29 (0.002)</td>
<td>-0.07 (0.442)</td>
</tr>
<tr>
<td>Hip External Rotation</td>
<td>-0.21 (0.024)</td>
<td>-0.22 (0.020)</td>
<td>-0.10 (0.310)</td>
</tr>
</tbody>
</table>

### Table 5: Correlation Matrix- Female Subjects

<table>
<thead>
<tr>
<th></th>
<th>Static Postural Stability Eyes Open</th>
<th>Static Postural Stability Eyes Closed</th>
<th>Dynamic Postural Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip Abduction</td>
<td>-0.03 (0.848)</td>
<td>-0.23 (0.111)</td>
<td>-0.04 (0.776)</td>
</tr>
<tr>
<td>Hip Adduction</td>
<td>-0.03 (0.825)</td>
<td>-0.20 (0.170)</td>
<td>-0.03 (0.812)</td>
</tr>
<tr>
<td>Hip Internal Rotation</td>
<td>-0.29 (0.039)</td>
<td>-0.28 (0.047)</td>
<td>-0.10 (0.502)</td>
</tr>
<tr>
<td>Hip External Rotation</td>
<td>-0.22 (0.120)</td>
<td>-0.31 (0.028)</td>
<td>-0.01 (0.945)</td>
</tr>
</tbody>
</table>

further examined in future studies. While some weak correlations were found, the relationship between isometric hip strength and postural stability is likely much more complicated than the factors assessed in the current study, and will require additional research.

The results of this study showed no association between isometric hip strength and dynamic postural stability across the entire group or within each sex. These results do not support the original hypothesis and differ from the results of other investigations. Ambegaonkar et al and Wilson et al both looked at the relationship between isometric hip strength and dynamic postural stability and found significant correlations between measurements of hip strength and dynamic balance scores.\(^{18,19}\) Both studies used similar methods to this study of using a handheld dynamometer for determining isometric hip strength, however this study utilized the Dynamic Postural Stability Index (DPSI) generated from a force plate during single leg landing activities to determine dynamic postural stability whereas Ambegaonkar et al utilized the Star Excursion Balance Test (SEBT)\(^{18}\) and Wilson et al utilized the Y Balance Test.\(^{19}\) The contradictory findings may be due to how postural stability was assessed. The DPSI, SEBT, and Y-Balance Test are all considered tests of dynamic postural stability, but the demands each test places on postural stability likely are different. The SEBT and Y-Balance Test consist of maintaining stability on a single-leg while performing reaching activities with the opposite leg.\(^{20,21}\) These tests do not require a change of base of support and could be described as somewhere in the middle of the continuum between a static task and a dynamic task. These tests require isometric strength in order to maintain stability while holding reaching positions which could explain the correlations Ambegaonkar et al and Wilson et al found. A single-leg landing task requires a
change of base of support, what would likely be considered truly "dynamic", thus increasing the difficulty of the task as compared to the SEBT or Y-Balance Test. Due to the increased difficulty of the task, added proprioceptive, vestibular, and somatosensory input and integration would likely be required in order to maintain balance.

Other studies that have utilized a single-leg landing task have found comparable results to this study. Williams et al utilized the DPSI during single-leg landing activities to measure dynamic postural stability.\textsuperscript{22} They compared these balance scores to measures of LE strength and flexibility. Their reported results showed correlations between flexibility and strength measures in the ankle and knee, but no correlation between hip strength and dynamic postural stability. Williams et al, however, only measured hip abduction to represent hip strength\textsuperscript{22} while this study utilized additional measurements including hip internal rotation, external rotation, and adduction.

Results of correlations between isometric hip strength and static postural stability have been found in previous studies. Kim and Kim found similar results in their study assessing the relationship between lower extremity strength and range of motion and static postural stability.\textsuperscript{25} Their study only measured hip flexor and extensor strength, however a significant correlation was found between hip flexor strength and postural sway during a standing balance task.\textsuperscript{23} These findings were surprising as it was hypothesized that due to the low physical demands of the static postural stability tests, less demand would be placed on strength and more on proprioceptive, vestibular, and somatosensory information which were not measured in this study. However, it is worth exploring the notion that static tasks may require more isometric strength while dynamic tasks may require more dynamic muscle functions (ie eccentric, concentric) thus explaining the results of this study.

Future studies regarding this topic may present clinical importance for those attempting to improve dynamic or static postural stability in athletes. This study demonstrated weak correlations between hip strength and static postural stability in mainly male athletes. Due to the low correlations and need for more research, particularly intervention-based studies, definitive statements such as "improvements in hip strength will lead to improvements in static postural stability" cannot be made at this time. It is likely that the relationship between hip strength and postural stability is more complicated than the relationship assessed in the current study.

CONCLUSION

There was no relationship between isometric hip strength and dynamic postural stability; whereas, there were some relationships between the strength measures and static postural stability. These significant, but minimal correlations were observed in more of the comparisons within the male cohort potentially demonstrating a sex difference. Future research on this relationship and the implications on injury prevention should include other measures of muscle performance (isokinetic strength and/or electromyography) and integrate other assessments of neuromuscular control including proprioceptive, vestibular, and somatosensory integration.

CONFLICTS OF INTEREST

All Authors have nothing to disclose

Submitted: December 18, 2019 CST, Accepted: July 24, 2020 CST

This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY-NC-ND-4.0). View this license's legal deed at https://creativecommons.org/licenses/by-nc-nd/4.0 and legal code at https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode for more information.
REFERENCES


Background
Few studies compare women with and without stress fractures and most focus on younger, elite runners.

Hypothesis/Purpose
Compare risk factors between female runners with and without a stress fracture history.

Study Design
Case control

Methods
An online survey targeting women age ≥18 years was distributed primarily via social media. Questions included demographics, running details, cross training, nutrition, injury history, medical/menstrual history, and medications. Women with stress fracture histories answered questions about location, number, and changes made. Data were compared between groups using t-tests, chi-square tests, or Fisher’s exact tests. Multivariable logistic regression models simultaneously investigated associations of multiple factors using backward variable selection.

Results
Data from 1648 respondents were analyzed. Mean age was 40 years, and 25.4% reported stress fractures. Significant differences were found between groups for days/week running, mileage/week, running pace, years running, having a coach, cycling or swimming, calorie consumption for activity, other running injuries, medical history, medication/supplement intake, age at menarche, and going ≥6 months without a menstrual period. Odds of having a stress fracture were increased with osteopenia (OR 4.14), shin splints (OR 3.24), tendon injuries (OR 1.49), running >20 miles/week (OR 1.74–1.77) compared to 11–20 miles/week, having a coach (OR 1.86), and cycling (OR 1.15). Women running 11:00–11:59 minutes/mile or slower were less likely to have a stress fracture compared to those running 9:00–9:59 minutes/mile (OR 0.45–0.54). The odds of having a stress fracture were 1.43 times higher for going ≥6 months without a menstrual period. Use of calcium, probiotics, and vitamin D increased odds. Post fracture, common changes made were with cross training (49%), mileage (49%), and strength training (35%).

Conclusions
Multiple intrinsic and extrinsic factors were identified for female runners who sustained one or more stress fracture during running. Prospective studies are warranted to infer a cause and effect relationship amongst these variables and stress fracture risk.
INTRODUCTION

Stress fractures (SFs) are non-traumatic incomplete fractures resulting from repetitive loading on normal bone.1 Running-related SFs account for 69% of SFs,1 and women have ≥2 times greater risk than men.2,3 In the 2018 United States National Runner Survey that included serious/competitive (19%), frequent fitness (60%), and jogger/recreational runners (21%), respondents were 54% female, and 52% of all runners were between ages 35 and 54.4 For female runners, risk factors for SFs are multifactorial. Factors associated with musculoskeletal injuries that differ in men and women include anatomy,5 body composition,4 metabolism,6 the cardiovascular system,7 hormonal status,2 and psychological status.2 Sex-specific factors of the female athlete triad5 [low energy availability,9 menstrual function,5,6 and bone mineral density2 (BMD)] are related to increased occurrence of SF in women.7 The factors related to SF are intrinsic and extrinsic. Intrinsic factors associated with SF include increased fat mass in relation to lean tissue, nutritional deficits,1,7 hormonal issues,1,8 and decreased BMD1,7,8 and altered bone structure.2,9 Menstrual abnormalities1,5,7 and energy deficiency1,5,7 can occur due to an imbalance between nutritional intake and the amount of activity.5–7 Both pre-menopausal and post-menopausal women are at risk of SF.6,10 Some of the extrinsic factors that are associated with SF include increased training intensity, especially in a short period of time;1,11 less compliant training surfaces;1 irregular running terrain;11 a higher percentage of running on hills; and inappropriate footwear.1,11

Several factors are related to SFs, including nutrition, hormonal status, and bone mineral density. Many of these factors are associated with the female athlete triad, which is characterized by low energy availability, menstrual dysfunction, and disordered eating. The triad can be a significant risk factor for SFs, with up to 80% of cases occurring in this population. The International Journal of Sports Physical Therapy published an article titled “Risk Factors for Stress Fractures in Female Runners: Results of a Survey” which discusses the role of these factors in the development of SFs. The article was written by the first author of the study, and the survey was developed using Qualtrics (QualtricsXM, Provo, UT). The framework for the survey included potential risk factors for SFs in female runners, and surveys were distributed online to identify potential risk factors. The study was designed to identify potential risk factors through an online survey, and the hypothesis was that there would be differences in demographics, running details, cross training, nutrition, injury history, and menstrual history. The study found that female runners were more likely to experience SFs compared to male runners, and that the risk of SFs increased with increasing energy availability and decreased bone mineral density. The study also identified other risk factors, such as hormonal status and previous history of SFs. The results of the study are presented using a level of evidence framework, and the study was published in the International Journal of Sports Physical Therapy.
questions were written, two research data analysts with expertise in survey design and development were consulted, and the survey was modified based on their feedback to improve clarity, conciseness, and ease of completion. Following these modifications, the survey was sent to two physical therapists who regularly evaluate and treat runners and are board-certified orthopedic specialists. Further changes were made based on their advice. The survey was then pilot-tested by 10 female runners who reported no difficulties or concerns with the survey.

The final survey consisted of 39 questions that focused on extrinsic and intrinsic factors for SF. Women who reported SFs received all 39 questions, while those without SFs received 34 questions. The estimated time to complete the survey as determined by Qualtrics was 9.3 minutes. All, except questions about age, height, and weight, were multiple choice, with some questions allowing one answer only and others allowing more than one answer. An "other" option was included, if appropriate, and participants could write in an answer when choosing this option. Questions focused on demographics, running details, cross training, nutrition, injury history, medical/menstrual history, and medications. Respondents were not asked to identify themselves as elite, competitive, or recreational runners. Instead, running pace was collected to attempt to differentiate runners’ abilities. Demographics included age, height, weight, race, level of education, and state in which participants resided. Body mass index (BMI) was later calculated using the height and weight entered. Running details requested were days per week of running, average weekly mileage within the past year during in-season and off-season training, typical running pace, years as a runner, increase in mileage per week, and shoes worn. Participants were also asked if they followed an organized running plan and who guided their running plan. For cross training, participants were asked to indicate which activities they performed. For nutrition, questions asked about self-perception of adequate caloric intake in relation to activity and self-perception about eating a healthy diet. For previous injuries, all participants were asked about previous injuries, and those with SFs received questions asking about SF details (number, location, and how long ago). Medical and menstrual history questions focused on medical issues, medications and supplements taken, age at menarche, pre/peri/post menopausal status, description of menstrual cycle, lack of menstruation for ≥ 6 months (other than pregnancy), and method of contraception, if used. For women who reported a SF, an additional question was asked to determine what, if anything, that the participant had changed following the SF.

The survey was determined to be exempt by the governing Institutional Review Board. It was distributed over a 3 month time period via social media (Facebook, Twitter, Instagram) and paid advertisement on websites frequented by female runners, with the target population being adult female runners with and without a history of SF. Participants were eligible to participate if they were a female runner, at least 18 years of age, and had or had not experienced a SF. Before entering the survey, the participant had to read the study purpose and consent by selecting to continue to agree to participation. The first 2 questions asked participants to identify as female/male/other and as a runner/non-runner, respectively. Those who chose male/other or non-runner were not provided with the remaining questions, and the survey ended. Women were able to stop at any point in the survey or not answer a question. As the survey was web-based, women self-identified as being eligible for the study.

DATA ANALYSIS

Demographics and participant responses were summarized with means and standard deviations for continuous variables and with counts and percentages for categorical variables. Age, height, weight, and BMI data were tested for normality using a Shapiro-Wilk Test. As this test showed a non-normal distribution for these measures, median values and first and third quartiles are also reported. Female runners with and without a SF history were compared using t-tests, chi-square tests, or Fisher's exact tests as appropriate. Multivariable logistic regression models were employed to simultaneously investigate the association of multiple possible risk factors with diagnosis of SFs among the female runners. Backward selection with the Schwarz Bayesian criterion was used for model selection. All analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, NC).

RESULTS

A total of 1905 participants completed the survey. Of these, 257 were removed due to being male/other (n=16) or a non-runner (n=54), or not answering the question about having a SF or not (n=54), the question about age (n=57), any question beyond the first 5 questions that gathered minimal information, if used. For men, 349 (25.4%) reported sustaining 1 or more SFs. Table 1 displays participant demographics. Women with SFs were younger, shorter, lighter in weight, and had lower BMIs than those without SFs. The sample was primarily white, had at least an associate's degree, with the majority living in a suburban setting.

Days per week running, average mileage within the past year during in and off-season training, running pace, and years being a runner all had statistically significant associations with SFs (p < 0.01, Table 2). An association was also found between having a coach and using a book or website to guide training (p<0.01, Table 2). Women who cycled or swam were more likely to have had a SF (p<0.01 for cycling, p=0.01 for swimming, Table 3), and there was an association between SFs and self-perception of not consuming enough calories for activity (p=0.04, Table 4). SF history was also associated with other injuries sustained (p<0.01 for all injuries, Table 5), with medical diagnoses of asthma (p<0.01, Table 6), osteopenia (p<0.01, Table 6), and osteoporosis (p<0.01, Table 6), and with the use of NSAIDs (p<0.01), calcium (p<0.01), probiotics (p<0.01, Table 6), and vitamin D (p<0.01, Table 6), age at menarche (p<0.01, Table 6), and going ≥ 6 months without a menstrual period (p<0.01, Table 6). The use of allergy medications was associated with not having a stress fracture (p=0.04, Table 6).

The odds of having had a SF were estimated with a multivariable logistic regression model. Table 7 shows the estimated odds ratios (OR) and the corresponding 95% confi-
Table 1: Demographics of female runners with and without stress fracture.

<table>
<thead>
<tr>
<th></th>
<th>All (n = 1648)</th>
<th>No stress Fracture (n = 1229, 75%)</th>
<th>Stress fracture (n = 419, 25%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean (SD)</td>
<td>40.1 (11.5)</td>
<td>40.6 (11.3)</td>
<td>38.9 (11.8)</td>
<td>0.01</td>
</tr>
<tr>
<td>Median (1st &amp; 3rd quartile)</td>
<td>39.0 (31.0, 48.0)</td>
<td>40.0 (32.0, 48.0)</td>
<td>38.0 (28.0, 48.0)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Height (in), mean (SD)</td>
<td>64.8 (3.1)</td>
<td>64.9 (3.1)</td>
<td>64.5 (3.0)</td>
<td>0.02</td>
</tr>
<tr>
<td>Median (1st &amp; 3rd quartile)</td>
<td>65.0 (63.0, 67.0)</td>
<td>65.0 (63.0, 67.0)</td>
<td>64.8 (63.0, 67.0)</td>
<td>0.05</td>
</tr>
<tr>
<td>Weight (lbs), mean (SD)</td>
<td>141.0 (24.6)</td>
<td>142.9 (24.5)</td>
<td>135.3 (23.9)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Median (1st &amp; 3rd quartile)</td>
<td>137.0 (125.0, 155.0)</td>
<td>140.0 (125.0, 155.0)</td>
<td>130.0 (120.0, 145.0)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Body Mass Index, mean (SD)</td>
<td>23.6 (4.1)</td>
<td>23.9 (4.0)</td>
<td>22.9 (4.4)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Median (1st &amp; 3rd quartile)</td>
<td>22.8 (20.8, 25.4)</td>
<td>23.0 (21.1, 25.8)</td>
<td>21.9 (20.1, 24.5)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Race, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>African American or Black</td>
<td>26 (1.6)</td>
<td>22 (1.8)</td>
<td>4 (1.0)</td>
<td></td>
</tr>
<tr>
<td>Asian or Pacific Islander</td>
<td>52 (3.2)</td>
<td>41 (3.3)</td>
<td>11 (2.6)</td>
<td></td>
</tr>
<tr>
<td>Caucasian or White</td>
<td>1453 (88.2)</td>
<td>1078 (87.8)</td>
<td>375 (89.5)</td>
<td>0.87</td>
</tr>
<tr>
<td>Hispanic/Latino</td>
<td>71 (4.3)</td>
<td>53 (4.3)</td>
<td>18 (4.3)</td>
<td></td>
</tr>
<tr>
<td>Mixed</td>
<td>34 (2.1)</td>
<td>26 (2.1)</td>
<td>8 (1.9)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>11 (0.7)</td>
<td>8 (0.7)</td>
<td>3 (0.7)</td>
<td></td>
</tr>
<tr>
<td>Education, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High school degree/equivalent or less</td>
<td>150 (9.1)</td>
<td>117 (9.5)</td>
<td>33 (7.9)</td>
<td></td>
</tr>
<tr>
<td>Associate or Bachelor's degree</td>
<td>736 (44.7)</td>
<td>540 (44.0)</td>
<td>196 (46.9)</td>
<td>0.52</td>
</tr>
<tr>
<td>Master's degree</td>
<td>508 (30.8)</td>
<td>386 (31.4)</td>
<td>122 (29.2)</td>
<td></td>
</tr>
<tr>
<td>Doctorate degree</td>
<td>251 (15.3)</td>
<td>184 (15.0)</td>
<td>67 (16.0)</td>
<td></td>
</tr>
<tr>
<td>Residence, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td>458 (27.8)</td>
<td>351 (28.6)</td>
<td>107 (25.5)</td>
<td>0.46</td>
</tr>
<tr>
<td>Suburban</td>
<td>923 (56.0)</td>
<td>674 (54.9)</td>
<td>249 (59.4)</td>
<td></td>
</tr>
<tr>
<td>Rural</td>
<td>238 (14.5)</td>
<td>181 (14.7)</td>
<td>57 (13.6)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>11 (0.7)</td>
<td>9 (0.7)</td>
<td>2 (0.5)</td>
<td></td>
</tr>
</tbody>
</table>

In the multivariable logistic regression analysis, participants with missing data in some covariates were removed, and 1,550 participants’ information (94%) was used in the multivariable logistic regression model. The odds of having a SF for those with osteopenia were about four times as high as those without osteopenia (OR: 4.14). Also, the odds of a SF were higher for those who reported shin splints by more than three times compared to those without (OR: 3.24) and for those who reported tendon injuries by almost 1.5 times (OR: 1.47). Participants who run more than 20 miles per week on average during off-season training had higher odds of SFs compared with those who run 11-20 miles per week (OR: 1.77 for 21-30 miles /week, OR: 1.74 for 31-40 miles /week, OR 1.86 from 41+). Odds were also increased when a coach guided training (OR: 1.40) and for those who cycled for cross training (OR: 1.51), but less for those who hiked for cross training (OR: 0.72). For running pace, women who run 11:00-11:59 minutes/mile or slower pace were less likely to have a SF compared to those who run 9:00-9:59 minutes/mile (OR: 0.45 for 11:00-11:59 and OR: 0.54 for 12:00+). The odds of having a SF were 1.45 times higher for those who have ever gone 6 months or more without a menstrual period other than during pregnancy. Use of calcium, probiotics, and vitamin D were associated with higher odds of SFs. Use of allergy meds and Omega-3s were associated with lower odds. Greater height and urban residence were also associated with lower odds.

A total of 419 women reported sustaining SFs. Of these, 522 sites were reported (Table 8). However, this number likely underestimates the number of SFs as 237 women reported 1 SF, 104 reported 2 SFs, 41 reported 3 SFs, 15 women reported 4 SFs, and 22 reported >5 SFs. As this number indicates at least 738 SFs, some women likely fractured the same site more than once. The most common SF sites were the tibia, fibula, and metatarsals. Most women sustained the most recent SF > 1 year prior to completing the survey (n=285), with 66 sustaining SF <6 months and 67 sustaining SF 6-12 months prior. Most women (91%) reported changing or planning to change some aspects their approach to running and training following a SF (Figure 1). The most common changes were with cross training activities and with running mileage followed by strengthening, running shoes, and supplements.
<table>
<thead>
<tr>
<th>Table 2: Running-related details reported by female runners with and without stress fracture</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Days/week, n (%)</strong></td>
</tr>
<tr>
<td>1-2</td>
</tr>
<tr>
<td>3-4</td>
</tr>
<tr>
<td>5-6</td>
</tr>
<tr>
<td>Everyday</td>
</tr>
<tr>
<td><strong>In-season training weekly mileage, n (%)</strong></td>
</tr>
<tr>
<td>0-10</td>
</tr>
<tr>
<td>11-20</td>
</tr>
<tr>
<td>21-30</td>
</tr>
<tr>
<td>31-40</td>
</tr>
<tr>
<td>41+</td>
</tr>
<tr>
<td><strong>Off-season training weekly mileage, n (%)</strong></td>
</tr>
<tr>
<td>0-10</td>
</tr>
<tr>
<td>11-20</td>
</tr>
<tr>
<td>21-30</td>
</tr>
<tr>
<td>31-40</td>
</tr>
<tr>
<td>41+</td>
</tr>
<tr>
<td><strong>Running pace (min/m), n (%)</strong></td>
</tr>
<tr>
<td>&lt;5:00</td>
</tr>
<tr>
<td>5:00-5:59</td>
</tr>
<tr>
<td>6:00-6:59</td>
</tr>
<tr>
<td>7:00-7:59</td>
</tr>
<tr>
<td>8:00-8:59</td>
</tr>
<tr>
<td>9:00-9:59</td>
</tr>
<tr>
<td>10:00-10:59</td>
</tr>
<tr>
<td>11:00-11:59</td>
</tr>
<tr>
<td>12:00+</td>
</tr>
<tr>
<td><strong>Years being a runner, n (%)</strong></td>
</tr>
<tr>
<td>&lt; 1</td>
</tr>
<tr>
<td>1-3</td>
</tr>
<tr>
<td>4-6</td>
</tr>
<tr>
<td>7-9</td>
</tr>
<tr>
<td>10-20</td>
</tr>
<tr>
<td>20+</td>
</tr>
<tr>
<td><strong>Typical increase in your mileage each week, n (%)</strong></td>
</tr>
<tr>
<td>1-10%</td>
</tr>
<tr>
<td>11-20%</td>
</tr>
<tr>
<td>21-30%</td>
</tr>
<tr>
<td>31%+</td>
</tr>
<tr>
<td><strong>Types of shoes, n (%)</strong></td>
</tr>
<tr>
<td>Minimalist</td>
</tr>
<tr>
<td>Neutral</td>
</tr>
<tr>
<td>Stability</td>
</tr>
<tr>
<td>Other</td>
</tr>
<tr>
<td>I’m not sure</td>
</tr>
</tbody>
</table>

* (p-value) indicates statistical significance.
### Table 3: Cross training activities reported by female runners with and without stress fracture

<table>
<thead>
<tr>
<th>Cross-training activities (yes), n (%)</th>
<th>All (n = 1648)</th>
<th>No stress fracture (n = 1229, 75%)</th>
<th>Stress fracture (n = 419, 25%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycling</td>
<td>744 (45.2)</td>
<td>516 (42.0)</td>
<td>228 (54.4)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Dance</td>
<td>64 (3.9)</td>
<td>54 (4.4)</td>
<td>10 (2.4)</td>
<td>0.07</td>
</tr>
<tr>
<td>Hiking</td>
<td>657 (39.9)</td>
<td>498 (40.6)</td>
<td>159 (37.9)</td>
<td>0.35</td>
</tr>
<tr>
<td>Organized team sports</td>
<td>101 (6.1)</td>
<td>74 (6.0)</td>
<td>27 (6.4)</td>
<td>0.76</td>
</tr>
<tr>
<td>Strength training</td>
<td>1139 (69.2)</td>
<td>836 (68.1)</td>
<td>303 (72.3)</td>
<td>0.10</td>
</tr>
<tr>
<td>Swimming</td>
<td>414 (25.1)</td>
<td>290 (23.6)</td>
<td>124 (29.6)</td>
<td>0.01</td>
</tr>
<tr>
<td>Yoga/Pilates</td>
<td>732 (44.4)</td>
<td>549 (44.7)</td>
<td>183 (43.7)</td>
<td>0.71</td>
</tr>
<tr>
<td>Other</td>
<td>247 (15.0)</td>
<td>183 (14.9)</td>
<td>64 (15.3)</td>
<td>0.85</td>
</tr>
<tr>
<td>None</td>
<td>93 (5.6)</td>
<td>72 (5.9)</td>
<td>21 (5.0)</td>
<td>0.51</td>
</tr>
</tbody>
</table>

### Table 4: Reported perception of caloric intake and consuming a well-balance diet by female runners with and without stress fractures.

<table>
<thead>
<tr>
<th>Consuming enough calories, n (%)</th>
<th>All (n = 1648)</th>
<th>No stress fracture (n = 1229, 75%)</th>
<th>Stress fracture (n = 419, 25%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>1380 (83.8)</td>
<td>1045 (85.1)</td>
<td>335 (80.0)</td>
<td>0.04</td>
</tr>
<tr>
<td>No</td>
<td>106 (6.4)</td>
<td>71 (5.8)</td>
<td>35 (8.4)</td>
<td></td>
</tr>
<tr>
<td>I’m not sure</td>
<td>161 (9.8)</td>
<td>112 (9.1)</td>
<td>49 (11.7)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Eat a healthy, well-balanced diet, n (%)</th>
<th>All (n = 1648)</th>
<th>No stress fracture (n = 1229, 75%)</th>
<th>Stress fracture (n = 419, 25%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most of the time</td>
<td>1202 (73.0)</td>
<td>887 (72.2)</td>
<td>315 (75.2)</td>
<td>0.44</td>
</tr>
<tr>
<td>Some of the time</td>
<td>419 (25.4)</td>
<td>320 (26.1)</td>
<td>99 (23.6)</td>
<td></td>
</tr>
<tr>
<td>Rarely or Never</td>
<td>26 (1.6)</td>
<td>21 (1.7)</td>
<td>5 (1.2)</td>
<td></td>
</tr>
</tbody>
</table>

### DISCUSSION

The results of this study indicate that differences exist between women with and without SF histories across many different categories of risk including demographics, running details, cross training, nutrition, injury history, medical/menstrual history, and medications. While some of these differences have been reported as possible risks in the literature as described in later sections, this study showed that these risks apply to female runners across a larger age range (18-79 years) and more diverse running profiles than typically included in other studies. Thus, this study applies to a broader population of female runners. It is important to note that the timing of this survey captured current information from participants, but information collected about the SF and items changed following a SF relied on memory.
Table 5: Other (non-stress fracture) injuries reported by female runners with and without stress fractures.

<table>
<thead>
<tr>
<th>Prior injuries (yes), n (%)</th>
<th>All (n = 1648)</th>
<th>No stress fracture (n = 1229, 75%)</th>
<th>Stress fracture (n = 419, 25%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT (iliotibial) band syndrome</td>
<td>348 (21.1)</td>
<td>239 (19.5)</td>
<td>109 (26.0)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Muscle strain</td>
<td>411 (25.0)</td>
<td>270 (22.0)</td>
<td>141 (33.7)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Patellofemoral pain syndrome</td>
<td>239 (14.5)</td>
<td>158 (12.9)</td>
<td>81 (19.3)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Plantar fasciitis</td>
<td>375 (22.8)</td>
<td>255 (20.8)</td>
<td>120 (28.6)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Shin splints</td>
<td>318 (19.3)</td>
<td>175 (14.3)</td>
<td>143 (34.1)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Tendon injury</td>
<td>322 (19.6)</td>
<td>202 (16.4)</td>
<td>120 (28.6)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>None</td>
<td>552 (33.5)</td>
<td>463 (37.7)</td>
<td>89 (21.2)</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

Figure 1: Changes made following stress fracture.

This approach to collect current data along with past SF data was chosen to minimize issues with recall bias. Several factors that were associated with having a SF could reflect post SF changes, but some of these factors still suggest increased risk.

Women with SF histories reported currently running more days/week, more miles/week, and at a faster pace, despite 12% indicating changing their running speed, and 50% their mileage/week after the SF. Thus, they are still exceeding what women without SF histories are doing with running. In a study of recurrent SFs in female and male athletes, Korpelainen et al. found that higher weekly mileage increased risk of another SF, and Tenforde et al. reported that running greater than 20 miles/week increased risk in adolescent runners, which corresponds to the findings of this study with participants of a wider age range. Thus, the >20 miles/week risk appears to apply across all women, and the increased risk of SF may be due to fatigue of the musculoskeletal system that exceeds biomechanical limits. For running pace, Damsted et al. found that the faster runners had fewer running-related injuries, which is similar to the results of this study except for those who ran <7 minutes/mile. Odds were decreased in this group, although not significantly, and the number of runners at this pace was small (n=58). Edwards et al. found increased peak tibial contact forces when male runners ran faster, suggesting greater risk at faster running paces. Overall, there is mixed evidence for the risk of running-related injuries based on running pace. Studies on the number of days/week of running in relation to running-related injury risk have mixed results with one study showing that risk is only increased for women when they run 7 days/week, while other studies show no effect of days/week running.

Some of the other differences found between women with and without SF histories could reflect changes made following the fracture. These included having a coach but using websites for training information less often, participating in cycling and swimming, and taking calcium, vitamin D, or probiotic supplements. Following SFs, women may have chosen to hire a coach for guidance for return to
Table 6: Medical and menstrual history reported by female runners with and without stress fractures

<table>
<thead>
<tr>
<th>Medical or Menstrual History</th>
<th>All (n = 1648)</th>
<th>No stress fracture (n = 1229, 75%)</th>
<th>Stress fracture (n = 419, 25%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diagnosed with the following medical issues (yes), n (%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asthma</td>
<td>264 (16.0)</td>
<td>181 (14.7)</td>
<td>83 (19.8)</td>
<td>0.01</td>
</tr>
<tr>
<td>Autoimmune disease</td>
<td>104 (6.3)</td>
<td>71 (5.8)</td>
<td>33 (7.9)</td>
<td>0.13</td>
</tr>
<tr>
<td>Diabetes</td>
<td>12 (0.7)</td>
<td>8 (0.7)</td>
<td>4 (1.0)</td>
<td>0.51</td>
</tr>
<tr>
<td>Gastrointestinal disease</td>
<td>77 (4.7)</td>
<td>52 (4.2)</td>
<td>25 (6.0)</td>
<td>0.15</td>
</tr>
<tr>
<td>Liver or kidney disease</td>
<td>9 (0.5)</td>
<td>7 (0.6)</td>
<td>2 (0.5)</td>
<td>1.00</td>
</tr>
<tr>
<td>Neurological condition or injury</td>
<td>47 (2.9)</td>
<td>36 (2.9)</td>
<td>11 (2.6)</td>
<td>0.75</td>
</tr>
<tr>
<td>Osteopenia</td>
<td>101 (6.1)</td>
<td>46 (3.7)</td>
<td>55 (13.1)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Osteoporosis</td>
<td>37 (2.2)</td>
<td>17 (1.4)</td>
<td>20 (4.8)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Rheumatoid arthritis</td>
<td>30 (1.8)</td>
<td>23 (1.9)</td>
<td>7 (1.7)</td>
<td>0.79</td>
</tr>
<tr>
<td>Thyroid disease</td>
<td>156 (9.5)</td>
<td>117 (9.5)</td>
<td>39 (9.3)</td>
<td>0.89</td>
</tr>
<tr>
<td>None</td>
<td>1000 (60.7)</td>
<td>778 (63.4)</td>
<td>222 (53.0)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td><strong>Medications taken on a regular basis (≥3 times/week), n (%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood pressure medication</td>
<td>70 (4.3)</td>
<td>54 (4.4)</td>
<td>16 (3.8)</td>
<td>0.61</td>
</tr>
<tr>
<td>Cholesterol medication</td>
<td>37 (2.2)</td>
<td>30 (2.4)</td>
<td>7 (1.7)</td>
<td>0.36</td>
</tr>
<tr>
<td>Diabetes medication</td>
<td>6 (0.4)</td>
<td>4 (0.3)</td>
<td>2 (0.5)</td>
<td>0.65</td>
</tr>
<tr>
<td>NSAIDs (i.e. Ibuprofen, Celebrex, Advil, Aleve, Nuprin, Naprosyn, Motrin)</td>
<td>179 (10.9)</td>
<td>118 (9.6)</td>
<td>61 (14.6)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Thyroid hormone medication</td>
<td>146 (8.9)</td>
<td>112 (9.1)</td>
<td>34 (8.1)</td>
<td>0.53</td>
</tr>
<tr>
<td>Tylenol or Acetaminophen</td>
<td>66 (4.0)</td>
<td>47 (3.8)</td>
<td>19 (4.5)</td>
<td>0.52</td>
</tr>
<tr>
<td>Anti-depression medication</td>
<td>53 (3.2)</td>
<td>40 (3.3)</td>
<td>13 (3.1)</td>
<td>0.88</td>
</tr>
<tr>
<td>Allergy medication</td>
<td>57 (3.5)</td>
<td>49 (4.0)</td>
<td>8 (1.9)</td>
<td>0.04</td>
</tr>
<tr>
<td>Autoimmune medication</td>
<td>16 (1.0)</td>
<td>10 (0.8)</td>
<td>6 (1.4)</td>
<td>0.27</td>
</tr>
<tr>
<td>Other</td>
<td>176 (10.7)</td>
<td>136 (11.1)</td>
<td>40 (9.6)</td>
<td>0.38</td>
</tr>
<tr>
<td>None</td>
<td>955 (58.0)</td>
<td>719 (58.6)</td>
<td>236 (56.3)</td>
<td>0.43</td>
</tr>
<tr>
<td><strong>Supplements taken on a regular basis (≥3 times/week), n (%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>325 (19.7)</td>
<td>189 (15.4)</td>
<td>136 (32.5)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Joint supplement (i.e., glucosamine, chondroitin, sulfate)</td>
<td>138 (8.4)</td>
<td>96 (7.8)</td>
<td>42 (10.0)</td>
<td>0.16</td>
</tr>
<tr>
<td>Multivitamin</td>
<td>656 (39.8)</td>
<td>481 (39.2)</td>
<td>175 (41.8)</td>
<td>0.35</td>
</tr>
<tr>
<td>Omega-3s (i.e., fish oil, flax seed)</td>
<td>307 (18.6)</td>
<td>233 (19.0)</td>
<td>74 (17.7)</td>
<td>0.55</td>
</tr>
<tr>
<td>Probiotics</td>
<td>302 (18.3)</td>
<td>205 (16.7)</td>
<td>97 (23.2)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Protein supplement</td>
<td>229 (13.9)</td>
<td>167 (13.6)</td>
<td>62 (14.8)</td>
<td>0.54</td>
</tr>
<tr>
<td>Vitamin D</td>
<td>492 (29.9)</td>
<td>319 (26.0)</td>
<td>173 (41.3)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Other</td>
<td>315 (19.1)</td>
<td>232 (18.9)</td>
<td>83 (19.8)</td>
<td>0.68</td>
</tr>
</tbody>
</table>
### Age of the first menstrual period, n (%)

<table>
<thead>
<tr>
<th>Age Category</th>
<th>All (n = 1648)</th>
<th>No stress fracture (n = 1229, 75%)</th>
<th>Stress fracture (n = 419, 25%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 years old or younger</td>
<td>682 (41.4)</td>
<td>535 (43.6)</td>
<td>147 (35.2)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>13-15 years old</td>
<td>873 (53.0)</td>
<td>639 (52.0)</td>
<td>234 (55.8)</td>
<td></td>
</tr>
<tr>
<td>16 years old or older</td>
<td>87 (5.3)</td>
<td>50 (4.1)</td>
<td>37 (8.9)</td>
<td></td>
</tr>
</tbody>
</table>

### Current phase in your menstrual cycle, n (%)

<table>
<thead>
<tr>
<th>Phase</th>
<th>All (n = 1648)</th>
<th>No stress fracture (n = 1229, 75%)</th>
<th>Stress fracture (n = 419, 25%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-menopausal</td>
<td>910 (55.3)</td>
<td>686 (55.9)</td>
<td>224 (53.5)</td>
<td></td>
</tr>
<tr>
<td>Post-menopausal</td>
<td>267 (16.2)</td>
<td>200 (16.3)</td>
<td>67 (16.0)</td>
<td>0.67</td>
</tr>
<tr>
<td>Peri-menopausal</td>
<td>254 (15.4)</td>
<td>182 (14.8)</td>
<td>72 (17.2)</td>
<td></td>
</tr>
<tr>
<td>I'm not sure</td>
<td>212 (12.9)</td>
<td>156 (12.7)</td>
<td>56 (13.4)</td>
<td></td>
</tr>
</tbody>
</table>

### Describe your menstrual cycle, n (%)

<table>
<thead>
<tr>
<th>Cycle Type</th>
<th>All (n = 1648)</th>
<th>No stress fracture (n = 1229, 75%)</th>
<th>Stress fracture (n = 419, 25%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular (every 28 days)</td>
<td>731 (44.4)</td>
<td>555 (45.2)</td>
<td>176 (42.0)</td>
<td></td>
</tr>
<tr>
<td>Typically regular, but irregular at times with heavier training loads</td>
<td>170 (10.3)</td>
<td>125 (10.2)</td>
<td>45 (10.7)</td>
<td></td>
</tr>
<tr>
<td>Irregular</td>
<td>256 (15.5)</td>
<td>184 (15.0)</td>
<td>72 (17.2)</td>
<td>0.75</td>
</tr>
<tr>
<td>I don't menstruate*</td>
<td>267 (16.3)</td>
<td>200 (16.3)</td>
<td>67 (16.0)</td>
<td></td>
</tr>
<tr>
<td>Didn't answer</td>
<td>223 (13.5)</td>
<td>164 (13.4)</td>
<td>59 (14.1)</td>
<td></td>
</tr>
</tbody>
</table>

### Without a period ≥ 6 months other than pregnancy, n (%)

<table>
<thead>
<tr>
<th>No period</th>
<th>All (n = 1648)</th>
<th>No stress fracture (n = 1229, 75%)</th>
<th>Stress fracture (n = 419, 25%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>508 (30.8)</td>
<td>339 (27.5)</td>
<td>170 (40.6)</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

### Types of contraceptives, n (%)

<table>
<thead>
<tr>
<th>Contraceptive Type</th>
<th>All (n = 1648)</th>
<th>No stress fracture (n = 1229, 75%)</th>
<th>Stress fracture (n = 419, 25%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hormonal</td>
<td>603 (36.8)</td>
<td>445 (36.5)</td>
<td>158 (37.8)</td>
<td></td>
</tr>
<tr>
<td>Non-hormonal</td>
<td>166 (10.1)</td>
<td>128 (10.5)</td>
<td>38 (9.1)</td>
<td>0.69</td>
</tr>
<tr>
<td>I don't use contraceptives</td>
<td>870 (53.2)</td>
<td>648 (53.1)</td>
<td>222 (53.1)</td>
<td></td>
</tr>
</tbody>
</table>

* Women who were postmenopausal were placed into this category.

Running, decrease loading by adding cycling or swimming if not a multisport athlete already, and add supplements to improve bone health. Dietary deficiencies, including dairy, calcium, and vitamin D intake, have been shown to have negative long-term impact on BMD and body mass index in female athletes. There is some evidence that calcium and vitamin D may be helpful in SF prevention, but the literature is not conclusive. Screening for low vitamin D levels is recommended. For probiotics, there is some evidence that improved intestinal health may help to prevent or treat bone loss by regulating absorption of calcium, phosphorous, and magnesium and producing endocrine factors that signal to bone cells.

More women with SF histories used NSAIDS compared to the non-SF group. Due to the nature of the study, it is not clear if women were taking more NSAIDs prior to the SF or as a result of it. In the final multivariable model, this association between NSAIDs and SF dropped out; however, NSAID use was strongly associated with shin splints and osteopenia, suggesting a possible role of NSAIDs in contributing to these conditions that did remain in the multivariable model. NSAID use is being studied more for positive and negative effects in runners. A survey by Tillander et al. found that 42% of marathon runners occasionally used NSAIDs, and there was an association between NSAID use and fewer injuries that resulted in lost time from running. Thus, runners seem to obtain some benefit from NSAIDs, but there is concern for SF and other bone injuries. A study by Hughes et al. found that NSAID prescription increased risk for SFs more than 3-fold in soldiers during periods of regular activity and more than 5-fold during periods of more heightened physical activity. These results are believed to be due to de-
Table 7: Estimated Odds Ratios based on a Logistic Regression with backward selection, n = 1550.

<table>
<thead>
<tr>
<th>Category</th>
<th>Odds Ratio</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>0.98</td>
<td>(0.97, 1.00)</td>
</tr>
<tr>
<td>Height (in)</td>
<td>0.95</td>
<td>(0.91, 0.99)</td>
</tr>
<tr>
<td>How would you best describe the area in which you reside?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban vs. Suburban</td>
<td>0.73</td>
<td>(0.54, 0.99)</td>
</tr>
<tr>
<td>Rural vs. Suburban</td>
<td>1.08</td>
<td>(0.74, 1.58)</td>
</tr>
<tr>
<td>Other vs. Suburban</td>
<td>0.14</td>
<td>(0.02, 1.18)</td>
</tr>
<tr>
<td>What is your average weekly mileage within the past year during off-season training?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10 vs. 11-20</td>
<td>0.88</td>
<td>(0.62, 1.25)</td>
</tr>
<tr>
<td>21-30 vs. 11-20</td>
<td>1.77</td>
<td>(1.26, 2.49)</td>
</tr>
<tr>
<td>31-40 vs. 11-20</td>
<td>1.74</td>
<td>(1.02, 2.98)</td>
</tr>
<tr>
<td>41+ vs. 11-20</td>
<td>1.86</td>
<td>(1.02, 3.40)</td>
</tr>
<tr>
<td>What is your most common running pace in minutes per mile?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 7:00 vs. 9:00-9:59</td>
<td>0.46</td>
<td>(0.15, 1.38)</td>
</tr>
<tr>
<td>7:00-7:59 vs. 9:00-9:59</td>
<td>1.59</td>
<td>(0.94, 2.71)</td>
</tr>
<tr>
<td>8:00-8:59 vs. 9:00-9:59</td>
<td>0.99</td>
<td>(0.69, 1.42)</td>
</tr>
<tr>
<td>10:00-10:59 vs. 9:00-9:59</td>
<td>0.71</td>
<td>(0.49, 1.04)</td>
</tr>
<tr>
<td>11:00-11:59 vs. 9:00-9:59</td>
<td>0.43</td>
<td>(0.26, 0.73)</td>
</tr>
<tr>
<td>12:00+ vs. 9:00-9:59</td>
<td>0.54</td>
<td>(0.31, 0.94)</td>
</tr>
<tr>
<td>Who guides your running plan?</td>
<td>Coach Yes vs. No</td>
<td>1.40 (1.01, 1.94)</td>
</tr>
<tr>
<td>Cross-training activities you participate in.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycling Yes vs. No</td>
<td>1.51</td>
<td>(1.16, 1.97)</td>
</tr>
<tr>
<td>Hiking Yes vs. No</td>
<td>0.72</td>
<td>(0.55, 0.94)</td>
</tr>
<tr>
<td>Have you ever been medically diagnosed with any of the following injuries as a result of running?</td>
<td>Shin splints Yes vs. No</td>
<td>3.24 (2.38, 4.39)</td>
</tr>
<tr>
<td>Tendon injury Yes vs. No</td>
<td>1.47</td>
<td>(1.07, 2.01)</td>
</tr>
<tr>
<td>Have you ever been diagnosed with any of the following medical issues?</td>
<td>Asthma Yes vs. No</td>
<td>1.43 (1.01, 2.02)</td>
</tr>
<tr>
<td>Osteopenia Yes vs. No</td>
<td>4.14</td>
<td>(2.38, 7.17)</td>
</tr>
<tr>
<td>Do you take any of the following medications on a regular basis (at least 3 times per week)?</td>
<td>Allergy medication Yes vs. No</td>
<td>0.42 (0.18, 0.97)</td>
</tr>
<tr>
<td>Do you take any of the following supplements on a regular basis (at least 3 times per week)?</td>
<td>Calcium Yes vs. No</td>
<td>1.78 (1.25, 2.55)</td>
</tr>
<tr>
<td>Omega-3s Yes vs. No</td>
<td>0.51</td>
<td>(0.35, 0.74)</td>
</tr>
<tr>
<td>Probiotics Yes vs. No</td>
<td>1.47</td>
<td>(1.05, 2.05)</td>
</tr>
<tr>
<td>Vitamin D Yes vs. No</td>
<td>1.54</td>
<td>(1.11, 2.15)</td>
</tr>
<tr>
<td>How old were you when you had your first menstrual period?</td>
<td>≤12 yrs old vs. 13-15 yrs old</td>
<td>0.81 (0.61, 1.06)</td>
</tr>
<tr>
<td>≥16 yrs old vs. 13-15 yrs old</td>
<td>1.62</td>
<td>(0.93, 2.80)</td>
</tr>
<tr>
<td>Have you ever gone 6 months or more without a period other than during pregnancy?</td>
<td>Yes vs. No</td>
<td>1.45 (1.10, 1.91)</td>
</tr>
</tbody>
</table>

Increased bone anabolism in response to loading after taking NSAIDS, possibly due to attenuation of prostaglandin production. Bone formation stimulated by loading can reduce bone fatigue, thus bone may become more fatigued with NSAID use, increasing SF risk. These findings are concerning for female runners who routinely or periodically take NSAIDS for pain management. NSAIDS should also be avoided with a new SF as they can have a negative effect on bone healing. There are other factors that are not or likely not related to changes made after a SF. In our study, women with SF histories were younger, shorter, and lighter, and had lower...
Table 8: Stress fracture locations. Across the 419 female runners who reported a fracture, 522 stress fractures were reported based on site.

<table>
<thead>
<tr>
<th>Location</th>
<th>Number reported</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibia or fibula</td>
<td>173</td>
</tr>
<tr>
<td>Metatarsal</td>
<td>155</td>
</tr>
<tr>
<td>Hip/pelvis/sacrum</td>
<td>64</td>
</tr>
<tr>
<td>Navicular/midfoot</td>
<td>44</td>
</tr>
<tr>
<td>Femur</td>
<td>42</td>
</tr>
<tr>
<td>Calcaneus/heel</td>
<td>31</td>
</tr>
<tr>
<td>Lumbar spine/low back</td>
<td>6</td>
</tr>
<tr>
<td>Other</td>
<td>5</td>
</tr>
<tr>
<td>Not sure</td>
<td>2</td>
</tr>
</tbody>
</table>

BMI. The significance of being younger and shorter is unclear as there are mixed reports about these factors. Being lighter with lower BMI is supported in the literature due to its relevance to the female athlete triad. Women with SFs also reported running for more years, had more other injuries, medical diagnoses of asthma and osteopenia/osteoporosis, later age of menarche, and increased likelihood of going 6 months or more without a menstrual period other than during pregnancy. These findings are overall consistent with other studies of female runners with SFs. While literature does not suggest asthma as a risk factor for SFs, brief courses of oral corticosteroids are often used to treat patients with asthma, which may increase risk of SF. For an unknown reason, women without SF histories reported taking more allergy medications.

The multivariable logistic regression analysis showed that the factors that increased the odds of having a SF included histories of osteopenia, shin splints, and tendon injuries, running more than 20 miles/week, having a coach, participating in cycling, going 6 months or more without a menstrual period, and taking calcium, vitamin D, and probiotic supplements. Factors that decreased the odds of having a SF included running 11 minutes/mile or slower, participating in hiking, and taking allergy medications and omega 3s. As discussed above, some of these factors could be impacted by changes made post SF while others may not be impacted. The increased odds of a SF based on prior shin splints and tendon injuries are of interest as other studies have shown relationships between SFs and prior injuries including a prior SF. Common tendons that are injured in runners include the Achilles, posterior tibialis, and peroneal tendons; each can impact running biomechanics. Pamukoff and Blackburn found that male runners with prior tibial SFs had increased plantar flexor musculotendinous and Achilles tendon stiffness; however, it is unknown if these changes contributed to the SF or occurred after. Although there is limited research on the incidence of SFs following other lower extremity running-related injuries, differences in running biomechanics and technique may provide some insight. In a cross-sectional study comparing women with and without prior tibial SFs, increased peak breaking vertical impact ground reaction force and peak shock were found in the women with prior SF, suggesting possible increased risk for injury. In this survey study, 182 of the 491 (37.1%) women with SFs reported greater than 1 SF, suggesting the importance of adequate healing and appropriate physical therapy and medical interventions with first SF diagnosis or other running-related injury.

Concerns exist for these women with SF based on the female athlete triad due to significant findings of self-reported insufficient diet for activity (low energy availability), menstrual dysfunction, and osteopenia. Similar concerns have been reported for younger female runners. Screening for the female athlete triad components and education on risk due to these components are therefore recommended for a broader population of female runners.

For the women who had SF histories, many changes were made, some that are supported by the literature and some that are not as far as reducing SFs or possible risks for SF. The changes that have support include cross training, weekly mileage, strength training, supplement use, running technique, diet, terrain, and speed. The most common change was in shoe wear, which is consistently felt by runners to be important but is not supported by the literature. Based on the findings of this study, there are clinical implications for screening that may be warranted and for educating female runners about SF risks. These recommendations apply to all women regardless of age as, this study included women ages 18-79 years. It is recommended that female runners be screened for osteopenia/osteoporosis, vitamin D deficiencies, menstrual issues, and other injuries including shin splints and tendon injuries and be provided with education and recommendations to manage these issues. Questions should focus on their cross training activities, miles per week of running, years running, running pace, age at menarche, medications, diet, supplement use, and NSAID use. Education is needed on possible SF risk for all women, such as limiting running to less than 20 miles/week if possible, decreasing or stopping NSAID use, obtaining sufficient dietary intake for activity, and appropriately managing any running-related injury especially shin splints and tendon injuries. Based on this study, risk is not increased based on days per week running or running pace, but these may still be considered. Screening and education...
may be even more critical for female runners after sustaining a first SF to decrease risk. Thus, health professionals should be more proactive with these women to hopefully prevent future SFs and allow women to remain active as runners.

There are several limitations to this study. The survey design only allows for associations and odds ratios to be determined. Thus, no causation can be inferred. Prospective studies are needed to determine causation. In this study, women self-identified as being eligible for the study and as the survey was internet based, it was not possible to limit who was taking the survey or to confirm the identity of respondents. A response rate is also unable to be determined based on the recruitment methods used. The sample was primarily white and well-educated with the majority living in a suburban setting. The survey was self-report and women could skip questions. Despite these limitations, the survey was completed by women of many different ages and running abilities, of whom 25.4% had sustained SFs. Future research should include prospective studies to determine if screening, education, and intervention can prevent a first or subsequent SF in female runners.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

ACKNOWLEDGEMENTS

The study was funded by the Office of the Provost, Thomas Jefferson University. We would like to acknowledge the following people for their assistance with this study: Brian Eckenrode, PT, DPT, OCS, Associate Professor, Arcadia University, Department of Physical Therapy; Robert Maschi, PT, DPT, OCS, CSCS, Associate Clinical Professor, Drexel University, Department of Physical Therapy and Rehabilitation Sciences; Momo Nakagawa, Research Data Analyst, Thomas Jefferson University; John Guarnieri, Senior Research Data Analyst, Thomas Jefferson University.

Submitted: November 14, 2019 CST, Accepted: July 24, 2020 CST

This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY-NC-ND-4.0). View this license's legal deed at https://creativecommons.org/licenses/by-nc-nd/4.0 and legal code at https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode for more information.
REFERENCES


Original Research

Post-Trial Feedback Alters Landing Performance in Adolescent Female Athletes Using a Portable Feedback System

Thomas W Kernozek, PhD, FACSM, Drew Rutherford, MS, Becky Heinert, PT, MSPT, SCS, Jessica Onsager, PT, DPT, Maria Lee, PT, DPT, Jeremie Schiedermayer, PT, DPT, Stephanie Dietrich, SPT, Renee Dade, SPT, Thomas Gus Almonroeder, PT, DPT, PhD

1 Department of Health Professions, Physical Therapy Program, University of Wisconsin – La Crosse, 1300 Badger Street, La Crosse, WI, USA; La Crosse Institute for Movement Science (LIMS), University of Wisconsin – La Crosse, 1300 Badger Street, La Crosse, WI, USA, 2 La Crosse Institute for Movement Science (LIMS), University of Wisconsin – La Crosse, 1300 Badger Street, La Crosse, WI, USA; Gundersen Health System, Sports Medicine, La Crosse, WI, USA

Keywords: training, movement system, motor learning, kinematics, kinetics, anterior cruciate ligament

10.26603/001c.18808

International Journal of Sports Physical Therapy
Vol. 16, Issue 1, 2021

Background

Post-performance verbal and visual feedback based on data collected via lab-based instruments have been shown to improve landing patterns related to non-contact ACL injury. Biomechanical methods are often complex, difficult to transport and utilize in field settings, and costly, which limits their use for injury prevention. Developing systems that can readily provide feedback outside of the lab setting may support large scale use of feedback training for ACL injury prevention.

Purpose/Hypothesis

The purpose of this study was to investigate the effectiveness of a single training session using a custom portable feedback training system that provides performance cues to promote changes in impact kinetics and lower extremity position during landing in female athletes.

Study Design

Repeated measures

Methods

One hundred fifty female athletes (ages 13-18 years old) landed from a 50 cm platform with and without feedback related to vertical ground reaction force (vGRF), vGRF symmetry and lower extremity position. Feedback was provided via a portable, low-cost system that included two custom-built force plates interfaced with a digital camera. Each athlete performed six pre-test trials followed by two blocks of six trials where they received visual feedback from the training system and individualized verbal cues from an investigator. Following training blocks, athletes completed six post-test trials without feedback and then six dual-task trials where a ball was randomly thrown to the performer during the landing (transfer task). vGRF and knee to ankle (K:A) separation ratio were measured and the average responses were reported for each trial block.

Results

Differences in vGRF between baseline, post-test and transfer task trial blocks were observed (F(2,298)=181.68, p < .0001). Mean (SD) peak vGRF (body weight) were 4.43 (0.90), 3.28 (0.61), and 3.80 (0.92), respectively. Differences in K:A ratio between baseline, post-test and transfer task trial blocks were shown (F(2,298)=68.47, p < .0001). Mean (SD) K:A ratio were 0.87 (0.21), 0.98 (0.19), and 0.92 (0.19), respectively.

Corresponding author: Thomas W. Kernozek, PhD, FACSM Department of Health Professions Physical Therapy Program University of Wisconsin–La Crosse La Crosse, WI 54601 e-mail: kernozek.thom@uwlaex.edu
INTRODUCTION

Non-contact injury to the anterior cruciate ligament (ACL) in female athletes has been investigated quite extensively. Despite the plethora of investigations, females are two to eight times more likely to suffer this traumatic injury as compared to males.1 Although the proposed etiology of non-contact ACL ruptures appears multifactorial, improper landing mechanics in female athletes has been cited as associated with increased injury risk.2–4 Furthermore, a second ACL rupture is more likely in athletes within two years after ligament reconstruction following return to sport that involve jumping and landing activities where aberrant landing patterns were shown.5–7

The best strategy for identifying these aberrant landing patterns and the most effective intervention for their remediation is debatable. Augmented feedback using external sources (ie. use of video display and verbal cueing and instruction based on expertise from an instructor) is most often employed in the clinical setting due to their relative ease of implementation. Traditionally, clinicians attempt to modify athletes’ landing mechanics by providing instructions to promote more optimal body postures and joint alignment; however, these types of instructions often only produce transient changes in landing mechanics.8 As a result, there appears to be a need for more advanced methods of athlete feedback. Post-performance video feedback has been shown to promote changes in landing patterns that may reduce ACL injury in female athletes (e.g. lower vertical ground reaction forces, less knee abduction).3,4,9–16 This is encouraging, as video can be recorded in clinical or field settings using widely available, low-cost equipment such as smartphones, tablets, etc. However, the information obtained from such videos is subjective and does not provide insight into the forces experienced during landing. In addition, most standard video cameras sample data at rates that are too low for dynamic movements such as drop landings.

Assessments that incorporate three-dimensional (3-D) analysis of drop landings have also been used to identify kinematic and kinetic measures that may be related to a higher risk of non-contact ACL injuries in female athletes.3,8,15,17,18 Post-trial feedback has been shown to be effective in modifying neuromuscular risk factors in drop landing and can provide more accurate and objective kinematic and kinetic information which may serve to better identify risk factors for injury or re-injury.15 However, many of these investigations have used expensive and elaborate laboratory-based methods to provide such feedback4,19–21 that would be impractical to implement large scale especially in field settings. Therefore, this type of performance-based feedback may not have the ability to reach the target population (ie. adolescent female high school athletes).

There appears to be a need to develop landing assessment and training tools that can provide immediate post-trial feedback relevant to an athlete’s performance that is both objective and qualitative. The purpose of this study was to investigate the effectiveness of a single training session using a custom portable feedback training system that provides performance cues to promote changes in impact kinetics and lower extremity position during landing in female athletes. Feedback provided during training was based on kinetic/kinematic data recorded via the system and individualized cues from an investigator.

METHODS

SUBJECTS

This study was approved by the University of Wisconsin La Crosse’s Institutional Review Board. Prior to participation in this study, all subjects or parent provided their written informed consent in accordance with University guidelines.

One hundred fifty females at regional high schools between the ages of 13–18 years old participated in this single session study. Age, height, body mass index, and Tegner level22 was recorded. All were actively participating female athletes. Exclusion criteria for the study included (1) any current lower extremity injury, (2) knee pain at rest or during running or jumping, (3) pregnancy, (4) any cardiovascular abnormalities or medical condition that limited training as indicated by a physical activity readiness questionnaire (PAR-Q).23 All participants utilized their own athletic footwear and wore comfortable athletic clothing during the study.

PROCEDURES

Participants were asked to complete a drop landing from a 50 centimeter (cm) platform. Prior to testing, athletes were given verbal instructions for the landing task including: 1) jump forward with both feet off the raised platform and land with both feet while having one foot near the center of each force platform, (2) jump bilaterally rather than stepping off the box, (3) land as to not fall forward off of the force platforms, (4) return to standing from landing position and maintain that position for two seconds. During data collection, trials were discounted if those requirements were not met. Participants were allowed up to three practice trials to familiarize themselves with the task. Data were collected generally in a gymnasium or common space with a ceiling height that could accommodate the experimental setup.

Kinetic data were obtained from two custom, high impact force plates designed for these in situ data collections. Each force platform was positioned adjacent to one another
and 25 cm in front of the 50 cm platform. Each force platform was custom made with 4 calibrated load cells (ntep-1kib shear beam load cell) capable of measuring vertical force. Bilateral vertical ground reaction force (vGRF) data were sampled at 2000 Hz and normalized to each participant’s body weight. Validation of the system was performed in a pilot investigation of 20 participants where the custom force platforms were placed directly on top of two commercially available force platforms (Model 4080, Bertec Corporation, Columbus, OH) and sampled at 2000 Hz on both systems. The peak vGRF was within 5% of that obtained with the commercially available force platforms. This accuracy criteria are likely considered reasonable regarding force plate accuracy for a portable system during a dynamic impact situation such as landing.24 Frontal plane video of each participant focused on the lower extremities were recorded from a high-speed camera at 100 Hz (DFK 23UV024, The Imaging Source, LLC, Charlotte, NC, USA) during each performance trial. The camera was positioned on a tripod at a height of 65 cm and at a distance of 150 cm from the force plates. Custom scripts were implemented within commercial software (Innovative Sports Training, Inc., Chicago, IL, USA) and used on a digital monitor in front of the performer to provide immediate post-trial feedback. (Figure 1)

Athletes completed 30 landing trials divided into five blocks of six trials with one minute of rest provided between each trial block. During the initial block (Pre-test), participants were blinded to any form of feedback to determine their baseline landing performance. Prior to beginning the training blocks, the athletes were provided with a brief overview of the information they would receive on the visual feedback display post each trial. This information included peak vGRF displayed in body weight, symmetry of lower extremity vGRF demonstrated through a seesaw/teeter totter display, and frontal plane video that was replayed by the investigator to depict a qualitative impression of the performer’s lower extremity alignment and overall body position during landing (Figure 2).

The baseline test was followed by the first training block (Training 1) where participants received post-trial feedback based on these data coupled with cues for improving landing performance from an investigator. Athletes were provided with both externally focused feedback first (e.g. “try to reduce the vGRF value”, “try to land quieter or more softly”) and then internally focused feedback (e.g. “try to keep your knees over your toes,” “try to land with your knees out”). The feedback provided was individualized and dependent upon what was observed based on the peak vGRF, vGRF symmetry and general impression from the video of the athletes’ frontal plane landing kinematics. The general order of the feedback was based on the order of processing of these data on the display (peak vGRF, vGRF symmetry and then video of performance). These data were available within 20 seconds after each landing. The video was available in second window initially behind the force display and was available last due to computer processing requirements associated with recording these images at high speed. Athletes were given time to review the data and then relevant cues were provided by the investigator. The next trial was then immediately performed such that the entire testing and training session took approximately 20 minutes. The general training and feedback used was systematic where once that variable such as vGRF showed substantial improvement, the next variable was selected for feedback. During the second training set (Training 2), the feedback from the investigator was gradually withdrawn and the athletes were asked to self-evaluate their peak vGRF, loading symmetry and body alignment and position projected to the display. Participants were encouraged to incorporate strategies that they felt were most helpful for performance im-

![Figure 1: Typical experimental setup taken to each school. Photo depicts the drop platform, two portable force platforms, high speed video camera focused on the frontal plane, and display showing the vertical ground reaction force (vGRF), vGRF symmetry and when cued the ability to review high speed frontal view of the performer landing. After each landing, the researcher and participant discussed the feedback and internal and external cues were provided prior to the next performance trial during the training blocks. During the pre-test, post-test and transfer task the display was turned off.](image1)

![Figure 2: Feedback display showing peak vertical ground reaction force (vGRF), vGRF symmetry and in another window the ability to replay and pause high speed frontal plane video.](image2)
Table 1: Means and standard deviations of demographic data for 150 female athletes tested

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Height (m)</th>
<th>Weight (kg)</th>
<th>Body Mass Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.94 (1.61)</td>
<td>1.7 (0.08)</td>
<td>60.95 (11.09)</td>
<td>20.86 (3.58)</td>
</tr>
</tbody>
</table>

Standard deviations are provided in within brackets.

Improve...t based on their first training block. Following completion of Training 1 and Training 2, a post-test (six trials) was completed without any verbal or visual feedback. Finally, a transfer task was examined where a dual task landing was performed without feedback. During the dual transfer task, participants were required to attend to catching a ball while landing. Six trials were performed with a tester either throwing the ball or faking a throw. The order of the testing condition (throw or fake throw) was randomized for each participant. Outcome data from the transfer condition performance trials were pooled.

DATA PROCESSING

Kinetic data were exported and processed in Excel where peak vGRF in body weight for each trial were determined. Scaled video data were analyzed within Kinovea (https://www.kinovea.org) to determine knee to ankle separation ratio (K:A ratio). Kinovea is a software program that allows various video formats to be opened, scaled and points where points on the image can be used to calculate various kinematic measurements. This approach to measuring knee abduction has shown high intra and inter-rater reliability (0.97 and 0.92 respectively). From a force threshold of 10 N, a single video frame was selected 100 ms after impact for analysis of frontal plane knee motion. K:A ratio was the distance from the estimated knee joint center to ankle joint center. K:A ratios of less than 1.0 are indicative of more knee valgus positioning during landing.

STATISTICAL METHODS

The dependent variables of interest were peak vGRF and K:A ratio. Means for peak total vGRF in multiples of body weight and K:A ratio were calculated for the three blocks of six trials (baseline, post-test, and transfer task). A repeated measures analysis of variance (ANOVA) (alpha set to 0.05) was then performed to examine differences in trial blocks (baseline, post-test, and transfer task) in vGRF and then on K:A ratio. Post hoc comparisons were performed using the Bonferroni approach. Effect sizes (Cohen’s d) were calculated between the same trial blocks. Statistical analysis was completed utilizing SPSS, version 25 (IBM Corporation, Armonk, NY, USA).

RESULTS

Demographic data on participants are provided in Table 1. Means and standard deviations for these participants were: age of 14.94 ± 1.61 years, height of 1.67 ± 0.08 m, weight of 60.95 ± 11.09 kg, and body mass index of 20.86 ± 3.58. Athletes reported a Tegner level of at least 5/10 and were currently competing in competitive volleyball and/or basketball programs at the high school or club level since the goal was to test actively participating female athletes.

Mean vGRF were different from baseline, post-test and transfer task trial blocks (F(2,298)=181.68, p < .0001).
Comparisons showed that baseline vGRF was 29.96% higher than post-test and 14.22% higher during the transfer task but the transfer task was 15.85% greater than the post-test (all p<.0001). The effect size for vGRF from baseline to post-test was 1.52, baseline to transfer was .69 and post-test to transfer was .68.

Mean K:A ratio were different from baseline, post-test and transfer task trial blocks (F(2,298)=63.47, p < .0001). The mean (standard deviation) K:A ratio for the baseline, post-test and transfer task respectively were 0.87 (0.21), 0.98 (0.19), and 0.92 (0.19). Post hoc comparisons showed K:A ratio during the baseline was 12.64% greater than post-test and 6.12% greater during the transfer task but the transfer task was 5.75% reduced compared to the post-test (all p<.0001). The effect size for K:A ratio from baseline to post-test was 0.55, baseline to transfer was .25 and post-test to transfer was .32.

DISCUSSION

Findings of the current study indicate that using a portable force plate system interfaced with a digital camera is an effective tool for providing feedback to promote immediate positive changes in vGRF and K:A ratio of adolescent female athletes. The participants in the study demonstrated a reduction in peak vGRF and higher K:A ratio (indicative of less knee abduction) following a training session which included visual feedback related to vGRF, vGRF symmetry and video of frontal plane landing kinematics, as well as cueing for an investigator. Effect sizes were large and moderate for baseline to post-test for vGRF and K:A ratio. Despite these variables regressing toward baseline values, these improvements persisted during the transfer task however both of their effect sizes were between small to medium. Positive transfer of an improved movement pattern to an untrained task, in this case, the dual-task where a ball was randomly passed to the performer is considered an indicator of motor learning.29 Despite previous investigations suggesting that augmented feedback is effective in eliciting improvements in landing mechanics, and this is the first time a portable system has been used that provides salient data that participants appear to respond to that can be used to alter landing mechanics for neuromuscular training on-site with athletic teams.4,10,13–15,18,30–33

The present findings differ in part from Munro and Herrington14 who also evaluated changes in vGRF and knee abduction angle using augmented feedback. In their study, the authors incorporated a combination of strategies including video demonstration of correct landing form, individualized post-trial expert video assessment and a checklist for self-analysis of the performance. Subjects were rated on kinetic variables such as trunk lean, knee valgus and knee flexion during landing. Using video analysis to determine the knee frontal plane projection angle (FPPA), the authors found a 23.9° reduction in knee abduction angle post feedback but no change in vGRF.14 In the current study, a decrease in K:A ratio was also found immediately after training, but these findings differed from Munro and Herrington14 in that the subjects in the present study displayed a nearly 30% decrease in peak vGRF after a single session. However, the present study’s findings do become more tempered as baseline vGRF were only 14.22% higher compared to the transfer task. One reason for these differences may be related to the type of feedback that was utilized for the training session. Both studies used feedback strategies that emphasized key kinematic risk factors with expert feedback for performance improvements; both also utilized self-directed assessments of landing mechanics. However, in the current study, implicit feedback that focused on the performance outcome also incorporated using vGRF and vGRF symmetry. As the participants demonstrated an understanding and mastery of targeted biomechanical variables, verbal cuing by the expert evaluator was withdrawn and the reliance on self-correction using external feedback increased. Studies have suggested that using external cues for skill acquisition may accelerate the learning process by facilitating movement automaticity and enhance the production of effective and efficient movement patterns.33–36 It has also been postulated that a new skill acquired using an external focus of attention is more resilient under psychological and physiological fatigue.33,37–41 Biomechanically, greater knee flexion angles and lower peak ground reaction forces have been reported when landing instructions invoke an external focus of attention.31,42,45 Therefore, in the present study, the utilization of the externally focused performance variables projected on the screen during the landing training may have resulted in reduced vGRFs during landing with feedback withdrawal and during the transfer task.

Previous research has reported that changes in landing mechanics achieved through augmented feedback may be transferrable to a new task. Stroube et al.44 reported that high risk landing mechanics that were identified during a tuck jump with subsequent feedback and training provided over 8 weeks resulted in 37-40% reductions in knee valgus angles during a drop landing. They did not measure ground reaction force nor force symmetry directly but did report changes to “excessive landing noise” and “foot contact timing not equal”. Etnoyer et al.10 showed that participants that received augmented feedback during a box drop-jump task were able to maintain greater peak knee flexion angles during a running stop-jump task compared to controls during a single training session; however, no kinematic differences were reported during a sidestep cutting maneuver. In the current study, reductions in both K:A ratio and vGRF values were found during performance of a transfer task of catching a ball during landing compared to baseline. Compared to baseline, the athletes in the present study demonstrated a 5.75% decrease in K:A ratio during the transfer task. Similarly, the vGRF changes were maintained throughout the transfer task with a 14.22% decrease in force attenuation after training compared to baseline. These findings are important as a transfer task may be more representative of an athletic activity in which the focus of attention is on multiple environmental cues often occurring simultaneously. Instructional sessions that rely solely on internally focused feedback may interfere with an athlete’s ability to apply the newly acquired movement strategies to a less controlled or unstructured task. It has been suggested that incorporating unknown patterns of movement to a training program may enhance the athlete’s motivation during training and stimulate the premotor cortex to find more optimal solutions to unanticipated events during per-
performance. Although the results of the transfer task activity show promise, it is speculative to apply these findings to actual athletic competition. Because only a single session of training was provided, the maintenance of any change in performance or how multiple sessions of training can further influence skill learning are currently unknown. Future studies should focus on longer term retention of the biomechanical changes and how landing performance changes during more complex movement patterns that more closely mimic athletic activities.

The feedback training system utilized in this study overcomes many of the barriers associated with conventional laboratory-based equipment, as it is relatively easy to use, inexpensive to develop, and portable. This contributed to the ability to assess/train a large number of athletes in the field. There have been preliminary attempts to explore the potential utility of lower cost gaming systems (e.g. Wii Balance Board or Microsoft Kinect) for movement assessment and feedback training. These systems overcome the barriers associated with laboratory-based equipment; however, they have technical limitations (e.g. low sampling rates, limited sensor range) that restrict their accuracy for dynamic tasks such as landing. The researchers believe that there is a need to continue to develop/utilize systems such as this which are conducive to testing/training in the field, but also overcome the technical limitations of other systems.

Findings from this investigation appear to indicate that a portable force plate interfaced with a digital camera provide promise to promoting biomechanical changes that may reduce an athlete's relative risk for ACL injury. Several researchers have reported that greater vertical ground reaction forces at impact and increased knee valgus predispose female athletes to non-contact ACL injuries. Greater impact forces have been associated with anterior tibial accelerations. In vitro and modeling studies have reported greater ACL strain and tibial shear with landing patterns that lack adequate knee flexion to absorb impact forces. Increased knee valgus angle during landing has been associated with increased risk for ACL injury in females. These kinetic and kinematic findings have led to the development of neuromuscular programs aimed at mitigating these risk factors. However, most preventative programs do not utilize visual feedback training. The effect of combining of this type of feedback system into a more traditional neuromuscular training program offers promise and appears to warrant further investigation. It is plausible that the use of an augmented feedback system may provide a more effective avenue for neuromuscular training that incorporates the principles of motor learning in skill development.

The present study has limitations. Although the use of a drop landing is widely used in research studies to evaluate kinematics and kinetics that may be related to knee injury, the task may lack external validity. Similarly, the transfer task utilized in this study of a random "catch" or "no catch" may not provide a close enough parallel to the multiple simultaneous environmental cues and motor planning required for sports. Lastly, this study was conducted over a single testing session therefore the long-term retention effects of these performance changes is unknown.

CONCLUSIONS

The results of this study indicate that using a portable clinical feedback system may be an effective tool in reducing peak vGRFs and knee abduction angles during a drop landing and transfer task in adolescent females. Future studies should focus on the retention effects of using augmented feedback systems on performance modifications.

CONFLICTS OF INTEREST

Authors present no conflict of interest associated with this work.

Submitted: January 20, 2020 CST, Accepted: July 24, 2020 CST
REFERENCES


Post-Trial Feedback Alters Landing Performance in Adolescent Female Athletes Using a Portable Feedback System


Background
Anterior Cruciate Ligament (ACL) injury prevention interventions have used trained experts to ensure quality feedback. Dyad (peer) feedback may be a more cost-effective method to deliver feedback to athletes.

Purpose
To determine the immediate effects of dyad versus expert feedback on drop landing kinematics and kinetics in female athletes.

Study Design
Cohort study

Setting
College gymnasium

Methods
Two teams (one female basketball and one female volleyball), from a local college, were team randomized to dyad feedback (volleyball team) or expert feedback (basketball team) (13 expert, 19±0.87 years, 1.7±0.09 m, 68.04±7.21 kg) (10 dyad 19.4±1.07 years, 1.73±0.08 m, 72.18±11.23 kg). Participants completed drop vertical jumps at two different time points (pre- and post-feedback). Knee flexion and abduction displacement were assessed with Inertial Measurement Units (IMUs) and vertical ground reaction force (vGRF) was assessed with a force plate during the landing phase of the drop vertical jump and compared across groups and condition (pre- and post-feedback) with a repeated measures ANCOVA a priori α <0.02 was set for multiple tests conducted.

Results
There were no significant differences between groups for flexion displacement. There was a significant change pre- to post- (decrease 4.65° p=0.01) in abduction displacement, with no group effect. There was a significant interaction of group by condition (p=0.01) for vGRF with no difference between groups before feedback (p>0.05). Between groups there was a decrease of vGRF in the expert group (difference 0.45 N*bw-1, p=0.01) at post-feedback relative to dyad. Within the expert group there was a significant difference between pre- and post-feedback (difference 0.72 N*bw-1, p=0.01), while the dyad group did not change pre- to post-feedback (difference 0.18 N*bw-1, p=0.67).

Conclusion
Movement screening experts giving real-time feedback were successful in improving key
injury-risk kinematics and kinetics in female athletes, while dyad feedback only improved
kinematics, indicating that expert feedback may be needed to ensure changes in
kinematics and kinetics.

Level of Evidence

INTRODUCTION

Anterior cruciate ligament (ACL) rupture is a common ac-

tivity-related knee injury that usually requires surgical re-

construction to restore knee stability and function. The life-
time burden of ACL injury costs the US over seven billion
dollars.1–3 The typical mechanism of an ACL injury involves
a non-contact mechanism resulting from an error in motor
control leading to excessive knee valgus, and increased
ground reaction forces.4–8 Females are a unique group at an
exceptionally high risk of sustaining an ACL injury.8 Ado-
lescent females who participate in sports that involve piv-

ing and jumping often sustain ACL injuries at 4–6 times
higher rate than their male counter parts in the same
sports.8–11 The cause of this higher incidence of ACL injury
in females is due to several contributing factors such as
anatomical, including greater Q angle, narrower femoral
notch and increased laxity,8,12 hormonal changes in liga-

ment laxity8 and biomechanical in terms of neuromuscular
control differences. The long-term outcomes of ACL injury
are poor with high recurrence rates and osteoarthritis.2
While recent debate is ongoing regarding the nature of spe-
cific mechanics relation to injury risk, interventions tar-

geting these risk factors do improve neuromuscular control
and reduce injury risk.13–15 Thus, prevention is a priority
especially in the higher risk female athlete and while ACL
injury prevention programs are effective, compliance and
widespread adoption are low as typically expert trainers

or clinicians are needed to implement the program, espe-

cially when incorporating movement coordination feed-

back.1,16–20

Feedback is widely used to correct biomechanics that
might be injurious during specific movements. Augmented
feedback, for example, has been shown to change jump-
landing biomechanics.21–23 A recent systematic review
concluded that a combination of expert feedback and self-

analysis modes have the greatest impact to reduce ground
reaction forces during a jump-landing task.21 Nonetheless,
the ideal mode or combination of feedback modes to reduce
ACL injury rates has not yet been established. Real-time
feedback is a tool that enables participants to track their
actions and make biomechanical changes instantly. Several
studies have shown positive results in altering lower ex-

tremity biomechanics during gait using real-time feed-

back.24–26 Real-time feedback can be given in different
manner. Recently, external focus of attention feedback
consisting of the clinician giving feedback to the athletes on

errors they make while using an expert focus of attention
such as sitting back further in a chair instead of stating to
increase knee flexion has shown promise to be superior over
the typical internal focus of attention feedback.1,27,28 While
expert feedback is the gold standard, it requires trained per-

sonnel, whereas a paradigm based on a dyad model of feed-

back may have more widespread application. Dyad training

consists of a partner or teammate who corrects a participant
on their task using a selected list of external feedback cues.1

Dynamic landing tasks are widely used to assess abnormal
lower extremity biomechanics, yet there is limited research
on the effects of real-time feedback, particularly expert and
dyad feedback on this kind of movement.29

Dyad training has a unique advantage in addition to min-

imizing the need for expert personnel and reducing clinici-

an burden, the use of a teammate or peer could increase
program efficacy and compliance. Working with a peer al-
\n
ows for constant feedback, as athletes are not waiting on a
single expert and provides a team-oriented atmosphere
that may increase accountability. However, the lack of ex-

pert training of the dyad partner may limit effectiveness.

If dyads feedback can improve injury risk mechanics to the
same degree as experts this may bolster implementation
and compliance of injury prevention programs. Thus, the
purpose of this study was to determine the immediate ef-

fects of dyad versus expert feedback on drop landing kine-

matics and kinetics in female athletes. The primary hypo-

thesis is the dyad group would have significantly better land-

ing kinematics and kinetics compared to the expert feed-

back group.

METHODS

PARTICIPANTS

This cohort study enrolled 23 female athletes between the

ages of 18-25 (19.30 ± 0.93 years, 1.71 ± 0.09 m, 68.44±9.82
kg; 13 basketball, 10 volleyball) that had completed the in-

formed consent and initial questionnaires to meet inclusion
criteria. All participants were given the informed consent
and had the opportunity to ask questions before they were
enrolled in the study. It was made clear to potential partici-
pants that they were free to opt out of the study at any time.
Two teams (one female basketball and one female volley-
ball), from a local college, were team randomized to either
dyad feedback (volleyball team) or expert feedback (bas-
ketball team) training conditions (13 expert, 19±0.87years,
1.73±0.08m, 72.18±11.23kg). Team randomization as dyad
feedback (volleyball team) or expert feedback (bas-
ketball team) training conditions (15 expert, 19±0.87years,
1.74±0.09 m, 68.04±7.21kg) (10 dyad 19±1.07years,
1.75±0.08m, 72.18±11.23kg). Team randomization as dyad
feedback is commonly used with a teammate thus, ensuring
v olleyball athletes provided feedback to volleyball players
and avoid cross contamination. Participants were given the
Tegner Activity Scale and Marx survey to ensure they were
at competitive athlete activity levels. Individuals were only
included in the study if they indicated Tegner Activity score
of ≥ seven (study cohort average: 8.1±0.5) and indicated
time four a week for all Marx sub-scales (running, cutting,
decelerating, and pivoting). In addition, participants were
given the International Knee Documentation Committee to
ensure no subjective deficits were present. Individuals were
only included in the study if they scored ≥ 80 (study cohort

International Journal of Sports Physical Therapy
average: 97.0±5.4).

Previous medical history and demographic information were documented. Any athlete with a previous history of knee ligament or lower extremity injury in the previous two months that limited activity for more than one day was excluded. In addition, any female athlete that self-reported a current history of lower extremity instability (episodes of ‘giving way’), balance problems not remedied (feelings of instability), any illness that would negatively affect performance or safety during drop landing, or had undergone any previous lower extremity surgery within the previous two years was excluded, as well as athletes who had previously participated in formal training in jump landing before participation in this study. No one was excluded based on any of the previously mentioned criteria.

PROCEDURES

TESTING DAY ONE:

INITIAL BASELINE

After participants enrolled and met the aforementioned inclusion and exclusion criteria they completed a DVJ pre-test as described by Hewett.\textsuperscript{30} Participants completed three trials of landing off of a box that was 30.38 cm in height and 38.1 cm in width. Participants dropped off the box, landing just in front of it, and immediately performed a maximum vertical jump. These drop jump tasks were recorded using Noraxon\textsuperscript{®} Inertial Measurement Units (IMU, 100 Hz) (Noraxon Inc., Scottsdale, AZ, USA) system to record ankle, knee and hip joint angles placed on the foot, tibia, femur, and pelvis to provide 3D kinematics of the ankle, knee and hip. Per manufacturer instructions, shank and thigh sensors were placed laterally, halfway between the distal and proximal ends of the segment, and with the x-axis aligned to point superiorly along the long-axis of the bone.\textsuperscript{31} The pelvis IMU was placed posteriorly over the sacrum with the x-axis pointed towards the head. IMUs for the foot segments were placed on top of the feet over the midfoot region.\textsuperscript{31} The x-axis of each foot segment sensor pointed toward the toes. A subject-specific neutral-posture calibration was conducted prior to completing trials following manufacturer guidelines.\textsuperscript{31} Native algorithms integrated the calibration and sensor data to report three-dimensional segment orientations and accelerations and joint angles (myoMOTION Software 3.14.52; Noraxon Inc., Scottsdale, AZ, USA).\textsuperscript{31} The placement of the IMU units was done by an experienced researcher with over 15 years of clinical experience and nine years of biomechanics research (D.G.). A portable Bertec® force platform (FP4060-05-PT, Bertec Inc., Columbus, OH, USA) was used to collect ground reaction forces (GRFs: 100 Hz using Acquire Software 4.0). Figure 1 includes the set up for the IMUs and force platform.

TESTING DAY TWO

PRE TEST–DOUBLE BASELINE

One week following initial pre-testing all participants were again asked to perform an IMU instrumented DVJ. This secondary assessment served as a double baseline and as a control for both intervention groups (i.e. participants served as their own control). It has been found that subjects will reliably land the same way at the same institution, even when with significant time between the assessments.\textsuperscript{32} An initial baseline and pre-test measure (double baseline) has been utilized in previous intervention studies.\textsuperscript{33–37} This study design is typically used when the dependent variables are relatively stable over time as the case for this study, as the kinetic and kinematic parameters have all been shown to be reliable within each site, across sites, and across examiners.\textsuperscript{32,38} The use of a double baseline design in collegiate athletes is particularly advantageous, as no team or athlete has to be the control group and receive no feedback.

IMMEDIATE FEEDBACK

Directly following the second baseline (pre-test), Expert or Dyad feedback occurred. As previously mentioned, the entirety of two teams from one institution was randomly assigned to either dyad feedback or expert feedback. Dyad training consisted of a partner or teammate who corrected their partner on a squat jump landing task by using a checklist so the feedback would be correct with regards to technique (Appendix A). Expert external feedback consisted of the expert trained clinician (the lead author, after >20 hours of movement screening training) who gave feedback to the athlete on errors they made while using an external focus of attention (Appendix B). The external focus of attention feedback provided was based on previous literature.\textsuperscript{1,39} In the expert group, participants were given feedback one on one by an certified athletic trainer and in the dyad group, participants completed the study in individual pairs. Prior to dyad training each participant was provided with the feedback checklist and underwent a short five-minute tutorial of what to look for by the certified athletic trainer. This was done to simulate how a clinician may do an initial session with a team or coach but then the team or individuals implement the program.

All groups completed five trials of a squat jump landing during their assigned feedback method. The squat jump was elected elected during the feedback, because it is a common exercise during injury prevention programs,\textsuperscript{40} allows feedback to be provided, requires no equipment to administer,
and is a bilateral landing task similar to the DVJ, but different sufficiently to limit participants simply becoming better at the DVJ with no transfer. Five trials were chosen to represent the minimal dose for potential efficacy, ensure compliance, and to be clinically translatable. Immediately following the feedback, a post-test of the IMU instrumented DVJ was conducted with the same procedure as the pre-test and baseline.

STATISTICAL ANALYSIS

The dependent variables were knee flexion displacement, knee abduction displacement, and peak vGRF. Data were only collected during the three DVJ trials and averaged and used for analyses. Three repeated measures ANCOVAs (RM ANCOVA) were conducted. Each RM ANCOVA had the same within subjects factor time (pre and post) and the same between subject factor group (expert and dyad) with the covariate initial baseline. The first RM ANCOVA was conducted for the dependent variable knee flexion displacement (initial contact to maximum knee flexion) with the covariate baseline knee flexion displacement. The second RM ANCOVA was conducted for the dependent variable knee abduction displacement (initial contact to maximum knee abduction) with the covariate baseline knee abduction displacement. The last RM ANCOVA was conducted for the dependent variable vGRF with the covariate baseline vGRF. If the individual RM ANCOVA was significant follow up pairwise comparisons were conducted. Additionally, \( \eta^2 \) was calculated for each ANOVA as a measure of the proportion of the total variance in a dependent variable that is associated with the two groups. \( \eta^2 \) was interpreted as 0.01 = small, 0.06 = medium, and greater than 0.14 as large. Lastly, individual changes in knee kinematics and kinetics were compared to previously established minimal detectable change (MDC) values. MDC values of 3° for knee kinematics and 0.02 N·bw\(^{-1}\) for vGRF were used. Based on the frequency of whether an individual met the MDC, frequencies were calculated for each group (yes [met MDC] and no [did not meet MDC]) and a Chi-square test was conducted to evaluate group differences. Alpha level was set at \( \alpha < 0.02 \) for all analyses to adjust for multiple tests using the Bonferroni correction method. All analyses were conducted in IBM SPSS Statistics for Windows, version 25 (IBM Corp., Armonk, N.Y., USA).

RESULTS

KINEMATICS

For the dependent variable knee abduction displacement the RM ANCOVA revealed there was a significant difference for time (\( F_{(1,20)} = 10.14, p=0.01, 1-\beta = 0.77, \eta^2 = 0.44 \) [large]), but no significant difference for group (\( F_{(1,20)} = 0.29, p=0.59, 1-\beta = 0.80, \eta^2 = 0.02 \)), or time by group (\( F_{(1,20)} = 0.17, p=0.68, 1-\beta = 0.07, \eta^2 = 0.01 \)). Following immediate feedback, the mean difference was (\(-4.65^\circ, p=0.01\)), indicating that following feedback there was a 4.65° decrease in knee abduction displacement regardless of group. For the dependent variable knee flexion displacement, the RM ANCOVA revealed there was no significance for time (\( F_{(1,20)} = 0.03, p=0.87, 1-\beta = 0.05, \eta^2 = 0.01 \)), group (\( F_{(1,20)} = 0.03, p=0.87, 1-\beta = 0.05, \eta^2 = 0.01 \)), or time by group (\( F_{(1,20)} = 1.54, p=0.23, 1-\beta = 0.22, \eta^2 = 0.08 \)). It is important to note that at the pre-test there was no difference between groups for any dependent variable (p>0.05) and the values reported for our dependent variables are similar to previously published work. Descriptive statistics are shown in Table 1. Based on the MDC values for knee flexion displacement, 84.6% (n=11) of the individuals in the expert group and 30% (n=3) of the individuals in the dyad group exceeded the MDC and was statistically significant between groups (\( X^2(1) = 7.07, p=0.008 \)). For knee abduction displacement, 76.9% (n=10) of the individuals in the expert group and 70% (n=7) of the individuals in the dyad group exceeded the MDC, which was not statistically different between groups (p>0.05).

For the dependent variable vGRF the RM ANCOVA revealed a significant difference by time (\( F_{(1,20)} = 5.66, p=0.03, 1-\beta = 0.64, \eta^2 = 0.21 \) [large]), a significant difference by group (\( F_{(1,20)} = 7.19, p=0.01, 1-\beta = 0.72, \eta^2 = 0.27 \) [large]), and significant time by group difference (\( F_{(1,20)} = 6.48, p=0.01, 1-\beta = 0.68, \eta^2 = 0.25 \) [large]). For vGRF, there was a significant interaction of group by condition (p=0.01) effect with no difference between groups before feedback (p>0.05). Be-

<table>
<thead>
<tr>
<th>Table 1. Descriptive Statistics for the Dependent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>Knee Flexion Displacement</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Knee Abduction Displacement</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>vGRF (N·bw(^{-1}))</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

N = Netwons, bw = bodyweight
*Significant difference from pre for condition (p<0.02)
†Significant difference (p<0.02) between groups at respective condition

International Journal of Sports Physical Therapy
tween groups there was a decrease of vGRF in the expert group (difference 0.45 N*bw-1, p=0.01) at post feedback relative to dyad. Within the expert group there was a significant difference between pre- and post-feedback (difference 0.72 N*bw-1, p=0.01), while the dyad group did not significantly change from pre- to post-feedback (difference 0.18 N*bw-1, p=0.67). Overall, the expert decreased vGRF from pre to post compared to the dyad group. It is important to note the values reported for our dependent variables are similar to previously published work.\textsuperscript{45,49} Descriptive statistics are shown in Table 1. For vGRF, 84.6% (n=11) of the individuals in the expert group and 20% (n=2) of the individuals in the dyad group exceeded the MDC, which was statistically different between groups ($X^2$ (1)\textsuperscript{1}=9.61, p=0.002).

**DISCUSSION**

The primary finding was that the expert group decreased vGRF from pre to post compared to the dyad group. Additionally, the kinematic data revealed a significant difference with abduction displacement decreasing in both groups post, but no significant group effect. However, when investigating the MDCs, a larger percentage of individuals in the expert group exceeded the MDCs for knee flexion displacement compared to the dyad group. The MDC analysis for the other variables supported the inferential statistical analyses; a large percentage in both the expert and dyad group exceeded the MDC for knee abduction displacement and a larger percentage of individuals in the expert group exceeded the MDC for vGRF compared to the dyad group. The expert group improved kinetics relative to the dyad group, not supporting previous reports that dyad training could lead to effects similar to or exceed expert training.\textsuperscript{1} Kinematic changes were supportive of feedback offered in both groups, as abduction displacement improved at post regardless of group, indicating dyad was at least as good as expert for kinematic adaptations. However, for knee flexion displacement the MDC analysis supports the need for use of an expert to create change.

Prior reports of dyad success have been attributed to combining partner observation and execution of motor skills, and have been shown to be more effective together than either component alone.\textsuperscript{1,50,51} In addition, dyad training adds social and competitive aspects to training that can increase motivation.\textsuperscript{52} While the results of the current investigation did not support the primary hypothesis that the dyad group would be superior to the expert group, dyad feedback was able to induce beneficial kinematic adaptations to the expert level feedback indicating a potential alternative to experts for injury prevention training feedback for knee abduction displacement. However, for kinetic and kinematic adaptations and in alignment with prior literature, the use of expert feedback is preferred to decrease jump landing impact forces for immediate effectiveness.\textsuperscript{2,4,20,53}

For vGRF, there was a significant difference between groups with the expert group decreasing vGRF at post while the dyad group did not change. This was also supported by the MDC analysis. A previously reported positive moderate association between increased vGRF and increased anterior tibial acceleration while landing from a jump supports the hypothesis that individuals who land with greater impact loads might have an increased risk of ACL injury suggesting the need for external feedback to alter landing mechanics.\textsuperscript{54} Previously, decreased vGRF was recorded during jump landing after simple instructions to "land softly."\textsuperscript{55} For the dyad group the individual providing feedback would have had to notice their partner landing stiffly to provide such feedback. It is likely that noticing more subtle landing stiffness that contributes to high vGRF requires further training as experts were able to identify individuals landing with high impact forces and provided feedback to "land softly". The findings of the current investigation agree with a systematic review\textsuperscript{21} which, reported when expert feedback is provided a decrease in vGRF is seen. More recently, Beauleau and Palmieri-Smith\textsuperscript{59} reported a decrease in vGRF following an intervention of real-time feedback in which participants were instructed to minimize their knee abduction moment as shown on a real-time graph. Additionally, McNair et al\textsuperscript{56} used expert feedback to successfully decrease vGRF in an immediate follow-up test, aligning with the current study results regarding outcomes in the expert group. The failure of the dyad group to improve vGRF is possibly due to the emphasis of the feedback to be on keeping knees aligned at neutral and the more novice dyad partners not attending to other cues to identify and thus avoid hard or loud landings.

Knee flexion displacement did not change with either method of feedback at post testing based on the ANOVA analysis. However, when investigating the MDCs a larger percentage of the individuals in the expert group exceeded the MDC for knee flexion displacement compared to the dyad group. The results in this study are partially supported by Onate et al.\textsuperscript{22} who used video feedback and found increases in knee flexion immediately after an intervention. Other investigations such as Etnoyer, et al.\textsuperscript{57} employed expert feedback only and found knee flexion improvements at post testing. It is possible the current study was underpowered to detect statistically significant differences, but the MDC analysis is not impacted by sample size and thus support the use of expert feedback to alter knee flexion displacement. However, both groups were successful to reduce knee abduction displacement. This is consistent with previous literature, when Myer, et al.\textsuperscript{58} used a tuck jump and augmented external feedback they found that frontal plane knee angle (FPPK) decreased by an average of 37.9% over the three trials. In contrast, Etnoyer, et al\textsuperscript{57} found that using a combination of expert feedback and self-feedback did not change knee abduction.

Multiple sessions of feedback are likely needed to realize the full benefits of either expert or dyad approaches.\textsuperscript{59} Alternatively, providing immediate feedback based on an inertial-based sensor system as opposed to visual observation, may allow the more precise targeting of multiple variables including knee flexion, abduction and trunk lean after a one time intervention.\textsuperscript{60} It also has been noted that combination of feedback modalities may be most effective at improving jump landing biomechanics.\textsuperscript{21,57} A combination of videotape feedback and real-time feedback may produce the most effective results in altering jump landing biomechanics and reducing ACL injury risk.
This study had several limitations. It used a small sample size and may have been underpowered to detect statistical differences in knee flexion displacement that the MDC analysis identified. However, this study adds to the limited literature on dyad vs expert feedback to alter kinematics and kinetics in the field. The first landing of the DVJ was only analyzed and while analysis of the second landing may also be useful, it was not feasible in this study. Female basketball and volleyball athletes were only used as participants; thus, the results are not generalizable to all female athletes or male athletes. However, females were selected due to their higher risk factors and risk for ACL injury. Team randomization was used specifically for the dyad feedback and there is the possibility that basketball and volleyball players could respond differently to the different feedback delivery methods. Additionally, because the intervention (squat jumps) was different from our tested task (DVJ) this may explain some of results found in this study. However, the squat jump intervention was selected as it is much easier to implement, requiring no equipment and may better simulate sport demands than the DVJ. The DVJ was selected as the test task for its easy standardization (set drop height) and validity to predict injury risk. It is also possible that the dyad feedback could have seen better results with a repeated intervention (more than five trials) as participants learn the movement errors. In the future, studies could be done with a repeated intervention and additional resources, such as increased error training and perhaps video feedback for the dyad intervention group. Additionally, future studies should investigate the second landing of the DVJ to evaluate different landing mechanics between the first and second landing. Lastly, it is possible the dyad group could engage in more extensive training to be able to more easily recognize errors and perhaps improve their results would to be more like that of the expert group.

CONCLUSION

The results of this study indicate that movement screening experts giving real-time feedback were successful in improving key injury-risk kinematics and kinetics in female athletes, while dyad feedback only improved kinematics. Based on these results there may be a need for movement screening experts (athletic trainers, physical or physio therapists, strength and conditioning professionals etc.) to give feedback in ACL prevention programs to address multiple movement variables. However, dyad feedback, with even minimal training may be effective in order to improve knee abduction displacement, a key kinematic variable that reduces injury risk. Thus, if a movement expert or clinician is not available, improving knee abduction displacement (a key variable in reducing injury risk) is still possible with a dyad approach.

CONFLICTS OF INTEREST

The authors have no conflicts of interest.

Submitted: January 31, 2020 CST, Accepted: July 21, 2020 CST
REFERENCES


SUPPLEMENTARY MATERIALS

Appendix A

Appendix B
Original Research

Differences in Lower Extremity Kinematics Between High School Cross-Country and Young Adult Recreational Runners

Mark F Reinking, PT, PhD, SCS, ATC, FAPTA1, Nina M Carson, PT, DPT1, Bridget M End, PT, DPT1, Olivia K Miller, PT, DPT1, Joshua D Munter, PT, DPT1, Thomas G McPoil, PT, PhD, FAPTA1

1 School of Physical Therapy, Regis University

Keywords: gait analysis, age differences, kinematics, running

10.26603/001c.18821

International Journal of Sports Physical Therapy
Vol. 16, Issue 1, 2021

Background
While previous research has assessed running kinematics for age-related differences that could increase the risk of a running-related injury, none of these studies have included high school aged runners or assessed running kinematics using 2-dimensional video analysis.

Purpose
The purpose of this study was to compare sagittal plane kinematics during treadmill running in high school cross-country and young adult recreational runners using 2-dimensional motion analysis techniques.

Methods
Twenty-five high school cross-country runners (13 women, 12 men) and 25 young adult recreational runners (12 women, 13 men) consented to participate in this study. Reflective markers were placed on each lower extremity over multiple anatomical landmarks. After a five-minute acclimation period in which the participants ran on a treadmill at their preferred running speed, video data were recorded at 240 frames per second for all participants while they continued to run on the treadmill.

Results
There were no significant differences between left and right extremities. The young adult recreational runners exhibited significantly greater vertical excursion of the center of mass ($t = 4.64$, $p = .0001$) compared to the high school runners. There was no significant difference between the two age groups regarding the six other sagittal plane variables.

Conclusions
The young adult recreational runners demonstrated an increased center-of-mass vertical excursion in comparison to high school cross-country runners. In addition, the results obtained in this study for kinematic variables using 2-dimensional motion analysis were similar to previously reported studies using 3-dimensional motion analysis, demonstrating that 2-dimensional motion analysis could be used for analyzing sagittal plane running kinematics in clinical settings.

Level of Evidence
4, Controlled laboratory study

BACKGROUND
Cross-country running continues to be a popular high school sport in the United States, with 493,613 participants during the 2017-2018 school year. This ranks cross-country as the fifth most popular sport behind football, track & field, basketball, and soccer. Previous studies have reported...
that 29% to 38.5% of these high school cross-country runners will sustain an injury annually, with many of these injuries resulting in a loss of 1 to 7 days of participation.\(^2\)\(^-\)\(^4\) The most common injury sites in high school cross-country runners are the leg (medial tibial stress syndrome, stress fractures, and compartment syndrome) and the knee (anterior knee pain).\(^2\)\(^-\)\(^3\)\(^,\)\(^5\) Most researchers agree that the etiology of running injuries is multifactorial with contributing factors including age, sex, history of previous injury, lower extremity bony alignment, running terrain, and running kinematics.\(^6\)\(^-\)\(^8\) While several intrinsic and extrinsic factors, including age, alignment, and history of previous injury cannot be altered, running kinematics can be modified based on a video analysis of running mechanics. Several running kinematic variables, including the foot inclination angle at initial contact, vertical displacement of the center of mass, and total knee flexion during stance phase have been related to higher peak vertical ground reaction forces, increased peak knee extensor moments, and reduced shock absorption, all of which can increase the stresses placed on the leg and knee during running.\(^7\) As previously noted, the leg and knee are common locations of running-related injuries in high school cross-country runners.

Based on this evidence, it would appear to be advisable that an assessment of running kinematics be incorporated into the care of high school cross-country runners, either as a component of a pre-season screen or as an injury management program during the season. Previous research has demonstrated that 2-dimensional analysis of kinematic sagittal plane motion using a single video camera with an adequate frame rate (greater than 100 frames per sec) is similar to kinematic values obtained with 3-dimensional analysis of sagittal plane motion during running.\(^9\)\(^-\)\(^11\) Wille et al. utilized 3-dimensional motion analysis in their study of 45 participants during treadmill running and suggested that 2-dimensional motion analysis would likely be sufficient to capture several kinematic variables during running including center of mass height at midstance and at double-float, the foot inclination angle at initial contact, and peak knee flexion angle.\(^10\) Wille et al. supported this suggestion based on the strong correlations between 2-dimensional and 3-dimensional motion analysis of sagittal plane motion during running.\(^10\) In a more recent study, Schurr et al. reported a high correlation between 2-dimensional and 3-dimensional motion analysis for sagittal plane lower extremity movement.\(^11\) The use of 2-dimensional motion analysis to assess sagittal plane kinematics enhances the ability of sports physical therapists to assess running kinematics in the clinic without the need for expensive equipment and complex analysis software that are required to perform 3-dimensional video-based running gait analyses. However, there is a paucity of published normative kinematic data for high school cross-country runners.

Several researchers have evaluated the effect of aging on running kinematics during both overground and treadmill running.\(^12\)\(^-\)\(^17\) However, the range of runners’ ages included in these studies was between 20 and 68 years of age. Devita and colleagues compared overground running kinematics and kinetics among four age groups: 20 to 29 years, 30 to 39 years, 40 to 49 years, and 50 to 60 years.\(^14\) The only sagittal plane kinematic variable assessed in their study was the maximum knee flexion angle that occurred during stance phase while running.\(^14\) While the mean maximum knee flexion angle for all groups combined was 39.6°, the mean value for the 20 to 29 year old group (40.6°) was significantly greater than the mean value for the 50 to 59 year old group (36.8°), indicating that maximum knee flexion during stance phase decreases with age. While Devita et al. reported that 110 runners participated in their study, they did not indicate the number of runners in each of the four age groups. When assessing overground running mechanics in two groups of 15 runners with mean ages of 21.2 years and 54.6 years, Silvernail and colleagues reported similar findings in that both maximum knee flexion during stance phase and total knee flexion (the difference between knee flexion at initial contact and maximum knee flexion during stance phase) were decreased in the older group of runners.\(^16\) In a more recent study, Boyer and colleagues reported that when running at matched speeds, the impact of aging on running mechanics is subtle for both men and women.\(^13\) However, these authors found that mature male runners have greater knee flexion in comparison to a group of younger male runners.\(^13\) In an assessment of 18 females (mean age 23.7 years) and 14 males (mean age 25.0 years) during treadmill running, Almonroeder and Benson found no significant difference in the maximum knee flexion angle during stance phase between male and female runners,\(^12\) supporting the conclusion offered by Boyer and colleagues.\(^13\) These findings indicate that there are minimal differences in sagittal plane running mechanics between male and female runners.

Based on the outcomes of these studies, there are mixed results regarding the effect of aging on maximum knee flexion during the stance phase of running. Unfortunately, previous studies have not evaluated the effect of aging on other commonly described sagittal plane kinematic variables other than those that are focused on the knee during running.\(^17\) In addition, none of these studies have included high school aged runners. After an extensive review of the literature, to the best of the authors’ knowledge, no study to date has assessed the differences in sagittal plane running kinematics between high school cross-country runners and an older group of runners using 2-dimensional motion analysis. A comparison of 2-dimensional sagittal plane kinematic data between high school runners and an older group of runners would inform clinicians of similarities and differences in running kinematics between these groups. These data could also be used to assess high school cross-country runners who are returning to activity following injury, as well as to better understand differences in running kinematics associated with aging. Thus, the purpose of this study was to compare sagittal plane kinematics during treadmill running in high school cross-country and young adult recreational runners using 2-dimensional motion analysis techniques. Based on the findings from previous studies that have assessed the effect of aging on running kinematics, we hypothesized that maximum knee flexion during stance phase and total knee flexion would be greater in the high school cross-country runners in comparison to the adult recreational runners. For this study, the definition for total knee flexion described by Silvernail et al. was utilized with total knee flexion representing the difference be-
between knee flexion at initial contact and maximum knee flexion during stance phase.\textsuperscript{16}

**METHODS**

**PARTICIPANT CHARACTERISTICS**

Twenty-five high school cross-country runners (13 women, 12 men) and 25 young adult recreational runners (12 women, 13 men) voluntarily consented to participate in this study. The mean age of the 25 high school runners was 15.4 years, with a range of 14 to 17 years. The mean age of the 25 young adult recreational runners was 28.2 years, with a range of 24 to 39 years. A sample of convenience was utilized based on a 3-month period of subject recruitment and excluded those athletes who did not meet the inclusion criteria. Participants were recruited from running clubs and local area high schools through community advertisements and public information sessions. All participants selected for this study met the following inclusion criteria: (1) were between the ages of 14 and 40 years; (2) ran, on average, at least 18 miles per week for no less than one year prior to participation in the study; (3) had experience running on a treadmill; and (4) had no previous history of a lower extremity congenital or traumatic deformity or previous surgery that resulted in altered bony alignment. Any participant who had an acute injury three months prior to participation in the study that led to the inability to run for at least three consecutive days was excluded from participating in the study. The inclusion and exclusion criteria for this study were based on criteria used in several previous studies assessing running kinematics.\textsuperscript{10,12,14,18} The Regis University Institutional Review Board approved the study protocol, and all participants provided written informed consent. In addition, a separate parental consent was obtained for all participants under the age of 18 years prior to participating in the study.

**DATA ACQUISITION**

Upon arrival at the testing center, each participant’s height, weight, and blood pressure were recorded. Next, participants were asked to begin shod running on a treadmill (Model Mercury S, Woodway USA Inc., Waukesha, WI 53186) for at least 5 minutes in order to acclimate to the treadmill as well as to determine their preferred running speed for testing. Once the preferred running speed was selected and the participant indicated that they were acclimated to the treadmill, 9 mm spherical reflective markers were placed on each lower extremity over the following locations: anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), lateral epicondyle of the femur, lateral malleolus, lower posterior calf above the Achilles tendon (two markers), and midline of the heel (two markers). To minimize ASIS and PSIS marker movement, elastic self-adhesive wrapping was applied around each participant’s waist prior to marker placement. The reflective marker placements used in this study were previously evaluated by Reinking et al., who reported high levels of intra-rater and inter-rater reliability when using these marker placements while performing a 2-dimensional sagittal plane motion analysis during running.\textsuperscript{18}

Once all markers were in place, the participant was asked to start running on the treadmill at their pre-selected running speed. When the participant indicated that they were in their typical running pattern, they continued to run at their preferred speed for a minimum of five minutes. After running for four minutes at their preferred running speed, video data were recorded for the right and left sagittal plane (side view) for 60 sec. All running motion data were recorded using a single high-speed camera (Model\textsuperscript{\textregistered} EX FH25, Casio America Inc., Dover, NJ 07801) at 240 frames per second. The lens of the high-speed camera was positioned at a 90-degree angle and at a distance of 2 m from the center of the treadmill for all video recordings based on previous research that assessed 2-dimensional motion analysis during treadmill running.\textsuperscript{18}

**DATA ANALYSIS**

The left and right sagittal plane video clips for each runner were assessed by a single rater (TGM) who has over 12 years of experience performing 2-dimensional video-based running analyses on both collegiate and recreational runners. The rater selected a stride for analysis after the third foot strike on the video clip to observe the runner’s gait pattern and enhance the rater’s ability to identify initial foot contact. The following seven sagittal plane (side view) kinematic variables were assessed on both the left and right lower extremities for all runners: 1) angle of shoe to treadmill at initial contact (SHOE_Ang), 2) angle of leg to vertical at initial contact (LEG_Ang), 3) knee flexion at initial contact (KN_FL_IC), 4) maximum knee flexion at midstance (Max_KN_FL), 5) distance of the vertical line from the estimated center of mass (center of the line connecting ASIS and PSIS) to the posterior aspect of the shoe (COM_To_Shoe), 6) vertical position of the estimated center of mass at midstance, and 7) highest vertical position of the estimated center of mass during double float phase. KN_FL_IC was subtracted from Max_KN_FL to calculate total knee flexion (KN_FL_Tot). The vertical position of the estimated center of mass at double float was subtracted from the vertical position of the estimated center of mass at midstance to calculate the vertical excursion of the center of mass (COM_Vt_Ex). The seven kinematic variables selected for analysis in this study have been previously identified as important sagittal plane variables that should be included in an analysis of running mechanics.\textsuperscript{7} In addition, all seven kinematic variables have been shown to have high levels of within and between rater reliability for both inexperienced and experienced raters.\textsuperscript{18} All angles were measured in degrees and all distance measurements were recorded in centimeters using a free-access video analysis software program (Kinovea, version 0.8.15, \texttt{http://www.kinovea.org}). Puig-Divi et al. have reported that the Kinovea software is a valid and reliable tool to assess kinematics at distances up to 5 m from the object and at an angle of 90 degrees.\textsuperscript{19}

In a previously published study, the rater in this study (TGM) demonstrated intra-rater levels of reliability between 0.75 and 0.98 (ICC) and inter-rater reliability values between 0.76 and 0.97 (ICC) for all kinematic variables assessed in the current study in comparison to another rater with a similar level of experience.\textsuperscript{18} The rater was blinded to start running on the treadmill at their pre-selected running speed. When the participant indicated that they were in their typical running pattern, they continued to run at their preferred speed for a minimum of five minutes. After running for four minutes at their preferred running speed, video data were recorded for the right and left sagittal plane (side view) for 60 sec. All running motion data were recorded using a single high-speed camera (Model\textsuperscript{\textregistered} EX FH25, Casio America Inc., Dover, NJ 07801) at 240 frames per second. The lens of the high-speed camera was positioned at a 90-degree angle and at a distance of 2 m from the center of the treadmill for all video recordings based on previous research that assessed 2-dimensional motion analysis during treadmill running.\textsuperscript{18}

**DATA ANALYSIS**

The left and right sagittal plane video clips for each runner were assessed by a single rater (TGM) who has over 12 years of experience performing 2-dimensional video-based running analyses on both collegiate and recreational runners. The rater selected a stride for analysis after the third foot strike on the video clip to observe the runner’s gait pattern and enhance the rater’s ability to identify initial foot contact. The following seven sagittal plane (side view) kinematic variables were assessed on both the left and right lower extremities for all runners: 1) angle of shoe to treadmill at initial contact (SHOE_Ang), 2) angle of leg to vertical at initial contact (LEG_Ang), 3) knee flexion at initial contact (KN_FL_IC), 4) maximum knee flexion at midstance (Max_KN_FL), 5) distance of the vertical line from the estimated center of mass (center of the line connecting ASIS and PSIS) to the posterior aspect of the shoe (COM_To_Shoe), 6) vertical position of the estimated center of mass at midstance, and 7) highest vertical position of the estimated center of mass during double float phase. KN_FL_IC was subtracted from Max_KN_FL to calculate total knee flexion (KN_FL_Tot). The vertical position of the estimated center of mass at double float was subtracted from the vertical position of the estimated center of mass at midstance to calculate the vertical excursion of the center of mass (COM_Vt_Ex). The seven kinematic variables selected for analysis in this study have been previously identified as important sagittal plane variables that should be included in an analysis of running mechanics.\textsuperscript{7} In addition, all seven kinematic variables have been shown to have high levels of within and between rater reliability for both inexperienced and experienced raters.\textsuperscript{18} All angles were measured in degrees and all distance measurements were recorded in centimeters using a free-access video analysis software program (Kinovea, version 0.8.15, \texttt{http://www.kinovea.org}). Puig-Divi et al. have reported that the Kinovea software is a valid and reliable tool to assess kinematics at distances up to 5 m from the object and at an angle of 90 degrees.\textsuperscript{19}

In a previously published study, the rater in this study (TGM) demonstrated intra-rater levels of reliability between 0.75 and 0.98 (ICC) and inter-rater reliability values between 0.76 and 0.97 (ICC) for all kinematic variables assessed in the current study in comparison to another rater with a similar level of experience.\textsuperscript{18} The rater was blinded
Differences in Lower Extremity Kinematics Between High School Cross-Country and Young Adult Recreational Runners

Table 1: Participant Demographics

<table>
<thead>
<tr>
<th></th>
<th>High School Runners (n=25)</th>
<th>Young Adult Recreational Runners (n=25)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>15.4 ± 1.3</td>
<td>28.2 ± 4.1</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>168.7 ± 9.4</td>
<td>172.9 ± 9.7</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>55.3 ± 9.2</td>
<td>67.8 ± 10.3</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>19.4 ± 0.8</td>
<td>22.7 ± 2.4</td>
</tr>
<tr>
<td>Treadmill Running Speed (m/s)</td>
<td>3.0 ± 0.4</td>
<td>3.0 ± 0.3</td>
</tr>
</tbody>
</table>

Table 2: Running kinematic variables (mean ± standard deviation) for the high school cross country and young adult recreational runners.

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>High School Cross-Country Runners</th>
<th>Young Adult Recreational Runners</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left (n=25)</td>
<td>Right (n=25)</td>
</tr>
<tr>
<td>Angle of shoe at initial contact (SHOE_Ang) - in degrees</td>
<td>7.76 ± 10.72</td>
<td>7.08 ± 11.25</td>
</tr>
<tr>
<td>Angle of leg at initial contact (LEG_Ang) - in degrees</td>
<td>8.20 ± 2.35</td>
<td>6.80 ± 3.38</td>
</tr>
<tr>
<td>Distance of center of mass to posterior aspect of shoe (COM_To_Shoe) - in cm</td>
<td>16.44 ± 3.73</td>
<td>15.09 ± 3.30</td>
</tr>
<tr>
<td>Knee flexion at initial contact (KN_FL_IC) - in degrees</td>
<td>11.20 ± 3.99</td>
<td>10.24 ± 5.25</td>
</tr>
<tr>
<td>Maximum knee flexion during stance phase (Max_KN_FL) - in degrees</td>
<td>38.80 ± 4.53</td>
<td>39.32 ± 4.50</td>
</tr>
<tr>
<td>Total knee flexion (Kn_FL_Tot) - in degrees</td>
<td>27.60 ± 3.99</td>
<td>29.08 ± 6.01</td>
</tr>
<tr>
<td>Total vertical excursion of center of mass (COM_VtEx) - in cm</td>
<td>6.38 ± 1.54</td>
<td>6.51 ± 1.64</td>
</tr>
</tbody>
</table>

*p = .0001

Table 1: Participant Demographics

Table 2: Running kinematic variables (mean ± standard deviation) for the high school cross country and young adult recreational runners.

while performing the video analyses on all runners.

STATISTICAL ANALYSIS

In addition to descriptive statistics, t-tests were performed to determine if there were significant differences between left and right extremities and between the high school cross-country and young adult recreational runners for all seven kinematic variables. The seven variables included SHOE_Ang, LEG_Ang, KN_FL_IC, COM_To_Shoe, Max_KN_FL, KN_FL_Tot, and COM_Vt_Ex. All statistical analyses were performed using JMP software, Version 8 (SAS Institute Inc., Cary NC 27513). Because of the multiple number of t-tests performed, the Holm-Bonferroni method was used to determine an alpha level of 0.001 for all tests of significance.

RESULTS

Participant demographics are listed in Table 1, and descriptive statistics for all seven kinematic variables are listed in Table 2. The mean (standard deviation) running speed for the high school runners was 3.0 (± 0.4) m/s and was 3.0 (± 0.5) m/s for the adult recreational runners. There was no significant difference in the running speed between the two groups (t = 0.00; df = 48; p = 1.00). A forefoot or midfoot strike pattern was noted for seven of the high school runners and four of the young adult recreational runners, with all other runners using a rearfoot strike pattern. The results of the t-tests indicated that mean values between the left and right extremities for the 25 high school and 25 young adult recreational runners for all seven kinematic variables were not significantly different. Based on these results, data for the left and right extremities were grouped for the high school runners (n=50) and the young adult recreational runners (n=50) for all further analyses. The only significant result of the t-tests on the seven kinematic variables between the high school and young adult recreational runners was COM_Vt_Ex (t = 4.61; df = 98; p = .00001). The mean value for COM_Vt_Ex for the young adult recreational runners was 1.51 cm greater than the mean value for the high school runners. None of the other six kinematic variables were significantly different between the high school cross-country and young adult recreational runners.
DISCUSSION

Knowledge of sagittal plane kinematic variables during running, including foot inclination angle at initial contact, vertical displacement of the center of mass, and maximum knee flexion during stance phase can aid the clinician in understanding the magnitude of ground reaction forces. High ground reaction forces have been shown to contribute to increased stress on the leg and knee during running. This is important information for the sports physical therapist since epidemiological studies have shown that the leg and knee are common locations of running-related injuries in high school cross-country runners. In addition, running kinematic data for sagittal plane motion would provide the clinician with normative kinematic values to utilize when assessing high school cross-country runners who are returning to activity following a running-related injury or as part of a pre-season screening examination. In addition, assessing running kinematics for high school runners in comparison to an older group of runners would enhance the understanding of the effect of aging on running kinematics. Thus, the intent of this study was to compare sagittal plane kinematics during treadmill running in high school cross-country and young adult recreational runners using 2-dimensional motion analysis techniques.

Based on the findings of previous studies comparing different age groups of runners, the authors of this study hypothesized that Max_KN_FL and total knee flexion would be significantly greater in the high school cross-country runners in comparison to the young adult recreational runners. The t-test results on the seven sagittal plane running variables that were assessed in this study found that only COM_Vt_Ex was significantly different between the high school cross-country runners and the young adult recreational runners. The mean difference in the COM_Vt_Ex between the two groups of runners was 1.51 cm, with a mean value of 6.45 cm for the high school runners and 7.96 cm for the young adult recreational runners. Based on these findings, the authors rejected their initial hypothesis. The 1.51 cm difference in the COM_Vt_Ex reveals that the high school runners assessed in the current study were more efficient in attenuating ground reaction forces during treadmill running than the adult recreational runners.

As noted in the review of the literature, previous studies assessing differences in running mechanics secondary to aging have focused on the kinematic variables of maximum knee flexion during stance phase and total knee flexion. While not significantly different between the two groups of runners in the current study, the mean values for Max_KN_FL was 39.06° for the high school runners and 41.28° for the young adult recreational runners. These mean values are comparable to the values reported in previous studies that have studied the effect of aging on running mechanics. The mean value for Max_KN_FL reported by Silvernail et al. was 39.17° for younger runners (mean age 21.1 years) and 38.06° for an older group of runners (mean age 54.6 years). Devita et al. reported that Max_KN_FL was 42.1° for a group of runners between the ages of 20 and 29 years and 39.8° for runners between the ages of 30 and 39 years. Silvernail et al. also reported that the mean total knee flexion for younger runners was 28.40°. This value is comparable to the mean total knee flexion obtained in the current study for the high school cross-country runners (28.54°). The similarity of the mean values for Max_KN_FL between the current study and the findings reported by Silvernail et al. and Devita et al. is remarkable in light of the fact that both Silvernail et al. and Devita et al. used 3-dimensional motion analysis in their studies. This would suggest that the data obtained using 2-dimensional motion analysis techniques to assess angular values in the sagittal plane during running are similar to the values obtained using 3-dimensional motion analysis techniques. In the current study, 2-dimensional motion analysis using a single, low-cost, high-speed camera to record sagittal plane running motion was utilized, as well as a free-access video analysis software program, in order to enhance the clinical applicability of the findings. Further research is required, however, to determine if sagittal plane kinematic variables assessed using 2-dimensional and 3-dimensional motion analyses are comparable.

In the current study, the mean value for Max_KN_FL was greater for the young adult recreational runners in comparison to the younger high school cross-country runners. Findings of recent studies indicate that older runners had greater knee flexion as compared to a group of younger runners. The findings of the current study agree with those by Boyer et al. and Jin and Hahn and further support the need for additional research to assess the differences in knee range of motion between different age groups of runners. As described earlier, previous studies have not evaluated the effect of aging on commonly described sagittal plane kinematic variables except for those that are focused on the knee during running. Thus, further comparisons of other sagittal plane running kinematic variables assessed in this study cannot be made.

A limitation in the current study was the use of a treadmill to assess both kinetic and kinematic variables during running. Several studies have reported on the validity of using a treadmill for running analysis, with the major concern being the alteration of the runner's pattern of lower extremity movement as well as ground reaction forces. In one of the only studies to compare overground and treadmill running kinematics and kinetics using a force-transducer instrumented treadmill, Riley et al. reported that a treadmill-based analysis of running mechanics can be generalized to overground running mechanics, provided that the running speed on the treadmill is similar to the individual's overground running speed.

Another limitation is that only 25 runners were assessed in each of the groups in the current study. However, it is important to note that these participant numbers are comparable to the number of runners utilized in previous studies assessing the effect of aging on running mechanics. While the assessment of the video clips for each runner by a single rater could also be viewed as a limitation of the study, the rater used in this study had previously demonstrated high levels of intra-rater and inter-rater reliability for all kinematic variables assessed in the current study in comparison to another rater with a similar level of experience. Although this study provides the clinician with preliminary normative values of selected sagittal plane variables that can be used when performing a 2-dimensional treadmill
motion analysis of high school cross-country runners, further investigations are required to provide more robust sagittal plane kinematic normative values for the assessment of high school cross-country runners.

CONCLUSION

To the best of the authors' knowledge, this is one of the first studies to assess differences in sagittal plane kinematics between high school cross-country and young adult recreational runners during treadmill running. The results of the current study suggest that the high school runners assessed in the current study were slightly more efficient in attenuating ground reaction forces by decreasing the COM_Vt_Ex during treadmill running. Additionally, the results obtained in this study for Max_KN_FL and total knee flexion using 2-dimensional motion analysis are similar to values previously reported studies using 3-dimensional motion analysis. The use of 2-dimensional motion analysis as well as a free-access video analysis software program in the current study enhances the feasibility of the sports physical therapist to assess these variables in high school cross-country runners in a typical clinical setting. Further research is required to determine if sagittal plane kinematic variables assessed in the current study are comparable irrespective of whether 2-dimensional or 3-dimensional motion analysis techniques are used, as well as to provide more robust normative kinematic values for high school cross-country runners.

Submitted: January 23, 2020 CST, Accepted: October 10, 2020 CST

This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY-NC-ND-4.0). View this license's legal deed at https://creativecommons.org/licenses/by-nc-nd/4.0 and legal code at https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode for more information.

International Journal of Sports Physical Therapy
REFERENCES


Differences in Physical and Psychological Parameters in Sub-Elite, Male, Youth Soccer Players with Jumper’s Knee Following Physical Therapy Compared to Healthy Controls: A Longitudinal Examination

Marc Niering, MA1, Thomas Muehlbauer, PhD2
1Department of Health and Social Affairs, FHM Bielefeld - University of Applied Sciences, 2Division of Movement and Training Sciences/Biomechanics of Sport, University of Duisburg-Essen

Keywords: young athletes, physical fitness, performance testing, patellar tendinosis/tendinitis/tendinopathy, movement system, adolescence

Purpose/Background
Many adolescent athletes suffer from jumper’s knee (JK) over a long period of time and return to sports before symptoms are fully resolved. Current treatment methods may not reduce pain in the short term, especially not during a competitive season. The purpose of this study was to investigate differences in physical, psychological, and injury-/pain-related parameters in sub-elite male youth soccer players, who previously underwent physical therapy for JK compared to healthy controls (HC) over the course of a season.

Methods
All subjects were tested four times (start of the season [T1], 6 [T2], 16 [T3], and 20 [T4] weeks after the start of the season). Outcome measures included muscle power (drop jump, jump-and-reach), change of direction speed [CODS] (acyclic sprint), speed (tapping, 50-m linear sprint), endurance (Yo-Yo intermittent recovery test level 1), the Achievement Motives Scale (AMS) Sport, and injury-/pain-related data. Univariate analysis of variance was used to compare differences in variables between the two groups over the course of a soccer season.

Results
Over the season, the jumper’s knee group (JK; 15.1 ± 0.8 yr) demonstrated significantly worse physical performance in CODS (to the left side: 1.37 ≤ Cohen's d ≤ 1.51 [T1-T4]; p < 0.001 / to the right side: 1.24 ≤ d ≤ 1.53 [T1-T4]; p < 0.001) and speed (0.48 ≤ d ≤ 1.26 [T1-T4]; p < 0.007) compared to healthy controls (HC; 15.0 ± 1.0 yr). Further, psychological parameters showed worse values in JK than in HC for the AMS Sport items "hope for success" and "fear of failure" that especially showed a significant difference at T1 (d = 0.65; p = 0.032 / d = 0.68; p = 0.027) and T2 (d = 0.50; p = 0.076 / d = 0.80; p = 0.012). Moreover, the JK group showed significantly higher incident rates for non-contact lower limb injuries (d = 0.69; p = 0.049) per 1,000 hours (i.e., practices/competitions), injury-related rest periods (d = 2.06; p = 0.043), and pain-related training interruptions (d = 1.35; p < 0.001).

Conclusions
The observed findings imply that there are significant differences in physical and psychological performance of youth soccer players after physical therapy for JK compared to HC. When designing rehabilitation and/or training programs, as well as determining the point of return to sport the impact of the injury needs to be taken into account.

Corresponding author: Marc Niering, M.A. FHM Hannover - University of Applied Sciences Department of Health and Social Affairs Lister Straße 18 30165 Hannover, Germany Fon: +49-(0)511 533 5880 Fax: +49-(0)511 533 58828 Email: marc.niering@arcor.de
INTRODUCTION

Jumper’s knee (JK), also referred to as patellar tendinopathy, is a functional overload injury that can occur after a time of intense and repeated stress to the patellar or quadriceps tendon.\(^1\,^2\) Sports that involve a lot of jumping or abrupt stops can increase the risk for developing JK. Soccer, considered as an explosive start-stop sport, is considered one of the high-risk sports.\(^1\) Epidemiological data show incident rates of JK of 13% in elite youth soccer players.\(^3\) Male adolescents\(^4\) aged 15 years or older\(^1\) are commonly affected. Elite and sub-elite youth soccer players have to perform repetitive maximal, multidirectional movements over a long period of time with only little time to recover.\(^5\) Although youth players have lower intensity of exercise and overall training volume in comparison to adult players, they have not reached their maximum physical and psychological capacity. Yet, they are required to perform high-intensity exercises and pressured to maintain a high level of performance during a competitive season,\(^6\) which could ultimately lead to a higher risk of injury. The large amount of total training and competition can result in an increased risk of sustaining an injury of the lower-extremity,\(^7\) most commonly in form of overuse injuries like JK.\(^8,^9\) In addition Kucera et al.\(^10\) described a consistently decreasing rate of injuries with increasing soccer and league experience in youth soccer players, which also leads to the conclusion that younger athletes are more susceptible to injury than adults.

Injury downtime due to ongoing symptoms along with recurring pain, as well as decreased mental or physical performance, can affect the level of competitive success and thus may impede the progress of an athlete’s career.\(^11\) Given the prevalence and high risk of sustaining JK at the beginning of a young athlete’s career, it is important to gather sufficient scientific data on performance changes that this injury results in. Previous studies\(^12–20\) that examined differences in physical and psychological characteristics in athletes with JK compared to healthy controls (HC) revealed varying results. For example, a cross-sectional study by Lian et al.\(^13\) showed a significantly better performance in vertical jump height for adult male volleyball players with JK (\(n=12\), age: 23.6 ± 3.0 yr) in comparison with HC (\(n=12\), age: 24.8 ± 4.6 yr). Siegmund et al.\(^21\) reported no significant differences in jump height in adult male basketball players (\(n=12\), age: 18-29 yr) with JK compared to HC (\(n=12\), age: 18-29 yr). Lastly, Cook et al.\(^12\) could not find a significant difference in jump height or 10-m sprint in affected (\(n=53\), age: 14-18 yr) versus healthy (\(n=38\), age: 14-18 yr) adolescent non-professional male basketball players. However, it is important to note that none of these studies compared subjects after a completed therapy to HC. Therefore, the final impact of JK on a youth athlete in the matter of physical performances following therapy has not been adequately reported upon in the current literature. Besides differences in physical performances, there is also evidence for discrepancies in psychological variables between injured and non-injured athletes. According to Nippert et al.,\(^19\) increased levels of psychological stress, fear of injury or low self-esteem following injury can result in lower sport performance. In this regard, Zafra et al.\(^20\) compared psychological variables of injured tennis players with HC. They described a negative relationship between tendinitis and the influence of performance assessment as a psychological variable. Especially in players suffering from tendinitis, stress management during performance assessment was poor compared to HC.

In sum, the existing studies focus on varying attributes and do not look into the effects of JK on measures of physical and psychological performance in different dimensions of human performance, therefore not reflecting all the abilities required to perform physically demanding activities.\(^22\) Furthermore, the described studies were limited by (i) relatively small sample sizes of \(N=7-19\) athletes,\(^13,17,21\) (ii) determining mostly physical but rarely psychological characteristics,\(^12–14,16–18,21,23\) and (iii) studying adult but not adolescent players.\(^13,14,16–18,21,23\) Moreover, previous studies have uniquely examined differences in physical\(^12–18\) or psychological\(^20\) performance in JK and HC. However, there is evidence that JK is an injury that affects an athlete over a longer period of time, varying from six months\(^4\) to four years.\(^24\) Therefore, a longitudinal approach was adopted in the present study in order to evaluate if the loss of performance could be observed only at the beginning of the season or if it also occurred over the course of a season. Additionally, the occurrence of further injuries was considered because a lower level of physical\(^25,26\) or psychological\(^27,28\) performance measures is associated with an increased risk of injury.

The purpose of this study was to investigate differences in physical and psychological variables in a comparatively large sample (\(N=35\)) of sub-elite male youth soccer players, who previously underwent physical therapy for JK compared to HC over the course of a season. The authors hypothesized that subjects with previous JK would show significantly (i) worse physical and psychological performances and (ii) greater values of injury-/pain-related variables over the course of a season.

METHODS

PARTICIPANTS

Eighteen young sub-elite male soccer players, who previously underwent physical therapy for JK (\(n=18\), age: 15.1 ± 0.8 yr, body mass: 60.5 ± 8.5 kg, body height: 170.7 ± 6.6 cm) and a group of 17 HC (\(n=17\), age: 15.0 ± 1.0 yr, body mass: 62.9 ± 6.9 kg, body height: 170.0 ± 6.2 cm) participated in this study. The conventional therapy was conducted two to three times a week and was composed of unilateral eccentric squat exercises, as well as static quadriceps and hip flexor stretching. All subjects were originally examined by a physician and diagnosed with pain in the inferior pole of the patella or the proximal patellar tendon by palpation of the tendon and its attachments. An ultrasound was performed, and in cases where the tendon was classified as ab-
normal, a hypoechoic lesion and/or fusiform swelling was located in the proximal insertion of the patellar tendon. If neither of these pathological changes were evident the tendon was classified as being normal and therefore the subject excluded from the study. In addition, all included subjects reported pain during jumping exercises, as well as explosive stop-start movements at the time of the physical examination. Before entering the study, participants were familiarized with the testing protocol. Prior to each training session, participants were continuously questioned about their present level of pain using a visual analogue scale. The JK group was recruited from different soccer teams. At the beginning of the therapy program, the JK group was advised to maintain a pain-related rest period (13.5 ± 4.1 days) and to perform a limited training load during their period of therapy (58.2 ± 24.6 days). All subjects of the JK group had completed their therapy program and participated in at least one full team training session without experiencing pain in the week prior to the first testing for the current study. All participants were required to have at least four sessions of team practice per week and were questioned about their level of pain prior to each training session. Subjects were excluded if they had (i) surgical treatment in the last twelve months, (ii) any kind of other injury six weeks prior to the start of the study, (iii) any pain during full training load, or (iv) been originally diagnosed with patellofemoral pain syndrome, plica syndrome, Osgood-Schlatter, or Sinding-Larsen-Johansson syndrome. Furthermore, all participants were instructed to complete all tests without using any kind of pain medication, taping, or medical insoles and to discontinue testing immediately if any patellar pain occurred. Subjects were only allowed to participate in testing when no pain (visual analogue scale = 0) was present at the beginning of the test. The Human Ethics Committee at the University of Duisburg-Essen, Faculty of Educational Sciences approved the study protocol.

PROCEDURES
A longitudinal study design was used to assess physical, psychological, and injury-/pain-related parameters of both groups over the course of a competitive season. All athletes were tested four times (T1-T4) (Figure 1). The tests were conducted at start of the season (T1) as well as six weeks (T2), 16 weeks (T3), and 20 weeks (T4) after the start of the season. A variety of physical fitness tests were used, including 15-s foot tapping [FTT15], drop jump [DJ], jump-and-reach [JaR], acrylic sprint [AS], 30-m linear sprint, and Yo-Yo intermittent recovery test level 1 [YYIRL1]. All tests were performed on the same day in the order mentioned above and with 10-minutes rest periods between each test. A standardized warm-up protocol (i.e., 15-minutes of running, jumping, movement preparation, and change-of-direction speed [CODS] drills) was performed before the testing started. In addition, psychological variables were assessed using the Achievement Motives Scale (AMS) Sport prior to the physical tests. Concerning injury- and pain-related characteristics, the incidence rate of lower extremity injuries and non-contact lower extremity injuries per 1,000 houtrs (i.e., practices/competitions) as well as the period of injury-related rest and the number of pain-related training interruptions were documented.

ASSESSMENT OF PHYSICAL PARAMETERS

MUSCLE POWER

DJ and JaR were used to determine players’ muscle power. Both jump tests were performed on a gym floor wearing athletic shoes. For the DJ test, the players stood in an upright position on a box (height: 40 cm), with their hands on their hips. They were instructed to step off the box with one leg, drop down, and land on both feet immediately followed by a maximal vertical jump. This test procedure has been reported to have a high reliability (ICC = 0.95). Jump height was determined using Optojump® photoelectric cells (Microgate, Bolzano, Italy), which were connected to a laptop using Optojump® software. During the JaR, players stood in an upright position and were then asked to perform a maximal countermovement jump, which was clinically acceptable showing a nearly perfect reliability (ICC = 0.97). Subjects were instructed to touch a scale marked in 0.5-cm increments for measurement purposes attached to the wall leaving a mark with stamp ink at their maximal JaR height. Jump height was assessed by subtracting standing reach height from JaR height. Standing reach height was determined to the nearest 0.5 cm. All players were instructed to jump as high as possible (DJ, JaR) and to keep ground contact as short as possible during DJ. Both jump tests were performed a total of five times (two practice trials followed by three trials for data collection), of which the greatest jump height value was used for further analysis. Breaks of ten minutes and 30 seconds were given between jump tests and single jump trials, respectively.

CHANGE OF DIRECTION SPEED

The AS time was measured using timing gates (Smartspeed Lite®, Fusion Sport, Brisbane, Australia). The setup of the test is comparable to that of the modified agility T-test, which uses a shorter distance than the CODS test and shows a high reliability (ICC = 0.95). In the execution of the test, side-steps were replaced by sprints, because side-steps are less relevant in soccer than linear sprints. After the start of a trial, which was signaled using a visual stimulus, participants were instructed to run straight to the first cone (5-m distance), then change direction to the second cone (2.5-m distance), and return the same way back. The first trial was performed with a change of direction to the left (AS left) while the second attempt included a directional change to the right (AS right). The test was performed on a surface with artificial grass in dry weather conditions wearing soccer shoes. A total of six trials (three per direction) were executed with 60-s breaks in between. Only the fastest trial for each direction of movement was used for data analysis.

SPEED

The FTT15 was used to assess cyclic speed performance and has been reported as moderate to nearly perfect (ICC = 0.69-0.98) regarding reliability. The athletes stood barefoot on a gym floor within Optojump® bars with their feet hip-width apart. Athletes were instructed to perform as

International Journal of Sports Physical Therapy
many floor contacts as possible with both feet during 15 s. Measurement started with an athlete’s first step. Three trials with 60-s rest periods in between were performed. Only the tapping frequency was assessed as it depends on a subject’s motor capabilities, thus representing a measure of speed whereas the fatigue-index is a measure of endurance. The trial with the highest frequency of taps of both legs combined was included in the analysis.

Sprinting performance was measured over a 30-m straight distance with interims at 5 m and 10 m using timing gates (Smartspeed Lite®, Fusion Sport, Brisbane, Australia). The start of a trial was signaled by a visual stimulus. The test was performed on an artificial grass surface in dry weather conditions wearing soccer shoes. Each athlete performed three trials with 60-s breaks between trials and the best result (i.e., shortest time) was used for further analysis. For this test procedure, large to near perfect ICC-values of 0.80 (5 m), 0.87 (10 m), and 0.97 (30 m) were reported.37

ENDURANCE
As previously described by Krustrup et al.,38 the YYIRL1 was used to determine soccer-specific endurance and is described as a reliable test procedure for young athletes (ICC = 0.82–0.94).39 The test consists of 2 x 20-m sprints alternated with 2 x 5-m recovery phases and was performed at increasing velocities on artificial grass in dry weather conditions wearing soccer shoes. The progressive increase in velocity as well as the allocated time to reach the finish line were signaled acoustically using a portable CD player (JVC, RVNB20W, Yokohama, Japan). Following each 40-m distance, the athlete had a 10-m phase of active rest lasting a total of 10 s during which he jogged slowly. Testing was terminated after an athlete failed to reach the finish line twice within the given course of the entire test. The total distance (m) covered was measured and used for analysis.

ASSESSMENT OF PSYCHOLOGICAL PARAMETERS
The AMS Sport was used to determine differences in psychological variables between athletes. The two achievement motive components “hope for success score” and “fear of failure score” were assessed using a questionnaire, which was filled out by the participants individually and without further explanation. Each scale has 15 items, with an answering scheme ranging from 1 (not true for me at all) to 4 (exactly true for me). To calculate the net hope, the sum of the component “fear of failure” was subtracted from the sum of the component “hope for success”.29

ASSESSMENT OF INJURY- AND PAIN-RELATED PARAMETERS
Injury- and pain-related characteristics were assessed through day-to-day tracking of data by the coaches and the athletic department of the participating clubs using a visual analogue scale (0-10). Any injuries or pain-related training interruptions were continuously documented using an online database (SoccerWeb, SoccerCollection oHG, Iserlohn, Germany). The operational definition of injury was an injury acquired during training or competition within the club that completely prevents the player from continuing soccer for at least one day.

STATISTICAL ANALYSES
Data are reported as means and standard deviations (SD) after normal distribution was confirmed by the Shapiro-Wilk test (p > 0.05). For each testing session, a univariate analysis of variance (ANOVA) was applied to analyze differences in physical and psychological parameters between the two groups. Further, effect sizes were calculated by converting partial eta-squared to Cohen’s d.40 Statistical analyses were conducted using SPSS version 24.0 (IBM Corp., Armonk, NY, USA). Statistical significance was set at p < 0.05.

RESULTS
Differences in physical fitness and psychological variables of sub-elite youth soccer players, who completed physical therapy after JK compared to HC across the season are presented in Table 1.

PHYSICAL PARAMETERS
The ANOVA revealed significantly lower levels of performance for the AS left (Δ 0.29-0.34 s; Δ2.5-6.5%; p < 0.001; 1.37 < d ≤ 1.51 [T1-T4]; Figure 2A), the AS right (Δ 0.28-0.35 s; Δ5.3-6.7%; p < 0.001; 1.24 ≤ d < 1.53 [T1-T4]; Figure 2B), and the 30-m linear sprint time (Δ 0.17-0.24 s; Δ3.8-5.4%; 0 p ≤ 0.007; 0.48 ≤ d ≤ 1.26 [T1-T4]; Figure 3) in players with previous JK compared to HC at each of the four testing timeframes. None of the other physical performance tests showed statistically significant differences at any of the four testing times.
PSYCHOLOGICAL PARAMETERS

At the start of the soccer season (T1; $\Delta$-14.8%; $p = 0.009$; $d = 0.85$) and six weeks after (T2; $\Delta$-17.2%; $p = 0.007$; $d = 0.89$), “net hope” was significantly lower in players with previous JK than in HC (Figure 4). Further, the ANOVA yielded significantly lower values for “hope for success” ($\Delta$-2.5%; $p = 0.032$; $d = 0.65$) in players with previous JK compared to HC at T1 (Table 1). Lastly, significantly higher values for “fear of failure” occurred among players with previous JK as in HC at T1 ($\Delta$97.9%; $p = 0.027$; $d = 0.68$) and T2 ($\Delta$135.6%; $p = 0.012$; $d = 0.80$) (Table 1). No further differences were found in these variables for the remaining testing points.

Figure 2A. Illustration of acyclic sprint time with first change to the left between soccer players after conventional therapy for jumper’s knee (JK) compared to healthy controls (HC) over the course of the soccer season.

T1 = start of the season; T2 = 6 weeks after the start of the season; T3 = 16 weeks after the start of the season; T4 = 20 weeks after the start of the season.
The percentage value indicates the mean difference between groups by measurement date. The $d$-value means Cohen’s $d$ effect size with $0 \leq d \leq 0.21$ indicating small, $0.22 \leq d \leq 0.49$ indicating medium, and $d \geq 0.50$ indicating large effects.

### Table 1. Differences in physical fitness and psychological variables of sub-elite male youth soccer players after conventional therapy for jumper’s knee (JK) compared to healthy controls (HC) during the season. Values are presented as means with standard deviations in parentheses.

<table>
<thead>
<tr>
<th>Variables</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical parameters</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DJ height (cm)</td>
<td>30.6 (2.9)</td>
<td>30.8 (3.1)</td>
<td>32.0 (3.2)</td>
<td>30.6 (3.5)</td>
</tr>
<tr>
<td>JaR height (cm)</td>
<td>48.9 (4.5)</td>
<td>50.1 (4.7)</td>
<td>51.3 (4.0)</td>
<td>49.8 (4.6)</td>
</tr>
<tr>
<td>AS left (s)</td>
<td>5.29 (0.18)</td>
<td>5.38 (0.23)</td>
<td>5.25 (0.23)</td>
<td>5.27 (0.21)</td>
</tr>
<tr>
<td>AS right (s)</td>
<td>5.30 (0.19)</td>
<td>5.33 (0.24)</td>
<td>5.27 (0.25)</td>
<td>5.27 (0.21)</td>
</tr>
<tr>
<td>FTT15 Hz</td>
<td>5.94 (0.64)</td>
<td>6.00 (0.44)</td>
<td>6.14 (0.63)</td>
<td>5.82 (0.44)</td>
</tr>
<tr>
<td>5-m time (s)</td>
<td>1.23 (0.06)</td>
<td>1.21 (0.08)</td>
<td>1.20 (0.07)</td>
<td>1.22 (0.09)</td>
</tr>
<tr>
<td>10-m time (s)</td>
<td>1.99 (0.08)</td>
<td>2.01 (0.10)</td>
<td>1.97 (0.08)</td>
<td>2.02 (0.14)</td>
</tr>
<tr>
<td>30-m time (s)</td>
<td>4.51 (0.15)</td>
<td>4.68 (0.22)</td>
<td>4.49 (0.23)</td>
<td>4.70 (0.23)</td>
</tr>
<tr>
<td>YYIRL1 (m)</td>
<td>2.018 (302)</td>
<td>1.892 (355)</td>
<td>2.096 (336)</td>
<td>2.044 (441)</td>
</tr>
</tbody>
</table>

| Psychological parameters | | | | |
| Net hope (pt) | 39.1 (6.1) | 33.3 (7.2) | 39.5 (6.6) | 32.7 (8.5) |
| Hope for success (pt) | 43.9 (1.3) | 42.8 (1.9) | 44.0 (1.1) | 43.2 (1.9) |
| Fear of failure (pt) | 4.8 (6.1) | 9.5 (7.5) | 47.9 (6.3) | 4.5 (6.3) |

AS left = acyclic sprint with first change of direction to the left; AS right = acyclic sprint with first change of direction to the right; DJ = drop jump; FTT15 = 15-s foot tapping test; JaR = jump and reach test; T1 = start of the season; T2 = 6 weeks after the start of the season; T3 = 16 weeks after the start of the season; T4 = 20 weeks after the start of the season; YYIRL1 = Yo-Yo intermittent recovery test level 1.
Table 2. Differences in exposure time, lower limb injury incidence, injury-related rest period, and pain-related training interruptions of sub-elite male youth soccer players after conventional therapy for jumper’s knee (JK) compared to healthy controls (HC) during the season. Values are presented as means with standard deviations in parentheses.

<table>
<thead>
<tr>
<th>Variables</th>
<th>HC (n=17)</th>
<th>JK (n=18)</th>
<th>p- and d-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure time (hours)</td>
<td>8,927.4 (1,910.9)</td>
<td>8,616.4 (2,335.0)</td>
<td>p = 0.335; d = 0.23</td>
</tr>
<tr>
<td>All injuries (incidence rate per 1,000 h)</td>
<td>7.90 (14.49)</td>
<td>10.65 (14.57)</td>
<td>p = 0.580; d = 0.19</td>
</tr>
<tr>
<td>Non-contact injuries (incidence rate per 1,000 h)</td>
<td>1.92 (3.07)</td>
<td>6.65 (9.07)</td>
<td>p = 0.049; d = 0.69</td>
</tr>
<tr>
<td>Period of injury-related rest (hours)</td>
<td>3.71 (6.45)</td>
<td>18.17 (33.1)</td>
<td>p = 0.043; d = 2.06</td>
</tr>
<tr>
<td>Pain-related training interruptions (number)</td>
<td>0</td>
<td>1.3 (1.3)</td>
<td>p &lt; 0.001; d = 1.35</td>
</tr>
</tbody>
</table>

The p-value indicates statistical significance between groups by measurement date. The d-value means Cohen’s d effect size with 0 ≤ d ≤ 0.49 indicating small, 0.50 ≤ d ≤ 0.79 indicating medium, and d ≥ 0.80 indicating large effects.

INJURY- AND PAIN-RELATED PARAMETERS

Differences in exposure time and injury-/pain-related variables between players with a history of JK and HC across the season are shown in Table 2. In terms of exposure time and incidence rate incorporating all injuries, the ANOVA showed no significant differences. However, significantly higher values for incidence for non-contact lower extremity injury (p = 0.049; d = 0.69), period of injury-related rest (p = 0.043; d = 2.06), and pain-related training interruptions (p < 0.001; d = 1.55) were found in players with previous JK compared to the HC over the course of the season.

DISCUSSION

To the authors’ knowledge, few studies have examined differences in physical, psychological, and injury-/pain-related variables over the course of a season between sub-elite male youth soccer players, who previously underwent physical therapy for JK versus HC. The main findings of this study revealed that players with a history of JK, in comparison to HC, have (i) significantly worse physical fitness values for measures of CODS (acyclic sprint time) and speed (30-m linear sprint time) at all four testing times; (ii) significantly worse values in psychological variables (i.e., net hope, hope for success, fear of failure) in the first two testing sessions after zero and six weeks (T1 and T2), (iii) no significant differences in muscle power (DJ and JAR) and endurance (YYIRL1), and (iv) significantly higher values for non-contact lower limb injuries, injury-related rest period, and pain-related training interruptions over the course of a competitive season. In addition to the p-value (indicator for statistical significance), the d-value was also quantified, which is used to determine whether a difference is of clinical relevance. According to Cohen\(^4\), the d-value can be classified as small (0 ≤ d ≤ 0.49), medium (0.50 ≤ d ≤ 0.79), and large (d ≥ 0.80). All of the detected significant differences in physical, psychological, and injury-/pain-related performance, can be considered as medium to large clinical relevance.
The findings of differences in physical performance were limited to parameters of CODS and speed. However, measurements of muscle power (i.e., DJ and JaR) and endurance (i.e., YYIRL1) were not significantly different between the two groups of players. This suggests that some components of performance (i.e., CODS, speed) seem to be more susceptible to a loss in performance due to patellar tendinosis/tendinopathy in youth athletes than others (i.e., muscle power, endurance). Since there are no prior studies that have measured CODS and speed post-rehabilitation, only speculative assumptions can be made of its causes. Dauty et al. measured a deficit in knee extension torque in players with symptomatic JK compared to HC using isokinetic tests. Assuming this deficit is persistent in subjects who completed rehabilitation after JK, this may be the cause of poorer performance in CODS and speed. Furthermore, a lower sensitivity of the applied jump (i.e., DJ and JaR) and endurance (i.e., YYIRL1) tests in the detection of JK-related changes in physical performance could be another reason for the lack of discrepancies between JK and HC. Further research should consider the inclusion of a wider range of high-speed activities in the test procedures, such as the cutting maneuver test or repeated-shuttle-sprint ability test. We could not confirm significant differences between JK and HC in muscle power, whereby the therapy routine of JK, focusing solely on strength training rather than high-velocity exercises, could provide an explanation. When interpreting the lack of significant differences in endurance, we should also consider the fact that the JK group had a long period of limited training load during their period of therapy, involving mostly low velocity technique and endurance training. Therefore, further research is needed to reveal whether these measurements of muscle power and endurance are less sensitive in detecting differ-
Differences in physical performance in youth soccer players with a history of JK compared to those of CODS and speed.

DIFFERENCES IN PSYCHOLOGICAL VARIABLES ACROSS THE SEASON

In accordance to the initial hypothesis of worse psychological performance values over the course of a season, significantly worse values in the parameters net hope, hope for success, and fear of failure were found in soccer players with previous JK than in HC. The low score of JK in "hope for success" shows the athlete's fundamental insecurity in facing and mastering an athletic challenge, or in other words the capability believing in his own physical abilities. A significantly higher score in "fear of failure" of JK compared to HC suggests an increased anxiety of failing in competition or not being able to perform certain movement skills. The criteria "fear of failure" and „hope for success” only showed significantly different scores at the first two testing sessions (i.e., start of the season and six weeks thereafter) and disagree with the finding of Elbe et al.29 who stated that the factors of the AMS Sport are consistent within a subject’s life and do not change under any circumstances. The effect sizes of the first two testing times (net hope: $d = 0.85-0.89$ [T1 and T2] / hope for success: $d = 0.50-0.65$ [T1 and T2] / fear of failure: $d = 0.68-0.80$ [T1 and T2]) indicate that the injury had a strong negative impact on the participants. Johnston et al.47 revealed similar difficulties of athletes in their qualitative analysis with competitive athletes. According to Johnston and colleagues, the athletes' lower performance after injury was associated with lower sport confidence, which was related to a fear of injury or recurrent injury. This fear of injury presented as being hesitant, holding back, not giving 100% effort or being wary of injury-provoking situations.47 Most likely, athletes underestimated the impact of JK on their physical performance even after treatment had been completed and therefore were not able to cope well with these new circumstances. Moreover, it may be speculated, that the sport coaches did not appropriately progress them into physical activity and had them take on higher training loads and intensity too soon. Gould et al.48 found that athletes returning after a severe injury identified their lower performance in competition as a source of stress and frustration. An explanation for the lack of significant differences between JK and HC at the two last points of data collecting (i.e., 16 and 20 weeks after the start of the season) may be that athletes had regained confidence in their physical capabilities after realizing that the symptoms were not reoccurring despite performing high-intensity exercises. This theory can be supported by the findings of Smith et al.49 who measured higher levels of anger and depression after injury, but also reported a swift improvement when the subject approaches full recovery. Thus, it is important to focus on improvements in the process of rehabilitation. Zafra et al.20 showed a relationship between psychological variables and injuries in tennis players. Especially players with tendinitis showed a significant relationship between a higher number of injuries and lower score in motivation.20 As a consequence, these findings should lead to further research on the impact of injuries and rehabilitation methods on psychological variables of athletes. For example, psychological counseling and the verification of its effects on psychological and physical parameters could be a field of interest. Moreover, optimizing physical recovery in form of holistic treatment procedures to secure the athletes’ belief in their own movement abilities could be another point of interest.

DIFFERENCES IN INJURY- AND PAIN-RELATED CORRELATES

This study showed significantly higher values of non-contact lower extremity injuries, injury-related rest periods, and pain-related training interruptions for soccer players with a history of JK compared to HC over the course of the season. The higher incidence rate of non-contact lower limb injuries may be attributed to the pain-related rest period and limited training load during therapy. It is likely that the subjects' muscle structure and overall physical fitness did not yet adapt to the requirements of competitive sports after only one full load training session. Therefore, it is possible that the players' training intensity was increased too soon. Although Le Gall et al.50 showed only a few percent ($n=29, 7.8\%$) of the players suffering from tendinopathy in light of our study's findings this could also lead to the conclusion that players with JK post-rehabilitation are also more susceptible to injuries during competition than HC. In another prospective cohort study, Kucera et al.10 described a positive association between previous injury and injury incidence in youth soccer players. Participants without previous injuries (2.5 per 1,000 h) showed a significantly lower injury incidence rate than those with two or more injuries (6.9 per 1,000 h). In relation to Table 2, the findings of the present study are in keeping with this report. The longer period of injury-related rest and the greater number of pain-related training interruptions may be indicative of an insufficient rehabilitation procedure. On a professional level, a successful rehabilitation should not only aim for the athlete to be game ready in general, but also rectify any abnormalities that led to the injury in the first place. A further reason might be that regular training and competition were resumed too early. Large effect sizes of $d = 2.06$ (injury related rest period) and $d = 1.55$ (pain-related training interruptions) are indicative of clinical meaningfulness and therefore suggest a high impact on the players return-to-competition process. Consequently, further research is necessary to investigate the effectiveness of conventional rehabilitation versus alternative programs targeted for athletes with the diagnosis of JK.

This study design has some limitations that should be considered when interpreting the results. For example, it would be of interest for further studies to measure knee extension torque in order to compare the results provided with recent studies measuring similar performance parameters. Furthermore, a measurement of baseline samples prior to the completion of therapy would provide a considerable amount of data to preclude any mistakes made by coaches or therapists during rehabilitation. Especially, isokinetic strength testing protocols should be added in further studies to combine sport specific tests outside of clinical settings with a more clinical evaluation of muscle strength parameters.
CONCLUSIONS

Differences in physical, psychological, and injury-/pain-related parameters in sub-elite male youth soccer players, who completed physical therapy after JK compared to HC were investigated over the course of a season. The results indicate significantly worse physical (i.e., for measures of CODS and speed) and psychological (e.g., hope for success, fear of failure) performance variables at the expense of players with previous JK, which indicate a specific significance of these components during rehabilitation and training interventions. Moreover, the higher incidence rate of non-contact lower extremity injuries, the longer periods of injury-related rest, and the higher number of pain-related training interruptions in athletes with a history of JK as in HC may be indicative of insufficient rehabilitation and/or training procedures. Thus, further research is required to determine the effectiveness of rehabilitation/training programs that counteract JK-related performance decrements accompanied with an adequate specification of the return to sport.

CONFlict OF INTEREST

Marc Niering and Thomas Muehlbauer declare that they have no conflict of interest.

Submitted: November 16, 2019 CST, Accepted: June 16, 2020 CST
REFERENCES


Individual Baseline Balance Assessments in a Large Sample of Incoming NCAA Division I Athletes Using a Force Plate System

Scott A. Weismiller, DO¹, Robert Monaco, MD, MPH², Jason Womack, MD³, Brandon Alderman, PhD⁴, Carrie Esopenko, PhD⁵, Fiona N. Conway, PhD⁶, Kyle Brostrand, MS, ATC⁷, Allison Brown, PT, PhD⁵, Nicola L. de Souza, MSc⁸, Jennifer F. Buckman, PhD⁴ a

¹ Dept. of Internal Medicine, Penn State Health, Milton S. Hershey Medical Center, ² Atlantic Sports Health, ³ Dept. of Family Medicine & Community Health, Rutgers - Robert Wood Johnson Medical School; Dept. of Athletics, Rutgers University - New Brunswick, ⁴ Dept. of Kinesiology and Health, Rutgers University - New Brunswick, ⁵ Dept. of Rehabilitation and Movement Sciences, Rutgers Biomedical and Health Sciences, ⁶ Steve Hicks School of Social Work, The University of Texas at Austin, ⁷ Dept. of Athletics, Rutgers University - New Brunswick; Robert Wood Johnson Barnabas Health - Rutgers Sports Medicine, ⁸ School of Graduate Studies, Rutgers Biomedical and Health Sciences

Keywords: sex differences, postural control, normative data, concussion, college

BACKGROUND

Individualized baseline testing is resource and time intensive. The use of normative data to approximate changes after a suspected concussion is thus an appealing alternative. Yet, few peer-reviewed, large-sample studies are available from which to develop accurate normative averages of balance using force-plate technology.

PURPOSE

This study sought to validate a normative dataset from the force-plate manufacturer and examine the magnitude and nature of sample variability.

STUDY DESIGN

Cross-sectional.

METHODS

Baseline balance and self-reported sex, sport, and concussion history were assessed in 533 prospective collegiate athletes (45% female) during pre-participation physical examinations. Balance was measured using four stances from the modified Clinical Test of Sensory Interaction and Balance and quantified as Sway Index Scores with the Biodex Biosway Portable Balance System. Group averages are contrasted to data from the force-plate manufacturer. Individual variability around these averages was visualized and analyzed by sex and sport.

RESULTS

Male student athletes showed significantly more sway in the eyes open, soft stance condition than female athletes. These differences were maintained when concussion history was included as a covariate. Athletes, particularly male athletes, in the high versus low contact sport group showed significantly more sway in the eyes open, soft surface and the eyes closed, hard and soft surface stances.

CONCLUSION

There was substantial individual variability that was partially explained by sex differences and sport differences. The development of normative averages for sway may benefit from consideration of sex and sport. Further studies should characterize other factors that influence baseline balance in collegiate athletes.
INTRODUCTION

Balance, or postural control, is an integral clinical measure in the comprehensive diagnosis and management of sport-related concussion.\(^1\) According to the most recent consensus statement from the fifth international conference on concussion in sport,\(^2\) balance disturbances are a clear on-the-field sign of a concussion. Assessments of postural control after a concussion often highlight transient deficits in an individual’s ability to integrate the sensory components necessary for maintaining balance.\(^3,4\) Sensory integration and balance deficits have been reported among concussed athletes,\(^5–7\) and collectively suggest that brain regions responsible for coordinating sensory and vestibular modalities may be disrupted following sport-related concussion.\(^8\)

Making accurate evaluations of balance disturbances post-injury may be compromised without an accurate pre-injury comparison.\(^4\) Normative averages (i.e., norms) are commonly used in place of individualized baseline testing for characterizing changes in balance after a suspected concussion. This is due to the time and expense of individual-level testing, perceptions of baseline testing inaccuracy, and clinical practice guides\(^2\) that suggest that baseline testing for other clinical measures (e.g., neuropsychological testing) may be “useful”, but not mandatory. However, to be effective, norms must be developed on large, representative samples and consider factors that systematically influence them.

The present study assessed balance in a large sample of incoming NCAA Division I collegiate student-athletes. The Modified Clinical Test of Sensory Interaction and Balance (mCTSIB) combined with force plate technology was used as a sensitive and objective test of postural control.\(^8\) The four-station mCTSIB was developed to assess the influence of somatosensory, visual, and vestibular systems on postural control.\(^9\) Its clinical and research utility comes from its relative ease of use and minimal cost.\(^10\) Combined with a force plate system, uniform, quantitative assessments of balance were obtained. The goals of the study were to validate the normative data previously published by the manufacturer of the balance system that was employed\(^11\) and examine the magnitude and nature of sample variability. Sample variability related to sex differences was hypothesized as female athletes have been shown to demonstrate superior balance compared to male athletes.\(^12–15\) Sample variability based on participation in high versus low contact sports was also hypothesized because of potential long-term cognitive effects of high contact risk sport participation.\(^16\) Finally, due to that possibility that individuals with a history of concussion may exhibit sustained balance disturbances compared with individuals without a history of concussion,\(^17\) self-reported concussion was controlled for in all analyses.

METHODS

PARTICIPANTS

Incoming NCAA Division I collegiate student-athletes between the ages of 18 and 23 years (n = 703) from 22 Division I teams at a northeastern US university were recruited when they attended their standard pre-participation physicals that took place before entry into the athletic program (2013 - 2016). On the day of recruitment, participants completed athletic program paperwork, research surveys, and a medical check-up; some participants also opted to participate in a separate study on heart rate variability that involved no physical activity.

Consented participant data were included if the athlete received a balance test using force plate technology in the Department of Sports Medicine, were active and uninjured members of an NCAA team at the time of testing, and received medical clearance for athletic participation (n = 554). Data from one individual were excluded due to baseline values that exceeded realistic expectations of a normal baseline test (i.e., > 3 standard deviations from next highest score). The final sample for analyses included 533 student-athletes (18.7 +/- 1.0 years; 45% female). All participants provided written informed consent and this study was approved by the university’s institutional review board. The study design was cross-sectional in nature.

BALANCE ASSESSMENT

Balance during the mCTSIB stances was objectively measured using the Biodex BioSway Portable Balance System (Biodex Medical Systems, Shirley NY), a force plate technology that evaluates balance as center of pressure (COP) trajectories, postural sway, and the ability to distribute and maintain one’s center of gravity over the base of support.\(^18\) Participants alternated between standing on a high-density foam pad or a firm surface, in both the eyes open and eyes closed positions.\(^9,18\) Participants completed four 20-second stances from the mCTSIB: standing on a firm surface with eyes open (Open/Firm), standing on a firm surface with eyes closed (Closed/Firm), standing on a compliant surface (foam) with eyes open (Open/Soft) and standing on a foam surface with eyes closed (Closed/Soft). Participants were asked to stand quietly and motionless in the upright position during each condition. Sway information was collected by positioning the patient centrally on the static force plate and recording movement from center as X, Y coordinates. The Sway Index, calculated by the Biosway system, is the root mean squared difference of the X, Y coordinates.\(^11\) Higher Sway Index scores are indicative of a more unsteady posture. All assessments were administered in the university’s sports medicine office suite by medical staff, athletic trainers, study investigators, or trained graduate-level research assistants and took less than 5 minutes per athlete.

SEX, SPORT TYPE, AND CONCUSSION HISTORY

Sex (male/female) and sport were collected from pre-participation questionnaires routinely administered by the Department of Sports Medicine to incoming athletes. A two-category sport contact risk level variable was created based on the relative risk of sustaining an acute injury by sport us-
ing classification recommendations by the Council of Sports Medicine and Fitness.19 The high contact risk sport category included sports with purposeful and forceful collision with persons or objects (football, lacrosse, wrestling) or routine but lower impact contact (basketball, field hockey, gymnastics, soccer). The low contact risk category included sports with minimal and unintentional contact (baseball, softball, volleyball) or rare to no contact (crew, golf, swimming/diving, track and field, tennis). Diving was considered a contact sport in a prior study;19 however, the university from which the present sample was recruited has a combined swimming/diving team, which historically has had few concussions; therefore, the team was considered low contact. Self-reported history of concussion (yes/no) was determined from the pre-participation physical questionnaire item (“Have you ever had a head injury or concussion?”) and from supplementary physician notes.

STATISTICAL METHODS

The BioSway Portable System allows testers to record whether a test was performed at baseline or post-injury. If baseline assessments were recorded on multiple days (e.g., due to participation in other studies), only the first day’s measurement was included to reduce potential of practice effects. If two baseline assessments were recorded within five min of each other (e.g., due to incomplete first recording, technical or computer error), only the second measurement was included.

All analyses were performed separately for the four stances (Open/Soft, Closed/Soft, Open/Firm, Closed/Firm). First, Sway Index scores per stance in the present sample were compared to those reported by the force-plate manufacturer for 17-23 year old male and female NCAA athletes (n=480)11 using Cohen’s d effect size calculations.20 Due to unequal variances in the two samples, Cohen’s d was computed using a pooled standard deviation term. Cohen’s d’s of >0.2, >0.5, and >0.8 are respectively considered small, medium and large effects.

Second, Sway Index scores in the present sample were graphically depicted by individual for each of the four stances. This was done to provide a qualitative assessment of balance differences between individuals. Graphs show overall sample variability.

Third, statistical analyses assessed whether sex differences or contact risk level differences accounted for the observed balance differences between individuals. A series of t-tests (SAS 9.4, SAS Institute Inc., Cary, NC) compared Sway Index scores across biological sex (male/female). A second series of t-tests compared Sway Index scores across contact risk level (high versus low contact). Analyses were performed again as general linear models (SAS 9.4, SAS Institute Inc., Cary, NC) that included self-reported concussion history as a covariate.

Finally, a chi-square test (SAS 9.4, SAS Institute Inc., Cary, NC) compared whether male and female athletes differ in their participation in high and low contact risk sports. Because there were significant differences by sex, a final set of t-tests assessed the effect of contact risk level on Sway Index scores separately for males and females. Differences were considered significant when p < .05.

### RESULTS

Distribution of the current sample by sex and sport contact risk level is shown in Table 1. Differences between the sample averages published by the manufacturer of the force plate system (Biodex) and the present sample are shown in Table 2. There were negligible differences in the Closed/Firm stance, small effect size differences in Open/Firm and Closed/Soft stances, and a moderate difference in the Open/Soft stance. The present sample had smaller standard deviations than the previously published dataset in all but the Closed/Soft stance.

Individual-level Sway Index scores for each stance are presented in Figure 1. This figure graphically illustrates the range in individual Sway Index scores around sample averages. Independent sample t-tests were then performed to assess whether this variability was due to differences in sex and risk of contact. As shown in Table 2, male student-athletes exhibited more sway than female student-athletes in the Open/Soft, t\(_{531} = 2.69, p = .007\), but not in the Closed/Soft, t\(_{531} = 1.87, p = .061\), stances, Open/Firm, t\(_{531} = 1.55, p = .122\), or Closed/Firm, t\(_{531} = 1.62, p = .105\), stances (Table 2). Athletes in high versus low contact risk sports showed significant more sway in the Closed/Firm, t\(_{531} = 2.18, p = .03\), Open/Soft, t\(_{531} = 2.47, p = .014\), and Closed/Soft, t\(_{531} = 2.48, p = .014\), stances, but not in the Open/Firm stance, t\(_{531} = 1.72, p = .09\) (Table 2).

There were no significant differences in Sway Index scores between those with and without a history of concussion for any of the stances. When self-reported history of concussion was included in the sex differences analyses, the pattern of results remained the same: only the Open/Soft stance was significant, F\(_{2,506} = 3.73, p = 0.025\). When self-reported history of concussion was included in the contact risk analyses, the pattern of results was very similar: significant differences were observed in the Closed/Firm, F\(_{2,506} = 3.54, p = 0.036\) and Open/Soft, F\(_{2,506} = 3.64, p = 0.027\); the Closed/Soft stance, F\(_{2,506} = 2.65, p = 0.072\), just missed the significance cutoff.

Since there was a significant difference in contact risk by sex (\(\chi^2 = 34.66, p < .001\)), data were then analyzed separately for men and women. As shown in Figure 2, male athletes in low contact risk sports (n = 91) differed significant-

| Table 1: Athletes Sex, Self-reported Concussion History, and Sport in the Low and High Contact Risk Groups |
|---------------------------------------------------------------|---------------------------------------------------------------|
| Low Contact (n = 228, 43%) | High Contact (n = 305, 57%) |
| % Male | 40% | 66% |
| Concussion history | 12% | 23% |
| Sport (% male) | Baseball (100%) | Basketball (50%) |
| | Crew (0%) | Field Hockey (0%) |
| | Golf (50%) | Football (100%) |
| | Softball (0%) | Gymnastics (0%) |
| | Swim/Diving (0%) | Lacrosse (65%) |
| | Track/Field (59%) | Soccer (46%) |
| | Tennis (0%) | Wrestling (100%) |

International Journal of Sports Physical Therapy
Table 2: Sway Index Values (± Standard Deviation) by Stance

<table>
<thead>
<tr>
<th>Stance</th>
<th>Biodex sample</th>
<th>Current sample</th>
<th>Sample comparison†</th>
<th>Current sample by sex</th>
<th>Current sample by sport contact risk category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Open Eyes/Firm Surface</td>
<td>Closed Eyes/Firm Surface</td>
<td>Open Eyes/Soft Surface</td>
<td>Closed Eyes/Soft Surface</td>
<td>Low contact</td>
</tr>
<tr>
<td>Biodex sample*</td>
<td>0.32 ± 0.40</td>
<td>0.67 ± 0.35</td>
<td>0.60 ± 0.33</td>
<td>2.08 ± 0.26</td>
<td>0.41 ± 0.16</td>
</tr>
<tr>
<td>Current sample</td>
<td>0.43 ± 0.16</td>
<td>0.62 ± 0.23</td>
<td>0.74 ± 0.23</td>
<td>1.95 ± 0.47</td>
<td>0.60 ± 0.22</td>
</tr>
<tr>
<td></td>
<td>d = 0.35 (S)</td>
<td>d = 0.17</td>
<td>d = 0.51 (M)</td>
<td>d = 0.33 (S)</td>
<td>0.72 ± 0.23</td>
</tr>
<tr>
<td>Current Sample by sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>0.44 ± 0.16</td>
<td>0.63 ± 0.22</td>
<td>0.77 ± 0.25†</td>
<td>1.99 ± 0.48</td>
<td>0.41 ± 0.16</td>
</tr>
<tr>
<td>Female</td>
<td>0.41 ± 0.16</td>
<td>0.60 ± 0.23</td>
<td>0.72 ± 0.20</td>
<td>1.91 ± 0.46</td>
<td>0.60 ± 0.22</td>
</tr>
<tr>
<td>Current sample by sport contact risk category</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low contact</td>
<td>0.41 ± 0.16</td>
<td>0.60 ± 0.22§</td>
<td>0.72 ± 0.22§</td>
<td>1.90 ± 0.46§</td>
<td></td>
</tr>
<tr>
<td>High contact</td>
<td>0.44 ± 0.16</td>
<td>0.64 ± 0.23</td>
<td>0.77 ± 0.23</td>
<td>2.00± 0.47</td>
<td></td>
</tr>
</tbody>
</table>

* Data are for 17-23 year old male and female NCAA athletes (n=480) published by the manufacturer of the force plate technology used in this study and publicly available on the manufacturer’s website.†
† Samples were compared using Cohen’s d measure of effect size (S = small; M = medium).
§ Males vs. Females, p < .05.
‡ Low vs. High Contact Risk Sports, p < .05.

DISCUSSION

This study characterized balance in a large sample of un-injured NCAA Division I collegiate student-athletes using force plate technology and the mCTSIB. Participants completed the mCTSIB stances without difficulty. Assessments took less than five minutes per person, including set up and explanation, and thus were easily integrated into mandatory pre-participation screening (even when done en masse).
Because force plate measurements are objective and require only limited training and technological ability, assessments can be administered by medical support staff as well as by medical and research trainees. Considering the identification of multiple factors that influence baseline postural control and the substantial variability in the present sample, the collection of individual baseline balance data is strongly recommended, whenever possible. When individual baseline data are not available, clinicians should interpret results of post-injury tests with care.

Sample averages were calculated for each of the four mCTSIB stances and compared to sample averages provided by Biodex in their manual. The observed small and medium effect size differences in three of the four stances was unexpected because both samples are large and comparably sized, and both consisted of ostensibly similar young healthy NCAA Division I athletes. The basis of these differences is unclear, but demographic (e.g., sex), athletic (e.g., sport), and college status (i.e., incoming versus current students) factors may have contributed. The university from which the present study was recruited, for example, has more contact/collision sports and fewer non-contact sports for men than the university from which the previously published Biodex sample was recruited. The present sample included women’s crew (non-contact), field hockey (contact), and gymnastics (contact), which do not appear to have been included in the Biodex sample.

Interestingly, the present sample had substantially lower standard deviations than the prior sample (i.e., present sample’s standard deviation in open eyes/firm surface stance was 40% of that of the Biodex sample), except in the most difficult stance during which participants stood on a foam surface with their eyes closed (Table 1). In this latter case, the present sample’s standard deviation was ~180% of that of the Biodex sample. Considering the degree of variability observed when individual Sway Index scores in the present sample were graphically displayed (Figure 1), further research is needed to characterize factors that affect collegiate athlete pre-injury balance, particularly as measured by mCTSIB and force plate technology.

Past research reports mixed findings regarding sex differences in baseline balance that may be dependent on age,12 sport type,13–15 assessment strategy (e.g., error monitoring, force plate sway),13 and stance difficulty.12,15 In studies using force plate technology, female athletes performed better on single leg, double leg, and tandem stance conditions.15 Female athletes in the present study showed modestly better balance performance in the open eyes, soft surface stance; performance in the closed eyes, soft surface stance just missed significance. Other reports of sex differences in balance have suggested that females have superior coordination of visual and proprioceptive systems, greater anatomical stability due to leaner body structures and wider pelvises,21 and physiological (central nervous system differences integrating proprioceptive input) and/or psychological (motivation and concentration) differences.13,22,23 Conversely, sport-specific training and skills, such as are required for gymnastics, may also drive these differences. These sex differences by soft versus firm conditions warrant further research that considers the contributions of proprioceptive and visual systems to balance in the soft stance condition. Additionally, these differences suggest a potential need for sex-specific normative averages to more fully inform clinical interpretation of an individual’s Sway scores.
following injury.

Past work has also demonstrated differences in baseline balance performance in athletes participating in different sports. The present study, however, is among the first to show that participation in high contact sports may also be associated with reductions in postural control during baseline assessments. Specifically, the low contact risk group, comprised of athletes who participate in sports with minimal or no contact, showed better balance than the high contact risk group in the more challenging Open/Soft, Closed/Firm, and Closed/Soft stances. When males and females were analyzed separately, results indicated that these differences were driven exclusively by the male athletes; no significant differences by sport contact risk were observed for the female athletes. Subconcussive impacts, sport-specific strength and conditioning regimens, or years of participation are potential explanations, but future research specifically addressing these factors is needed before conclusions can be drawn. As with sex-specific normative averages, sport-specific averages may improve clinical interpretation of post-injury balance disturbances.

These results should be considered in light of some limitations. The data were collected from a sample of collegiate athletes at one university; thus, the findings may not generalize to all collegiate athletes. Only NCAA Division I athletes were tested; future studies should include athletes from other NCAA divisions and sports. Nearly all participants were tested on a limited number of days in the summer prior to their arrival on campus and most were incoming first-year students. Balance may improve with training, during the intensive competitive season, and from overall exposure to the collegiate athletics environment; thus, means and/or SDs may be lower in more experienced collegiate athletes. Future studies would benefit from further assessment of concussion history, including number of prior concussions and recency of concussive symptoms.

A critical observation of this study was the substantial variability in baseline balance performance in every stance, even among this sample of ostensibly healthy, uninjured NCAA Division I athletes across a narrow age range (18-23 years). This may suggest a large range of 'normal' balance function in non-injured collegiate athletes. It also suggests that factors such as years of collegiate sport participation, subconcussive impact exposure, testing time (e.g., during intensive training periods, during the competitive season), and proximal health factors (e.g., fatigue, recent exercise, past lower body injuries) can alter balance through their influence on motor control, responses to proprioceptive and visual cues, coordination, strength, and range of motion. This study cannot address these specific causal factors, but the large distribution of individual values around the mean suggests such studies are needed, particularly for supporting clinical interpretation of changes in balance from pre- to post-injury.

CONCLUSION

The present results suggest that changes in balance from pre- to post-injury may be clinically interpreted differently for individuals with substantially below average sway (i.e., superior balance) versus those at or above the average. For example, an individual's post-injury Sway score of 0.64 during the Open Eyes/Soft Surface stance may not be seen as a clinically significant impairment if the current sample's (or the Biodex sample's) baseline averages are used as proxies for pre-injury balance. However, if that individual had a baseline Sway Index score of 0.39 (1 standard deviation below the group average), a 0.64 represents a 60% increase in sway from baseline, which may, in fact, be clinically meaningful. Much research remains needed in this area, but these results suggest that physical therapists and other clinicians should be cautious of the risk for over- or under-diagnosing balance disturbances when referencing published sample averages during patient examination. The results also support the need for additional studies in this domain to build a comprehensive database from which accurate normative averages may be developed.

ACKNOWLEDGMENTS

The authors thank the staff of the Rutgers Department of Sports Medicine for their assistance with this study and thank Anthony Bocchine for assistance with figure preparation. This study was supported, in part, by a grant (NJCBI R13IRG028) from the NJ Commission on Brain Injury Research (Trenton, NJ) and a grant (K02 AA025123) from the National Institutes of Health to JFB. The grantors had no involvement in the development, execution, or analyses of this study.

CONFLICT OF INTEREST STATEMENT

All authors report no conflict of interest.
REFERENCES


Does the Direction of Kinesiology Tape Application Influence Muscle Activation in Asymptomatic Individuals?

Michelle Dolphin, PT, DPT, MS, OCS, Gary Brooks, PT, DrPH, Blair Calancie, PhD, Adam Rufa, PT, PhD, DPT, OCS

Physical Therapy Education, SUNY Upstate Medical University; Public Health and Preventive Medicine, SUNY Upstate Medical University; Neurosurgery, SUNY Upstate Medical University

Keywords: vertical jump, triple hop, tape, quadriceps, movement systems, isokinetic, emg

10.26603/001c.18799

International Journal of Sports Physical Therapy
Vol. 16, Issue 1, 2021

Background
Despite the popularity of tape among athletes and rehabilitation practitioners, there is controversy regarding the specific effects of kinesiology tape. Based on conflicting results and limitations of the literature, a well-designed study was desired to examine kinesiology tape application direction on muscle activation.

Hypothesis/Purpose
The purpose of this pilot study was to determine if the direction of kinesiology tape application influences quadriceps activation. This study compared taping techniques with outcome measures selected to assess quadriceps muscle activation. The outcome measures included EMG, isokinetic strength, and functional hop and jump performance.

Study Design
Double-blind Crossover study

Methods
A total of fifteen asymptomatic participants (10 females and 5 males) completed the study. Mean age was 23.3 years. Kinesio® Tex Gold™ was applied to the dominant lower extremity of each participant using a Y-strip method. Two taping conditions (proximal to distal, distal to proximal) were applied to the quadriceps. Participants and testers were blinded to tape condition. Pretest and posttest measures included electromyographic output during isokinetic testing of quadriceps muscle torque at 60°s⁻¹ and 120°s⁻¹, single leg triple-hop distance, and vertical jump.

Results
Two-way, repeated measures analysis of variance resulted in no significant differences in baseline to taped condition for quadriceps electromyographic output, quadriceps isokinetic knee extension muscle torque at 60°s⁻¹ and 120°s⁻¹, single leg triple-hop distance or vertical jump height.

Conclusion
The results of this pilot study do not support the hypothesis that kinesiology tape application direction influences muscle performance as measured in this study.

Levels of Evidence
Level 1 – Controlled Clinical Trial

Clinical Relevance
Kinesiology tape is commonly used as an intervention for a wide range of musculoskeletal conditions and for promoting performance including sporting activities. Kinesiology tape...
INTRODUCTION

Kinesiology tape is commonly used as an intervention for a wide range of musculoskeletal conditions and for performance enhancement.1 Despite the current popularity of various brands of kinesiology tape among athletes and rehabilitation practitioners, the specific effects of kinesiology tape are unknown. Previous studies have examined the effect of kinesiology tape on muscle activity and strength, with varying results. A 2012 meta-analysis on “Kinesio tape” for the prevention and treatment of sports injuries identified 10 articles that met the inclusion criteria of including a control and reporting musculoskeletal outcome(s).2 The authors concluded kinesiology tape has trivial or inconsistent results on pain and range of motion and may have a small role in muscle activation or strength.2 A 2015 meta-analysis by Csapo et al. investigating Kinesio® Tape efficacy for muscle activation identified 19 studies (530 subjects) with a variety of comparisons for muscle strength.3 The researchers found that overall effects are negligible for facilitation of muscle contraction and strength and the effects were not muscle group dependent.3

Specific directional taping techniques have been popularized, proposing that the direction of kinesiology tape application alters the activation effect on the underlying muscle(s).4 Kinesiology tape applied in a proximal-to-distal direction is purported to facilitate muscle activation while kinesiology tape application from distal-to-proximal inhibits muscle contraction through changes in the “tension elements”.4 Despite these claims, proponents of this taping method have not provided a clear physiological mechanism by which tape direction influences muscle contraction. It has been speculated that taping may modify muscle activity through the stimulation of cutaneous afferents and motor unit firing.5–8

However, research exploring the relationship between kinesiology tape application techniques and muscle activity has failed to confirm the impact of application direction.5,9–11 Lee et al. tested plantar flexor strength with kinesiology tape applied on the calf from distal to proximal and proximal to distal and found no significant correlation between direction of tape application and muscle strength.12 Similarly, kinesiology tape application direction (proximal to distal to facilitate) was found to have no impact on the activation of the biceps brachii or wrist extensors.5

Several studies have examined the impact of kinesiology tape on the function of the quadriceps. Mostaghim et al. utilized kinesiology tape applied from proximal to distal to the middle of thigh and found a statistically significant difference in vertical jump performance.6 A previous investigation of kinesiology tape application direction to the quadriceps muscle in 36 healthy adults did not show any significant change in isokinetic knee extension torque over baseline.11 Effects of tape on the electromyographic activity of the quadriceps femoris in healthy adults also has conflicting results. Halski et al., for example, utilized kinesiology tape with tension and kinesiology tape without tension applied to the quadriceps and found no changes in resting or functional surface EMG.14 Halski et al., however, did not report the specific direction of tape application.14

Based on conflicting results and the methodological limitations of the current literature, additional studies utilizing rigorous methodology are needed to determine if the direction of tape application has an impact on muscle activation. The purpose of this double-blind crossover study was to determine if the direction of kinesiology tape application influences quadriceps activation and performance of functional tasks. This study compared taping techniques with a variety of outcome measures selected to assess quadriceps muscle activation, namely EMG recorded during isokinetic strength testing, and functional hop and jump performance.

METHODS

RESEARCH METHODS

This is a double-blind crossover study. Subjects gave informed consent to participate in this study. The study was approved by the Institutional Review Board and registered on ClinicalTrials.gov (NCT02318264).

PARTICIPANTS

We recruited study participants via e-mail correspondence and word of mouth. Eligible participants were between the ages of 18 to 35 and naive to the use of kinesiology tape. Exclusion criteria included musculoskeletal injury to the lower extremities (within the previous year), past surgery to the lower extremities, or known allergy to adhesive tape. All participants were screened for physical activity and exercise testing using the Physical Activity and Readiness Questionnaire (PAR-Q)15 (British Columbia Ministry of Health, British Columbia/Canada), resting vital signs, and American College of Sports Medicine guidelines for exercise testing.

TESTING PROCEDURES

Testing was performed in a motion analysis laboratory over 2 sessions with a 2-week washout period between sessions. The first session included informed consent followed by eligibility screening. Two potential participants were ineligible due to prior knowledge or training in the use of kinesiology tape. Refer to Figure 1 for the flow of testing procedures. Leg dominance was determined during the first session by asking participants to identify their preferred leg for kicking and jumping. Testing for each session began with a 5-minute warm up on a stationary bike followed by baseline testing (functional tests and isokinetics), which occurred prior to tape application. The order of baseline testing measures and tape condition was determined initially by a research assistant via a coin toss and then alternated. This process determined if the participant began testing with functional activities (single-leg triple hop for distance followed by vertical jump) or isokinetic knee extension. After baseline testing, subjects were taped by an individual who was not involved in measurement. Participants then repeat-
ed testing under the taped condition. Testing during sessions 1 and 2 was identical with the exception of the direction of tape application. Tape application direction was alternated such that some subjects were taped distal to proximal at session 1 and other subjects taped proximal to distal at session 1, with the direction for each subject reversed during session 2.

MEASUREMENTS

Single-Leg Triple Hop. Horizontal hop testing was utilized to provide a functional assessment of strength and neuromuscular control. Participants used their dominant leg to hop three consecutive times for maximal horizontal distance. The total hop distance was measured using a standard tape measure to the nearest 1.0 mm from the starting line to closest point of the participant’s heel. One practice trial and three testing trials were completed with a 30-second rest between each trial. Participants needed to maintain stationary contact with the ground on the dominant leg upon landing from the hop to allow for measurement of the total hop distance. A trial was repeated if the participant was unable to complete a triple hop without losing balance or contacted the ground with the opposite leg. In a previous study the single-leg triple hop for distance was reliable (test-retest) with interclass correlation coefficients of 0.92 and 0.96 for dominant and non-dominant limbs respectively. Munro et al. demonstrated that between session hop tests are moderately reliable (r=0.80 to 0.92).

Vertical Jump. We assessed lower extremity muscular strength and power using the vertical jump. Participants were asked to stand with their dominant side to the wall, with his/her feet together and parallel to the wall. In standing, the participant reached overhead and marked the wall to establish his/her reach height. The participant then performed one practice jump and three test jumps, each separated by 30 seconds of rest. Instructions were to jump as high as he/she can jump. Vertical distance was measured using a standard tape measure to the nearest 1.0 mm from reach height to peak height of each vertical jump. Vertical jump tests have been demonstrated to have high validity (r=0.99, p=0.001), intra-evaluator reproducibility (r=0.99, p=0.001) and inter-evaluator reproducibility (r=1.0, p=0.001).

Biodex Isokinetic Dynamometer. A Biodex System 3 Pro Isokinetic Dynamometer (Biodex, Shirley, NY/USA) was utilized to assess knee extension torque. We initialized and calibrated the Biodex before each testing session according to the manufacturer protocol. To measure mean and maximal knee extension torque, participants were positioned in the Biodex chair for hip and knee joint alignment and stabilization per the Biodex manual. Participants were tested in the seated position with the pelvic strap, thigh strap, and shoulder strap for stabilization to minimize upper body and pelvic or thigh motion during testing. The dynamometer was aligned with the anatomical axis of rotation of subjects’ knees. Biodex range of motion limits were set at the resting position (approximately 90 degrees of knee flexion) and at full knee extension. Gravity correction for limb weight was performed by the dynamometer and the software system.

Participants performed two practice repetitions for familiarization with the protocol and five test repetitions of full range concentric knee extension at 60°s⁻¹ and 120°s⁻¹. Standardized verbal encouragement was provided along

<table>
<thead>
<tr>
<th>Session 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Full participation screening performed.</td>
</tr>
<tr>
<td>2. Resting heart rate and blood pressure measurements were recorded.</td>
</tr>
<tr>
<td>3. Participants randomized to start with either distal-to-proximal or proximal-to-distal taping technique.</td>
</tr>
<tr>
<td>4. 5-minute warm up on a stationary bike followed by placement of EMG sensors.</td>
</tr>
<tr>
<td>5. Baseline testing</td>
</tr>
<tr>
<td>6. Tape application</td>
</tr>
<tr>
<td>7. Follow Up Testing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Session 2: 2 Weeks After Session 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Participants were asked about any change in health status.</td>
</tr>
<tr>
<td>2. Resting heart rate and blood pressure measurements were recorded.</td>
</tr>
<tr>
<td>3. 5-minute warm up on a stationary bike followed by placement of EMG sensors</td>
</tr>
<tr>
<td>4. Baseline testing</td>
</tr>
<tr>
<td>5. Tape application</td>
</tr>
<tr>
<td>6. Follow Up Testing</td>
</tr>
</tbody>
</table>

Figure 1: Flow of Testing Procedures
with a countdown for the number of remaining repetitions to be completed. All dynamic torque data were filtered, windowed, and gravity corrected through the software system. Outcome measures included mean and maximum torque (Nm) and average power at 60°s\(^{-1}\) and 120°s\(^{-1}\). Test-retest data for the Biodev have shown high intraclass correlation coefficients for peak knee extension torque testing at ranging from 0.88 to 0.97 at 60°s\(^{-1}\) and 180°s\(^{-1}\) and 60°s\(^{-1}\) to 300°s\(^{-1}\).

**Electromyography (EMG).** EMG data were collected during the isokinetic testing. Participants had pairs of round self-adhesive Ag/AgCl gel surface electrodes (Cleartrace, Conmed, Utica, NY/USA), with diameter of active region = 23 mm) placed over the vastus lateralis and vastus medialis of the test limb. For the vastus medialis, the distance from the anterior superior iliac spine (ASIS) to the medial joint line was measured and two electrodes were placed on 4/5 (80%) of that line, 55 mm apart (on-center). For the vastus lateralis, the distance from the ASIS to the lateral joint line was measured and two electrodes were placed at 2/3 (66%) of that line, 55 mm apart. Reliability of quadriceps surface EMG is improved by recording from two sites per muscle. Balshaw demonstrated this approach with the quadriceps and found decreased coefficient of variations by 16-26%. Another Cleartrace electrode was placed over the C7 spinous process of the neck, and connected to the ground input of the EMG amplifier. The skin under all targeted electrode sites was wiped with an alcohol swab, then gently rubbed with Nu-Prep Skin Prep Gel (Weaver and Co.) applied with a cotton gauze pad.

EMG signals were amplified (gain = 1000) and filtered (2 Hz – 2.5 kHz), digitized (sampling rate: 5000 Hz; Power 1401; (Cambridge Electronic Devices [CED], Cambridge/ England), displayed visually on a computer monitor, and stored for later analysis. A differential amplifier (Intronix 2024F) with a remote preamplifier (unity gain) was used. This device has an input impedance of 100 GΩ, common mode rejection >90 dB (@ 60 Hz), a signal: noise ratio >110 dB, and employs active Butterworth filters. Audio feedback of EMG to the participant was avoided. For analysis, EMG was DC-offset to zero volts. The EMG magnitude (root-mean-squared, in mV) during each contraction was quantified (Spike2; CED). This measure reflects the mean activity between cursors positioned just after the onset and prior to offset of contraction-related activity, hence is independent of a time component.

**INTERVENTION (TAPE APPLICATION)**

Kinesio® Tex Gold™ was applied by the same physical therapist (20+ years of experience) who completed Kinesio Taping Fundamentals Concepts and Advanced Concepts provided by Kinesio Taping Association International® in Syracuse, NY/USA, and had over 15 years’ experience with Kinesio Taping. The tape was applied to the dominant lower extremity of each participant using a Y-strip method. For the Y-strip method proximal to distal application the base of the Y cut tape was applied to the dominant quadriceps muscles from the Anterior Inferior Iliac Spine (AIIS) to just proximal to the patella. The tape split at the patella with the short tails of the Y cut wrapping around the knee medial-

![Figure 2: Intervention Tape Application](image)

ly and laterally, and meeting at the tibial tuberosity (Figure 2). For the distal to proximal application the tape was applied in the same manner but started at the tibial tuberosity and terminated at the AIIS. For each application (proximal to distal and distal to proximal) approximately 25% tension was applied to the quadriceps (therapeutic zone) and the tape was anchored with no tension on the tails of tape at either the AIIS or tibial tuberosity. Investigators performing EMG and functional tests were blinded to tape direction. Participants were unaware that tape direction was being tested and they were naïve to the application direction theory of elastic tape. Two different colors of tape were utilized in an attempt to distract the participant from the variation in taping direction between sessions.

**STATISTICAL ANALYSIS**

The same investigator performed all analyses, was blinded to the taping direction, and was not involved in testing. For each tape condition the average and peak values of multiple trials were calculated. Individual subjects’ average and peak values were pooled and described using means and standard deviations. Reliability was assessed by calculating interclass correlation coefficients (ICC) using the two baseline (no tape) conditions for each trial session. Minimal detectable change (MDC) for each testing condition was determined from peak values obtained during testing using the method described by Haley and Fragala-Pinkham. Two-way, repeated measures ANOVAs were used to assess associations between tape direction and each outcome (muscle force, EMG activity, hop and jump performance). For each analysis, factors included tape condition (tape proximal-distal v. distal-proximal) and time (baseline [no tape] v. taped condition). Thus, for each analysis the outcome of interest...
Table 1: Subject Characteristics (n=15)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value (Mean ± Standard Deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>23.3±1.75</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>65.6±13.32</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>168.9±10.67</td>
</tr>
</tbody>
</table>

Values are Means ± Standard Deviations

Table 2: ICC (2,1) and MDC for Peak (Maximum) Values Under Testing Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>ICC (2,1)</th>
<th>MDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jump height (Cm)</td>
<td>.973</td>
<td>6.90</td>
</tr>
<tr>
<td>Hop distance (Cm)</td>
<td>.952</td>
<td>42.0</td>
</tr>
<tr>
<td>Isokinetic torque – 60 deg./sec (N-M)</td>
<td>.874</td>
<td>33.1</td>
</tr>
<tr>
<td>Isokinetic torque – 120 deg./sec (N-M)</td>
<td>.917</td>
<td>32.8</td>
</tr>
<tr>
<td>EMG output – medial quadriceps, 60 deg./sec. (Mv)</td>
<td>.735</td>
<td>.120</td>
</tr>
<tr>
<td>EMG output – medial quadriceps, 120 deg./sec. (Mv)</td>
<td>.719</td>
<td>.127</td>
</tr>
<tr>
<td>EMG output – lateral quadriceps, 60 deg./sec. (Mv)</td>
<td>.643</td>
<td>.116</td>
</tr>
<tr>
<td>EMG output – lateral quadriceps, 120 deg./sec. (Mv)</td>
<td>.480</td>
<td>.164</td>
</tr>
</tbody>
</table>

ICC, Intraclass correlation coefficient; MDC, Minimal detectable change; Cm, Centimeters; N-M, Newton-Meters; EMG, Electromyography; Mv, Millivolts.

RESULTS

Ten females and 5 males completed the study. Mean (SD) age was 23.3 (1.8) years. Descriptive characteristics of the participants are presented in Table 1. Intraclass correlation coefficients (2,1) are displayed in Table 2. Table 3 displays mean and maximum EMG output of the medial and lateral quadriceps, for each taped direction under baseline (no tape) and taped conditions and the baseline-taped differences, at 60 and 120°s⁻¹ knee rotation rates. Two-way, repeated measures ANOVAs resulted in no significant differences in baseline-taped conditions in EMG output according to tape direction. Average power at 60°s⁻¹ increased by 6.5°s⁻¹ for the proximal to distal taped condition and decreased by 2.1°s⁻¹ for the distal to proximal taped condition. This was at a significance level of 0.03. Due to the multiple comparisons used in this study and the subsequent risk of error rate inflation, this was not considered significant.

Table 4 displays mean and maximum isokinetic quadriceps torque, for each taped direction under baseline and taped conditions and the baseline-taped differences, at 60°s⁻¹ and 120°s⁻¹. Two-way, repeated measures ANOVAs resulted in no significant differences in baseline-taped conditions in knee extension torque according to tape direction. Average power at 60°s⁻¹ increased by 6.5°s⁻¹ for the proximal to distal taped condition and decreased by 2.1°s⁻¹ for the distal to proximal taped condition. This was at a significance level of 0.03. Due to the multiple comparisons used in this study and the subsequent risk of error rate inflation, this was not considered significant.

Table 5 displays mean and maximum triple-hop distance and vertical jump height, for each taped direction under baseline and taped conditions and the baseline-taped differences with effect sizes. Two-way, repeated measures ANOVAs resulted in no significant differences in baseline-taped conditions in triple-hop distance or in vertical jump height according to tape direction. Average hop distance increased 13.7 cm for the proximal to distal taped condition and decreased 0.7 cm for the distal to proximal taped condition (p=0.0462). Maximum hop distance increased 9.4 cm for the proximal to distal taped condition and decreased 5.8 cm for the distal to proximal taped condition (p=0.0331). Effect sizes for these measures were trivial at best.

DISCUSSION

Kinesiology tape has been commonly used in clinical practice to influence muscle recruitment despite a lack of evidence to support this use. The purpose of this study was to determine if the direction of elastic tape application applied to the quadriceps influences muscle activation. Our results show that kinesiology tape application direction is not associated with significant changes in quadriceps EMG output, isokinetic performance, jump height, or hop distance. The average single leg triple hop distance in our study increased 13.7 cm for the proximal to distal taped condition and decreased 0.7 cm for the distal to proximal taped condi-
The study included 34 volunteers and the participants were randomly assigned to one of three groups: No tape, Non-Elastic tape, and Kinesio tape. Vercelli et al. conducted a single blinded study of kinesiology tape applied to the quadriceps utilizing three tape conditions (tape applied to the Vastus Medialis, Vastus Lateralis, and Rectus Femoris, and kinesiology tape applied P-D with 50% tension to the same muscles). There was no significant difference in EMG, concentric and eccentric peak torque, single leg hop distance at 5 time-points in subjects taped with a horizontally applied placebo tape, a proximal to distally applied experimental tape, and a no tape control group. Researchers concluded that kinesiology tape did not improve quadriceps strength or hopping distance. Unlike

Lins et al. also found that Kinesio® Tape applied to the quadriceps did not cause significant changes in neuromuscular performance or lower limb function. Their design included three groups of 20 women: No tape, Non-Elastic tape applied to the Vastus Medialis, Vastus Lateralis, and Rectus Femoris, and kinesiology tape applied P-D with 50% tension to the same muscles. There was no significant difference in EMG, concentric and eccentric peak torque, single leg hop, single leg triple hops, or single leg balance.

A 2016 randomized controlled trial by Fernandes de Jesus et al. found no difference in dynamometer measurement and single leg hop distance at 5 time-points in subjects taped with a horizontally applied placebo tape, a proximal to distally applied experimental tape, and a no tape control group. Researchers concluded that kinesiology tape did not improve quadriceps strength or hopping distance. Unlike

**Table 3: Mean and Maximum EMG Output for Medial and Lateral Quadriceps Muscles at 120 and 60 Degrees per Second**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Baseline P-D</th>
<th>Taped P-D</th>
<th>P-D Condition Difference (95% CI)</th>
<th>Effect Size</th>
<th>Baseline D-P</th>
<th>Taped D-P</th>
<th>D-P Condition Difference (95% CI)</th>
<th>Effect Size</th>
<th>p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean, Lateral Quadriceps, 120 deg./sec.</td>
<td>0.1796 ±0.0551</td>
<td>0.1847 ±0.0657</td>
<td>0.0052 (-0.0058, 0.0161)</td>
<td>0.93</td>
<td>0.2063 ±0.0879</td>
<td>0.1964 ±0.0827</td>
<td>-0.0099 (-0.0241, 0.0043)</td>
<td>0.113</td>
<td>0.1008</td>
</tr>
<tr>
<td>Maximum, Lateral Quadriceps, 120 deg./sec.</td>
<td>0.1987 ±0.0569</td>
<td>0.2071 ±0.0727</td>
<td>0.0084 (-0.0070, 0.0238)</td>
<td>0.148</td>
<td>0.2328 ±0.0993</td>
<td>0.2234 ±0.0980</td>
<td>-0.0094 (-0.0246, 0.0058)</td>
<td>0.095</td>
<td>0.1105</td>
</tr>
<tr>
<td>Mean, Medial Quadriceps, 120 deg./sec.</td>
<td>0.2274 ±0.0965</td>
<td>0.2195 ±0.0873</td>
<td>-0.0079 (-0.0234, 0.0075)</td>
<td>0.080</td>
<td>0.2330 ±0.0991</td>
<td>0.2319 ±0.1010</td>
<td>-0.0012 (-0.0100, 0.0076)</td>
<td>0.011</td>
<td>0.3887</td>
</tr>
<tr>
<td>Maximum, Medial Quadriceps, 120 deg./sec.</td>
<td>0.2511 ±0.1032</td>
<td>0.2469 ±0.0965</td>
<td>-0.0042 (-0.0171, 0.0088)</td>
<td>0.041</td>
<td>0.2616 ±0.1089</td>
<td>0.2612 ±0.1118</td>
<td>-0.0004 (-0.0152, 0.0145)</td>
<td>0.004</td>
<td>0.7005</td>
</tr>
<tr>
<td>Mean, Lateral Quadriceps, 60 deg./sec.</td>
<td>0.1925 ±0.0712</td>
<td>0.1978 ±0.0727</td>
<td>0.0053 (-0.0074, 0.0180)</td>
<td>0.074</td>
<td>0.2257 ±0.0997</td>
<td>0.2271 ±0.0961</td>
<td>0.0014 (-0.0143, 0.0170)</td>
<td>0.014</td>
<td>0.5808</td>
</tr>
<tr>
<td>Maximum, Lateral Quadriceps, 60 deg./sec.</td>
<td>0.2089 ±0.0745</td>
<td>0.2248 ±0.0867</td>
<td>0.0159 (-0.0035, 0.0352)</td>
<td>0.213</td>
<td>0.2463 ±0.1106</td>
<td>0.2438 ±0.1056</td>
<td>-0.0026 (-0.0241, 0.0190)</td>
<td>0.023</td>
<td>0.0601</td>
</tr>
<tr>
<td>Mean, Medial Quadriceps, 60 deg./sec.</td>
<td>0.2406 ±0.1203</td>
<td>0.2392 ±0.1057</td>
<td>-0.0014 (-0.0195, 0.0168)</td>
<td>0.012</td>
<td>0.2478 ±0.0977</td>
<td>0.2497 ±0.1020</td>
<td>0.0020 (-0.0186, 0.0226)</td>
<td>0.019</td>
<td>0.7390</td>
</tr>
<tr>
<td>Maximum, Medial Quadriceps, 60 deg./sec.</td>
<td>0.2632 ±0.1301</td>
<td>0.2672 ±0.1212</td>
<td>0.0041 (-0.0155, 0.0236)</td>
<td>0.031</td>
<td>0.2690 ±0.1052</td>
<td>0.2724 ±0.1165</td>
<td>0.0034 (-0.0190, 0.0258)</td>
<td>0.032</td>
<td>0.9505</td>
</tr>
</tbody>
</table>

*p-values are from 2-way, repeated measures ANOVAs, hypothesis test for time x condition interaction
Taped Conditions: P-D = Proximal to Distal, D-P = Distal to Proximal
CI = Confidence Interval
Data are reported in Millivolts; Values are Means ± Standard Deviations except where otherwise noted

Does the Direction of Kinesiology Tape Application Influence Muscle Activation in Asymptomatic Individuals?

International Journal of Sports Physical Therapy
our study, both the Lins and Fernandes de Jesus studies did not precisely follow the proposed Kinesio Taping Association International® taping method for facilitation or inhibition. Our results are also in alignment with a study by Cheung et al. that examined vertical jump performance utilizing a...

Table 4: Mean and Maximum Knee Extension Torque at 120 and 60 Degrees per Second

<table>
<thead>
<tr>
<th>Condition</th>
<th>Baseline P-D Condition</th>
<th>Taped P-D Condition</th>
<th>P-D Condition Difference (95% CI)</th>
<th>Effect Size</th>
<th>Baseline D-P Condition</th>
<th>Taped D-P Condition</th>
<th>D-P Condition Difference (95% CI)</th>
<th>Effect Size</th>
<th>p- value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Peak Torque, 120 deg./sec.</td>
<td>124.7 ±50.6</td>
<td>128.3 ±52.1</td>
<td>3.6 (-5.7, 12.8)</td>
<td>.071</td>
<td>118.1 ±49.3</td>
<td>121.6 ±54.0</td>
<td>3.5 (-4.6, 11.5)</td>
<td>.071</td>
<td>0.9920</td>
</tr>
<tr>
<td>Maximum Peak Torque, 120 deg./sec.</td>
<td>134.8 ±50.9</td>
<td>136.8 ±54.3</td>
<td>2.0 (-7.5, 11.6)</td>
<td>.039</td>
<td>135.9 ±61.5</td>
<td>132.9 ±55.7</td>
<td>-3.0 (-12.5, 6.5)</td>
<td>.049</td>
<td>0.3741</td>
</tr>
<tr>
<td>Average Power, 120 deg./sec.</td>
<td>150.3 ±62.2</td>
<td>155.6 ±65.6</td>
<td>5.3 (-6.4, 17.1)</td>
<td>.085</td>
<td>139.8 ±61.4</td>
<td>145.5 ±69.2</td>
<td>5.8 (-4.0, 15.5)</td>
<td>.093</td>
<td>0.9421</td>
</tr>
<tr>
<td>Average Peak Torque, 60 deg./sec.</td>
<td>156.3 ±59.9</td>
<td>159.2 ±59.8</td>
<td>2.9 (-17.3, 13.0)</td>
<td>.048</td>
<td>159.3 ±64.4</td>
<td>153.3 ±62.3</td>
<td>-6.0 (-13.6, 1.6)</td>
<td>.093</td>
<td>0.0814</td>
</tr>
<tr>
<td>Maximum Peak Torque, 60 deg./sec.</td>
<td>172.3 ±65.5</td>
<td>169.4 ±62.6</td>
<td>-2.9 (-12.2, 6.3)</td>
<td>.044</td>
<td>175.5 ±73.8</td>
<td>165.0 ±63.5</td>
<td>-10.5 (-20.8, -0.2)</td>
<td>.142</td>
<td>0.1059</td>
</tr>
<tr>
<td>Average Power, 60 deg./sec.</td>
<td>102.0 ±40.3</td>
<td>108.5 ±42.0</td>
<td>6.5 (0.6, 12.4)</td>
<td>.161</td>
<td>107.2 ±43.4</td>
<td>105.0 ±44.1</td>
<td>-2.1 (-7.9, 3.7)</td>
<td>.051</td>
<td>0.0300</td>
</tr>
</tbody>
</table>

* p-values are from 2-way, repeated measures ANOVAs, hypothesis test for time x condition interaction
Taped Conditions: P-D = Proximal to Distal, D-P = Distal to Proximal
CI = Confidence Interval
Data are reported in Newton·Meters; Values are Means ± Standard Deviations, except where otherwise noted

Table 5: Mean and Maximum Hop Distance and Jump Height

<table>
<thead>
<tr>
<th>Condition</th>
<th>Baseline P-D Condition</th>
<th>Taped P-D Condition</th>
<th>P-D Condition Difference (95% CI)</th>
<th>Effect Size</th>
<th>Baseline D-P Condition</th>
<th>Taped D-P Condition</th>
<th>D-P Condition Difference (95% CI)</th>
<th>Effect Size</th>
<th>p- value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Hop Distance</td>
<td>468.4 ±90.8</td>
<td>482.0 ±99.5</td>
<td>13.7 (-2.5, 29.8)</td>
<td>.150</td>
<td>472.3 ±88.1</td>
<td>471.5 ±91.6</td>
<td>-0.7 (-12.3, 10.9)</td>
<td>.009</td>
<td>0.0462</td>
</tr>
<tr>
<td>Maximum Hop Distance</td>
<td>484.8 ±95.0</td>
<td>494.2 ±101.6</td>
<td>9.4 (-3.3, 22.1)</td>
<td>.102</td>
<td>486.0 ±89.1</td>
<td>482.2 ±89.1</td>
<td>-3.8 (-16.3, 8.8)</td>
<td>.043</td>
<td>0.0331</td>
</tr>
<tr>
<td>Average Jump Height</td>
<td>41.6 ±18.0</td>
<td>41.1 ±16.8</td>
<td>-0.5 (-2.6, 1.6)</td>
<td>.028</td>
<td>40.9 ±18.5</td>
<td>41.6 ±18.3</td>
<td>0.7 (-1.4, 2.7)</td>
<td>.038</td>
<td>0.4480</td>
</tr>
<tr>
<td>Maximum Jump Height</td>
<td>43.0 ±17.7</td>
<td>42.3 ±16.9</td>
<td>-0.7 (-3.0, 1.5)</td>
<td>.040</td>
<td>42.6 ±18.2</td>
<td>42.8 ±18.2</td>
<td>0.2 (-2.1, 2.5)</td>
<td>.011</td>
<td>0.6132</td>
</tr>
</tbody>
</table>

* p-values are from 2-way, repeated measures ANOVAs, hypothesis test for time x condition interaction
Taped Conditions: P-D = Proximal to Distal, D-P = Distal to Proximal
CI = Confidence Interval
Data are reported in cm; Values are Means ± Standard Deviations, except where otherwise noted
Smartjump\textsuperscript{TM} (Fusion Sport, Queensland, Australia) force pad and a “deceptive crossover” design.\textsuperscript{29} In their study, kinesiology tape was applied (Facilitative kinesiology tape, Sham kinesiology tape, and No tape) to the quadriceps and to the gastrocnemius/soleus under the guise of applying muscle sensors. Their results indicated that kinesiology tape application does not make a meaningful change in vertical jump height.

An innovative design by Poon utilized blindfolds to cover the eyes of participants while they were taped under three different conditions (No tape, kinesiology tape applied proximal to distal with 35% tape tension, and Sham kinesiology tape defined as no tension on tape).\textsuperscript{5} This study reported no statistically significant differences in isokinetic peak torque at 60°s\textsuperscript{-1} and 90°s\textsuperscript{-1}, total work or time to peak torque.

Several studies reported that kinesiology tape application technique to the quadriceps did make a difference for muscle recruitment. A study by Mostaghim et al. tested 2 groups (no tape, kinesiology tape applied proximal to distal with 15 to 25% tension also known as “paper off” tension).\textsuperscript{6} Their taping technique was a variation of that used in the present study, as it started in the middle of the thigh instead of anchored proximally at the AIIS. They reported a statistically significant difference in vertical jump (mean difference of 0.95 cm), however, the clinical significance of this small difference is unclear. Mostaghim et al. also reported a small but statistically significant difference in maximum voluntary isometric quadriceps contraction utilizing a digital myometer but without EMG.\textsuperscript{6}

Wong et al. demonstrated a shorter time to peak torque during knee extension with the tape condition (p < 0.001).\textsuperscript{30} This is in contrast to the findings by Guedes et al. in which they found no significant difference between groups with kinesiology tape applied to the quadriceps for time to reach peak torque.\textsuperscript{31} Unlike the Guedes et al. study and our study, the study by Wong et al. did not include a placebo or control group.\textsuperscript{30}

The results of our study are also in contrast to the work by Yeung et al. in which kinesiology tape treatment resulted in higher knee extension peak torque at 60°s\textsuperscript{-1} compared to inhibitory taping.\textsuperscript{32} The peak torque difference was small (Cohen’s d=0.26). Yeung et al. did not find a statistically significant difference under three taping conditions for EMG or patellar reflex latency.

Discrepancies in the literature may be explained by the lack of clear mechanism(s) by which tape application and specifically tape application direction may influence muscle activation. Several mechanisms have been proposed including neural effects and mechanical effects. Neural effects may occur through tactile driven facilitation of cutaneous receptors and mechanical effects may be mediated by the impact of tape on muscle length.\textsuperscript{5-8}

It is possible that the mechanism may vary related to the specific population tested. Tape application direction may have less impact on individuals who are not injured or not in pain. Our participants were healthy and active young adults with no complaints of pain or recent injury. This is consistent with the meta-analysis by Csapo et al. in that kinesiology tape did not increase strength in healthy participants and work by Fu et al., who speculated that the tactile input of kinesiology tape may not be strong enough to stimulate the muscles of healthy athletes.\textsuperscript{3,8} Without a clear mechanism of action and given the consistent findings that tape direction does not have an impact on muscle function in healthy active adults, it is questionable whether continued scientific exploration of this concept is warranted.

STRENGTHS AND LIMITATIONS

Strengths of the current study include a repeated measures design and corresponding statistical analysis in which subjects acted as their own controls. This ensured that both within-subject and between-condition variability were addressed. Additionally, our study used double blinding. The practitioner applying the tape did not make observations and participants were not informed of the two different taping directions. Also, two different tape colors were utilized as a potential distractor from the taping technique. Another strength of this study was the use of a rigorous conservative statistical approach. Reliability of the triple hop distance and jump height was excellent and the reliability of isokinetic performance was very good.

There are several limitations to our study. This was a relatively small homogeneous sample of convenience. This study has limited generalizability as the participants were young, healthy adults without musculoskeletal injury. The use of a crossover design reduced the threat to internal validity resulting from the small sample, but generalizability may be limited. The study may be underpowered due to a small sample size of 15. Post-hoc power analysis for maximum hop distance change (the outcome that was closest to being significant) revealed a power of 55% given the sample size of 15 and the adjusted alpha of 0.0125. To achieve a significant difference (adjusted alpha =.0125) at an effect size of .102 (see Table 5) 34 participants would be required. Contributing to suboptimal power was the modest correlation (r =.55) of change scores between taped conditions. With a sample size of 15, the smallest difference in maximum hop distance change between the two conditions that our study could detect would be 21 mm, assuming adequate (80%) power and the adjusted alpha of .0125. A limitation related to tape color is that we did not assess the effectiveness of the subject blinding or distraction using tape color. Tape application may have been improved by the standardization of tape tension using a strain gauge. Reliability for EMG measurements was poor to fair. Despite these limitations, we feel that the repeated measures design with blinding of the participants and testers makes this study a valuable contribution to the literature on kinesiology tape.

CLINICAL IMPLICATIONS

Kinesiology tape continues to be commonly utilized by clinicians and athletes despite evidence that questions its effectiveness for muscle activation. The results of our pilot study add to the growing body of literature that suggests kinesiology tape application and specifically kinesiology tape application direction does not have a significant impact on quadriceps function. Clinicians and athletes who utilize kinesiology tape should be aware of this evidence when mak-
ing decisions about if and how to utilize kinesiology tape.

CONFLICTS OF INTEREST

All authors declare no conflicts of interests.

Submitted: June 20, 2020 CST, Accepted: October 10, 2020 CST

This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY-NC-ND-4.0). View this license’s legal deed at https://creativecommons.org/licenses/by-nc-nd/4.0 and legal code at https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode for more information.
REFERENCES


---

**International Journal of Sports Physical Therapy**
Original Research

Quadriceps Strength Influences Patient Function More Than Single Leg Forward Hop During Late-Stage ACL Rehabilitation

Meredith Chaput, PT¹, Marcus Palimenio, PT, ATC², Brooke Farmer, MS, ATC³, Dimitrios Katsavelis, PhD⁴, Jennifer J. Bagwell, PT, PhD⁵, Kimberly A. Turman, MD⁶, Chris Wichman, PhD⁷, Terry L. Grindstaff, PhD, PT, ATC¹ a

¹ Department of Physical Therapy, Ohio University, ² Makovicka Physical Therapy, ³ Department of Physical Therapy, Creighton University, ⁴ Department of Exercise Science and Pre-Health Professions, Creighton University, ⁵ Department of Physical Therapy, California State University Long Beach, ⁶ MD West ONE, ⁷ Department of Biostatistics, University of Nebraska Medical Center

Keywords: quadriceps strength, movement system, hop test, anterior cruciate ligament reconstruction

10.26603/001c.18709

International Journal of Sports Physical Therapy
Vol. 16, Issue 1, 2021

Background
A comprehensive battery of tests are used to inform return to play decisions following anterior cruciate ligament (ACL) reconstruction. Performance measures contribute to patient function, but it is not clear if achieving symmetrical performance on strength and hop tests is sufficient or if a patient also needs to meet minimum unilateral thresholds.

Hypothesis/Purpose
To determine the association of quadriceps strength and single-leg forward hop performance with patient-reported function, as measured by the IKDC Subjective Knee Form (IKDC), during late-stage ACL rehabilitation. A secondary purpose was to determine which clinical tests were the most difficult for participants to pass.

Study Design
Descriptive Laboratory Study

Methods
Forty-eight individuals with a history of ACL-R (32 female, 16 male; mean±SD age=18.0±2.7 y; height=172.4±7.6 cm; mass=69.6±11.4 kg; time since surgery=7.7±1.8 months; IKDC=86.8±10.6) completed the IKDC survey, quadriceps isometric strength, and single-leg forward hop performance. The relationship between IKDC scores and performance measures (LSI and involved limb) was determined using stepwise linear regression. Frequency counts were used to determine whether participants met clinical thresholds (IKDC ≥ 90%, quadriceps and single-leg forward hop LSI ≥ 90%, quadriceps peak torque ≥ 3.0 Nm/kg, and single-leg forward hop ≥ 80% height for females and ≥ 90% height for males).

Results
Quadriceps LSI and involved limb peak torque explained 39% of the variance in IKDC scores while measures of single-leg forward hop performance did not add to the predictive model. Nearly 90% of participants could not meet established clinical thresholds on all five tests and quadriceps strength (LSI and peak torque) was the most common unmet criteria (71% of participants).

Conclusions
During late-stage ACL rehabilitation deficits in quadriceps strength contribute more to patient function and are greater in magnitude compared to hop test performance.

a Corresponding Author: Terry L. Grindstaff Creighton University, School of Pharmacy & Health Professions Physical Therapy Department 2500 California Plaza, Omaha, NE 68178. E-mail: GrindstaffTL@gmail.com
INTRODUCTION

Approximately 250,000 anterior cruciate ligament (ACL) injuries occur each year in the United States, mostly impacting physically active individuals ages 15 to 25 years.¹ Risk of reinjury is high for the first two years following ACL reconstruction (ACL-R),² and risk is further increased for those who demonstrate impairments and disability at return to sport.³,⁴ A comprehensive battery of measures, including patient-reported outcome measures, strength tests, and hop tests, are used to inform return to sport decisions.³–⁵ Patient-reported outcome measures, such as the International Knee Documentation Committee Subjective Knee Form (IKDC) are frequently used after ACL-R,⁶,⁷ and provide insights into the patient’s perception of their functional abilities ranging from activities of daily living to sport activities (e.g. squat, run, jump).⁸

The IKDC is used in conjunction with performance-based outcome measures, such as quadriceps strength and single-leg forward hop performance, to inform rehabilitation progression and return to sport decisions.³–⁵ Measures from the uninvolved limb are used as a patient specific reference standard and a limb symmetry index (LSI=involved/uninvolved) is calculated to express the magnitude of differences between limbs. An LSI greater than or equal to 90% is often used as a clinical threshold indicative of recovery⁵,⁹ and meeting these thresholds is thought to decrease the risk of re-injury.³,⁴ A limitation of the LSI is that it may overestimate performance,¹⁰,¹¹ specifically if the uninvolved limb (i.e. comparison limb) has a history of previous injury¹² or develops weakness due to disuse.¹⁰,¹³,¹⁴ Diminished performance in the uninvolved limb can result in more symmetrical LSI values, but identifies symmetrically poor performance (e.g. two symmetrically flat bike tires). It is suggested that LSI values also be interpreted in context to normative performance benchmarks¹⁵ to ensure patients achieve symmetrical performance between limbs and that the overall performance meets age, sex, and/or sport performance thresholds. Clinical thresholds have been established for both isometric quadriceps strength (5.0-3.1 Nm/kg)¹⁶,¹⁷ and single leg forward hop performance (females 80% of height, males 90% of height),¹⁸ but the incorporation of unilateral thresholds to inform return to sport decisions is limited.⁵,¹⁹–²¹

Hop performance (e.g., forward hop, timed side hop, vertical jump) and patient-reported outcome measures are relatively easy to obtain in a clinical environment at little cost and with minimal equipment. Conversely, quantifiable measures of quadriceps strength require more expensive specialized equipment (e.g., electromechanical or handheld dynamometer) that may not be available in all clinical environments. These factors likely contribute to practice patterns of clinicians which indicate only about 40% of physicians and 55% of physical therapists utilize a quantifiable measure of quadriceps strength following ACL-R while 60% to 89% of providers utilize hop tests.²²,²³ Since there is a moderate to good positive relationship between LSI values for quadriceps strength and hop distance (R²= 0.41) in individuals with a history of ACL-R,²⁴ it is often assumed that inferences regarding quadriceps strength can be made based on hop test performance. This assumption is not correct as quadriceps strength LSI deficits are of greater magnitude when compared hop tests.⁵,¹⁹,²⁵–²⁸ Using only functional performance measures and failure to obtain quantified quadriceps strength measures limits well-informed return to sport decisions and places a greater emphasis on measures that can be influenced by compensatory movement strategies yet yield similar performance (i.e., hop distance) between limbs.²⁹,³⁰

Deficits in both quadriceps LSI and single-leg forward hop LSI are known to negatively impact patient-oriented outcomes following ACL-R²⁴,³¹ but evidence is conflicting regarding the relationship between quadriceps strength symmetry, single-leg forward hop performance symmetry, and patient-reported function.²⁰,₂⁶,₃₂ While previous studies have examined the individual contribution of LSI values or unilateral performance on patient-reported outcomes,³² there is limited research examining the collective contributions of both LSI values and unilateral performance. More specifically it is not known if achieving symmetrical performance is enough or if a patient also needs to meet minimum unilateral thresholds. Better understanding the relationships between performance- and patient-oriented measures can help optimize rehabilitation approaches and maximize knee function after ACL-R at the time return to sport decisions are being made. Therefore, the purpose of this study was to determine the association of quadriceps strength and single-leg forward hop performance with patient-reported function, as measured by the IKDC, during late-stage ACL rehabilitation. It was hypothesized that measures of quadriceps strength (peak torque and LSI) would better predict patient-reported outcome measures than single-leg forward hop (distance and LSI). In an effort to better guide rehabilitation efforts, a secondary purpose was to determine which clinical tests were the most difficult for participants to reach established thresholds. It was hypothesized that quadriceps peak torque would be the most difficult clinical test to achieve established thresholds.

METHODS

PARTICIPANTS

This was a cross-sectional study and all data collection was completed in a university research laboratory. Forty-eight individuals with a history of ACL-R volunteered for this study (Table 1). Participants were recruited or referred from the surrounding community (physical therapy clinics, athletic training rooms, orthopedic surgeon offices) and we did not control or monitor rehabilitation approaches. Measures collected during this study were used to help inform return to sport decisions during late stages of ACL rehabilitation as requested by the participant’s medical care team (physician, physical therapist, athletic trainer). Actual return to sport status was not specifically monitored. Inclusion cri-
teria included (1) unilateral ACL-R with bone-patellar tendon-bone or semitendinosus autograft, meniscus pathology permitted, (2) ≥ 5 months following surgical reconstruction, (3) age 14-25, (4) participation in athletics at recreational level or higher (Tegner Activity Scale Score ≥ 6). Exclusion criteria included (1) bilateral knee injury or (2) previous knee injury requiring surgical intervention, or other ligament injury (medial collateral, posterior collateral) that required surgical repair. All ACL revision and multiple ligament repairs were also excluded. The current study was part of two larger studies used to clinically inform return to sport decisions and was approved by the Creighton University Institutional Review Board (IRB 656803 and 928791).

All participants signed an approved informed consent form, compliant with the Declaration of Helsinki, and completed a standardized health history form. Participants first completed measures of height and body mass, then performed tests to determine maximum quadriceps isometric strength followed by single-leg forward hop tests, and finished with patient-reported outcome measure (IKDC).

OUTCOME MEASURES

PATIENT-REPORTED OUTCOME MEASURES

The IKDC Subjective Knee Form was used to quantify patient-reported function and includes 18 questions related to symptoms, function, and sport activity (0–100), with higher scores indicative of better status. The IKDC has good intersession reliability (ICC= 0.95 95% CI= 0.91–0.98) and a minimal detectable change of 8.8 points.35

QUADRICEPS STRENGTH

Isometric quadriceps strength was assessed using an electromechanical dynamometer (BiodeX System 3; Computer Sports Medicine Inc., Stoughton, MA, USA) and standardized procedures with the knee at 90° knee flexion.34–36

The dynamometer was interfaced with a data acquisition system (MP150; Biopac Systems, Inc., Goleta, CA, USA) and torque data were sampled at 2000 Hz. Quadriceps strength was measured on both limbs, with the uninvolved limb measured first. Participants performed a standardized and progressive warm-up, including submaximal and maximal isometric contractions. The maximum torque was obtained during the warm-up and used to provide visual feedback (e.g., computer monitor with torque provided in real-time) during subsequent trials. Participants were provided visual feedback of torque (90% and 100% targets) and loud verbal encouragement to ensure maximal effort during testing.37

Following the warm-up, participants performed two trials, at maximum effort, with the average peak torque (Nm) normalized to body mass (Nm/kg) used for data analysis. An LSI was also calculated by dividing the involved limb quadriceps peak torque by the uninvolved limb quadriceps peak torque and expressed as a percentage. Measures of quadriceps strength using an electromechanical dynamometer have good to excellent intersession reliability (ICC 0.98).38

SINGLE-LEG FORWARD HOP

Participants performed the single-leg forward hop, which requires a maximum jump for distance and a controlled single-leg landing.5,31 Participants began the forward hop in a single limb stance position where they could utilize counter arm movement and were instructed to hop as far forward as possible while maintaining a controlled single-leg landing, defined as maintaining position on a single leg for at least two seconds. An unsuccessful hop was classified by loss of balance resulting in contralateral lower extremity touchdown, either upper extremity touchdown, excessive loss of balance, additional hops upon landing, or sliding of the heel. If a hop was unsuccessful, the participant was reminded of criteria for a successful hop, and they completed additional trials until a successful hop was obtained. Participants performed three successful trials. Trial one was used as a warm-up and the maximum distance (cm) of trials two or three was used for data analysis. Hop distance normalized to height was recorded and expressed as a percentage for data analysis. Single-leg forward hop distance was also represented as an LSI by dividing the involved limb distance by the uninvolved distance and expressed as a percentage. The single-leg forward hop has excellent between session reliability (ICC= 0.92 to 0.95) and a minimal detectable change of 8% for limb symmetry index39 and 13-14 cm for absolute distance.40

STATISTICAL ANALYSIS

Statistical analysis was conducted using SPSS software (version 26.0 IBM SPSS Statistics; Armonk, NY, USA). Mean values and standard deviations were calculated for all vari-

Table 1: Participant demographics. Values are mean ± standard deviation or frequency counts.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean ± SD or Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>32 female; 16 male</td>
</tr>
<tr>
<td>Age</td>
<td>18.0 ± 2.7 years</td>
</tr>
<tr>
<td>Height</td>
<td>172.4 ± 7.6 cm</td>
</tr>
<tr>
<td>Mass</td>
<td>69.6 ± 11.4 kg</td>
</tr>
<tr>
<td>Time Since Surgery</td>
<td>7.7 ± 1.8 months</td>
</tr>
<tr>
<td>IKDC Subjective</td>
<td>86.8 ± 10.6%</td>
</tr>
<tr>
<td>Graft Type</td>
<td>41 hamstring; 7 bone-patellar-bone</td>
</tr>
<tr>
<td>Tegner Activity Scale (pre-injury)</td>
<td>8.5 ± 1.1</td>
</tr>
<tr>
<td>Primary Sport</td>
<td>Soccer n= 24; Basketball n=9; Football n=4; Softball n=4; Other n=5</td>
</tr>
</tbody>
</table>

International Journal of Sports Physical Therapy
The involved limb, relative to the uninvolved limb, had significantly less quadriceps strength and decreased single-leg forward hop distance (Table 2). Participants had quadriceps peak torque LSI values (85.5%) that were significant lower (p= 0.002) than single-leg forward hop LSI values (92.7%) (Table 2). All predictor variables were significantly correlated with IKDC scores and were entered into the regression model (Table 3). Quadriceps LSI showed the strongest association with IKDC scores and explained 31% of the variance in IKDC scores (Table 4). Involved limb quadriceps peak torque normalized to body mass added to the predictive model (8%) explaining 39% of the variance in IKDC scores (Table 4). While single-leg forward hop distance and LSI did have a fair association with IKDC scores (Table 3), these clinical tests did not add to the predictive model.

Regarding meeting clinical thresholds, only five participants (10.4%) met or exceeded clinical thresholds on all five tests (IKDC, quadriceps LSI, quadriceps peak torque normalized to body mass, forward hop LSI, and forward hop normalized to height) while seven participants (14.6%) failed to meet any of the clinical thresholds (Table 5). The most common unmet criteria were related to quadriceps strength where only 37.5% met peak torque thresholds for the involved limb and 41.7% met quadriceps LSI thresholds (Table 6).

### DISCUSSION

The current study assessed quadriceps strength, single-leg forward hop performance, and a patient-reported outcome measure during late-stage ACL rehabilitation, a time when many patients are considering return to sport. Both quadriceps LSI and hop performance LSI are known to predict pa-
tient-oriented outcomes following ACL-R. As it was hypothesized, quadriceps LSI and involved limb quadriceps peak torque normalized to body mass were the strongest predictors of IKDC scores ($R^2 = 0.39$) and single-leg forward hop LSI and involved limb hop distance normalized to height did not significantly add to the predictive model. Additionally, the most common unmet test battery criteria were related to quadriceps strength (LSI and peak torque). Furthermore, 89.6% of participants did not meet suggested clinical thresholds for return to sport approximatively eight months following ACL-R.

When considering which clinical outcomes best predicted IKDC scores, quadriceps strength symmetry and involved limb quadriceps peak torque were better predictors while single-leg forward hop performance did not add to the predictive model. Characteristics of quadriceps strength, specifically LSI and involved limb peak torque, explained 39% of the variance in IKDC scores. Symmetry accounted for 31% of the variance in IKDC scores and peak torque added a unique contribution to the predictive model (8%). These data highlight the clinical importance of a patient achieving both symmetrical quadriceps strength and having the capacity to produce a threshold of peak torque normalized to body mass (i.e., symetrically strong). Understanding the collective influence of variables that contribute to function allows clinicians to better weigh the information of tests and measures that inform rehabilitation progression and return to sport decisions. While previous studies have examined the individual contribution of LSI values or unilateral performance on patient-reported outcomes, this study demonstrates the importance of achieving both symmetry and unilateral performance thresholds. Evidence is conflicting regarding the magnitude of the relationship between quadriceps strength and patient-reported function in a study which demonstrated the lowest LSI (68%) and peak torque (1.59 Nm/kg) values, but specific point estimates were not provided in the manuscript. It is possible that a minimum level of quadriceps symmetry and strength are necessary to contribute to patient reported outcome measures. Based on the current findings, clinicians should place greater clinical value in measures of quadriceps function, specifically symmetry between limbs and involved limb peak torque, as opposed to single leg forward hop metrics.

Measures of single-leg forward hop performance (LSI and distance) each had a fair association ($r = 0.54$) with IKDC scores, but did not contribute a greater amount to the predictive model than quadriceps strength, nor did measures add a unique contribution to the predictive model. The moderate association with IKDC scores in the current study are consistent with previously reported correlation coefficients ($r = 0.55$) but results contrasts with a previous study which indicated symmetrical single-leg forward hop performance and age have been shown to predict IKDC scores ($R^2 = 0.18$) and that quadriceps LSI values did not add to the predictive model. A key difference is that in a study by Menzer et al., the average LSI (68%) and peak torque (1.59 Nm/kg) values were substantially lower than values in the current study. While direct comparisons cannot be made between studies, Menzer et al. included a potential wide range of athletic ability (pre-injury level of activity not provided) and did not utilize visual feedback during isometric strength measures. Participants in the current study included recreational to collegiate athletes with a Tegner score greater than or equal to six. The

<table>
<thead>
<tr>
<th>Table 4: Regression models developed to predict IKDC Scores.</th>
<th>Model</th>
<th>Variable</th>
<th>Standardized $\beta$</th>
<th>$p$</th>
<th>$R$</th>
<th>$R^2$</th>
<th>$R^2$ Change</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Constant</td>
<td></td>
<td>&lt; .001</td>
<td>.556</td>
<td>.309</td>
<td>.089</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quadriceps LSI</td>
<td></td>
<td>.556</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Constant</td>
<td></td>
<td>&lt; .001</td>
<td>.627</td>
<td>.393</td>
<td>.084</td>
<td>.085</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quadriceps LSI</td>
<td></td>
<td>.356</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quadriceps peak torque (Nm/kg)</td>
<td></td>
<td>.352</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

IKDC= International Knee Documentation Committee Subjective Knee Form; LSI= limb symmetry index

<table>
<thead>
<tr>
<th>Table 5: Number of clinical criteria met during late stages of ACL rehabilitation (n= 48).</th>
<th>Number of criteria met</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>7</td>
<td>14.6%</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>8</td>
<td>16.7%</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>25.0%</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>12.5%</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>20.8%</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>10.4%</td>
<td></td>
</tr>
</tbody>
</table>
current study also included the use of visual feedback which has been shown to result in higher peak torque values than trials without visual biofeedback.\textsuperscript{37} These results do not negate the importance of hop testing, but indicate in this sample of participants hop testing did not provide additional insights into IKDC scores beyond information that was already provided by quantifying quadriceps strength. Hop tests are still an important component of return to sport testing and can help predict return to previous sport\textsuperscript{26} and possibly osteoarthritis development,\textsuperscript{44} although the magnitude of the association with these outcome variables may be considered low.\textsuperscript{43} Currently, there is no gold standard battery of functional assessments to determine return to sport readiness following ACL-R, but a commonality across most test batteries is inclusion of quadriceps strength and single-leg forward hop performance.\textsuperscript{3–5} In the current study, quadriceps strength explained 39% of the variance in IKDC scores, leaving 61% of the variance unexplained. The unexplained variance may be attributed to sex, age, graft type, additional components of testing batteries, or other unknown factors. Future studies should include measures of psychological readiness, performance on additional functional tests (e.g. side hop, triple hop), and other strength measures (e.g. hamstring, hip musculature).\textsuperscript{45}

In an effort to better guide rehabilitation efficiency, a secondary purpose of this study was to determine which clinical tests were the most difficult for participants to reach established thresholds (Table 6). While most studies have incorporated LSI thresholds to inform return to sport decisions, few have incorporated both unilateral thresholds and LSI values.\textsuperscript{5,19–21} Utilizing unilateral thresholds for both strength and functional performance measures can provide valuable clinical information, especially if the uninvolved limb (i.e. comparison limb) has a history of previous injury\textsuperscript{12} or develops weakness due to disuse.\textsuperscript{10,15,14} Criteria that focus on achieving both unilateral performance and symmetrical performance may help address limitations of LSI values that can overestimate function\textsuperscript{10,11} and help improve clinical decision making. The most common test failure (71% of participants) was not having quadriceps function that would be considered symmetrical and strong (Table 6). Additionally, nearly 60% of participants did not meet hop test LSI and unilateral hop test performance thresholds. Measures of quadriceps function were more difficult to achieve versus the single leg forward hop test. On average, participants in the current study had quadriceps LSI values that were 7% lower than single-leg forward hop LSI (Table 2). These findings are in agreement with previous studies that have found LSI values for hop performance are greater than LSI values for quadriceps strength.\textsuperscript{5,19,25–28} This suggests that quadriceps strength may be more of a rate limiting factor when compared to single leg forward hop performance, but impairments in both measures exist during late stages of ACL rehabilitation and should be addressed.

Unilateral performance was consistently a more rate limiting factor for participants versus achieving LSI thresholds (Table 6). This highlights the importance of addressing unilateral performance deficits in rehabilitation and the clinical utility to incorporate normative benchmarks for performance into return to sport testing.\textsuperscript{15} On average participants met unilateral quadriceps strength\textsuperscript{16,17} and single leg forward hop performance.\textsuperscript{18} (Table 6) benchmarks for the uninvolved limb, suggesting the capacity for adequate performance in the involved limb was available, but not achieved. A limitation of previous studies\textsuperscript{16,17} that established quadriceps strength thresholds is that they do not specifically account for sex specific or age specific differences in strength\textsuperscript{46,47} which may make application of threshold metrics confusing when applying to an individual patient (e.g. female high school soccer player versus male collegiate football player). Additionally, normative hop test thresholds need further validation as these were developed based on clinical observations.\textsuperscript{18} Future studies should better develop age, sex, and/or sport performance thresholds to better guide clinical decisions for individual patients.

Despite the evidence supporting the results that quadriceps strength is an essential determinant of function, it is a common clinical outcome that goes unassessed.\textsuperscript{22,25} While there is a moderate to good relationship between measures of involved limb quadriceps peak torque and single leg forward hop distance ($r=0.55$) as well as a moderate

---

**Table 6: Clinical tests and percent of participants that achieved clinical thresholds during late stages of ACL rehabilitation.**

<table>
<thead>
<tr>
<th>Clinical Test</th>
<th>Pass Criteria</th>
<th>Percent that Met Criteria</th>
<th>Percent that Did Not Meet Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>IKDC</td>
<td>&gt; 90%</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>Quadriceps LSI</td>
<td>&gt; 90%</td>
<td>41.7%</td>
<td>58.3%</td>
</tr>
<tr>
<td>Quadriceps Peak Torque (Nm/kg)-involved limb</td>
<td>&gt; 3.0 Nm/kg</td>
<td>37.5%</td>
<td>62.5%</td>
</tr>
<tr>
<td>Single Leg Forward Hop LSI</td>
<td>&gt; 90%</td>
<td>64.6%</td>
<td>35.4%</td>
</tr>
<tr>
<td>Single Leg Forward Hop (normalized to height)-involved limb</td>
<td>&gt; 80% height females, &gt; 90% height males</td>
<td>45.8%</td>
<td>54.2%</td>
</tr>
<tr>
<td>Quadriceps Symmetrical and Strong</td>
<td>LSI &gt; 90% and involved limb &gt; 3.0 Nm/kg</td>
<td>29.2%</td>
<td>70.8%</td>
</tr>
<tr>
<td>Single Leg Forward Hop Symmetrical and Good Performance</td>
<td>LSI &gt; 90% and involved limb &gt; 80% height females, 90% height males</td>
<td>39.6%</td>
<td>60.4%</td>
</tr>
</tbody>
</table>

IKDC= International Knee Documentation Committee Subjective Knee Form; LSI= limb symmetry index
to good relationship between the associated LSI values ($r = 0.62$), caution should be exercised in assuming that individuals with more symmetrical single-leg forward hop performance therefore have adequate quadriceps strength. It is not clear why LSI values for single leg forward hop performance were significantly greater than LSI values for quadriceps strength. It is possible individuals shorted hop distance on the contralateral limb or employed different hop strategies (e.g., trunk position, increased contributions from the hip and ankle) between limbs to achieve more symmetrical performance.29,30 This is a limitation of clinical hop test measures since it is difficult to determine specific hop strategies without biomechanical testing. Biomechanical testing would provide insights into joint specific contributions to hop tests performance. Since this technology is often not available in clinical settings, this further strengthens the rationale to obtain quantifiable measures of both quadriceps strength (joint specific function) and single-leg forward hop performance (lower extremity function). Obtaining lower extremity strength measures in a clinical environment can be challenging without access to an electromechanical dynamometer, which requires extensive training, practice, time, and cost. A hand-held dynamometer offers a less expensive, user-friendly, option to quantify quadriceps isometric strength in a clinical environment and is a valid measure ($r = 0.89$-0.95) when compared to a gold standard electromechanical dynamometer.35,36 Future research should examine the clinical utility of an hand-held dynamometer to assess quadriceps strength in individuals returning to activity following ACL-R, as the current results demonstrate an ongoing need for this clinical assessment feasibility.

Utilizing a battery of tests, including functional performance, strength, and patient-reported outcome measures, is the recommended standard to inform rehabilitation progression and return to sport decisions.3,4 Early identification of deficits is important since athletes not meeting return to sport criteria ($\geq 90\%$ LSI quadriceps strength, hop tests, patient-reported outcomes) and returning to higher-level activities are at a significantly greater risk of re-injury (4-5x more likely).3,4 Additionally, individuals who do not pass criteria at 6 months are about twice as likely to fail return to sport criteria 12 and 24 months following ACL-R.26 A substantial concern from the current study population, in late stages of ACL rehabilitation, is that only 10.4% of participants (5 of 48) met benchmarks for IKDC scores, quadriceps strength (LSI and peak torque), and single-leg forward hop (LSI and normalized hop distance) and 14.6% (7 of 48) did not meet any of the five clinical criteria used to inform return to sport decisions (failed all 5 criteria). Rates for passing return to sport criteria within the first year following ACL-R vary from 7-58%,5,21,25,26,48 The wide range of differences between studies may be due to the thresholds and outcomes used to inform return to sport decisions,5 population investigated,25,48 and control of pre and post-operative rehabilitation.26 Previous studies have used a cut-off as low as 76% for IKDC scores20 and 80-85% for quadriceps strength and single leg forward hop LSI values.13,49 While these studies have selected relatively low thresholds other studies have suggested that IKDC scores,32,50 quadriceps LSI,17 and single leg forward hop LSI20 should be higher (e.g. $\geq 92$-95%). Higher thresholds or more stringent criteria would make overall pass rates lower, but may help ensure athletes are indeed ready to return to activity. Studies which derive participants from a health registry48 or large metropolitan area,25 without control of post-operative rehabilitation, have relatively low rates (14-30%)25,48 of individuals who pass return to sport criteria compared to higher rates (50-58%) of individuals who pass return to sport criteria from studies with greater control of post-operative rehabilitation.26 The current study demonstrates a population of individuals recovering from ACL-R from a variety of local physical therapy clinics and surgery performed by several area orthopedic surgeons. These results likely reflect the variance in clinical practice and factors used to inform rehabilitation progression or return to sport decisions. The findings are consistent with studies of similar design which demonstrates the need for more consistent and improved rehabilitation strategies.25,48 Supervised rehabilitation, performed greater than 6 months in duration, has been shown to result higher LSI values for strength and hop test performance.27

A limitation of this study was that, although the results were obtained during late-stage ACL rehabilitation, athlete status of actual return to sport or previous level of play (e.g., starter versus secondary), contact hours per week, and type of sport were not monitored. Thus, it is unknown whether results of testing were actually used to inform return to sport decisions or if participants indeed did return to sport. Additionally, participants underwent a primary unilateral ACL-R with minimal concomitant injuries (meniscus injury permitted), thus results cannot be generalized to those with more extensive knee injuries. The current study did not control for surgical technique or graft type (bone-patellar tendon-bone or semitendinosus autograft) which is known to influence quadriceps- and hamstring strength-related outcomes differently.51 When utilizing LSI as a measure for return to sport, baseline measures prior to ACL-R can decrease overestimation of symmetry and uninjured limb deficits that result from decreased activity;10 baseline measures (preoperative) were not available in this study. Another study limitation was the relatively limited sample size (n=48) which may have decreased the statistical power and contributed to findings which are of greater magnitude than studies with larger sample sizes (n=88-139).20,32 Despite these limitations, the current study presents real clinical applications that rehabilitation specialists face in everyday practice. Therefore, the conclusion and clinical implications are of great value for the present subject population and timeframe of return to sport indicated in the current study.

CONCLUSION

Limb-to-limb asymmetries are prominent in both quadriceps isometric strength and single-leg forward hop during late stages of ACL rehabilitation (5-12 months post-surgery). During late-stage ACL rehabilitation quadriceps peak torque symmetry (85.5%) was significantly less than single-leg forward hop for distance symmetry (92.7%). Quadriceps function (LSI and involved limb peak torque) showed the strongest association with IKDC scores (39% variance) and single-leg forward hop (distance and LSI)
measures did not add to the predictive model. Collectively this suggests that quadriceps strength is a more rate limiting factor that contributes to patient function during late stages of ACL rehabilitation when compared to measures of single leg forward hop performance. Additionally, nearly 90% of participants in this study had not achieved acceptable values for any of the clinical criteria used to inform return to sport decisions (IKDC, quadriceps strength, and hop performance) within 5-12 months after ACL-R, suggesting they were not adequately prepared to return to activity/sport. The clinical relevance of this work is that, during late-stage ACL rehabilitation, clinicians should utilize a series of isolated strength measures, functional tests, and self-reported outcome measures to comprehensively assess the athlete function and objectively inform rehabilitation progression and return to sport decisions.

FUNDING
Portions of research reported in this publication was supported by the National Institute of General Medical Sciences of the National Institutes of Health under award number 5P20GM109090 (PI Stergiou)

ETHICAL APPROVAL
Study was granted by the Institutional Review Board at Creighton University (IRB 636803 and 928791). Written informed consent was obtained from each participant prior to participation.

PUBLIC TRIALS REGISTRY
NCT03132987

Submitted: December 02, 2019 CST, Accepted: July 21, 2020 CST
REFERENCES


Background

The incidence of ACL injuries continues to rise secondary to an increase in sport participation. Evidence supports the use of force plate testing to quantify kinetics during rehabilitation after injury and recovery; however, there is limited current research regarding if jump kinetics can identify athletes who are at higher risk for injury. Altered kinetics could potentially lead to abnormal force dissipation and resultant injury.

Purpose

The purpose of this investigation was to identify whether the force-time variables from vertical jumps could predict ACL injuries in collegiate athletes.

Study Design

Retrospective cohort.

Methods

Vertical jump testing is performed by all healthy varsity collegiate athletes at several intervals throughout the athletic year at a Division I institution using a commercially available force plate system with dedicated software. Athletes who sustained an ACL injury between 1/1/15 and 6/1/19 were identified (n=16) and compared to healthy athletes who participated in the same sports (n = 262). ACL injuries were considered for this study if they occurred no more than 10 weeks after a jump test. The outcome variables were load, explode, and drive, operationally defined as the average eccentric rate of force development, average relative concentric force, and concentric relative impulse, respectively, which the system normalized to T scores. Mann-Whitney U tests were used to assess group differences for load, explode, drive, and the ratio between the variables. Logistic regression was used to determine if the battery of variables could predict whether or not an athlete would sustain an ACL injury. The p-value was set to 0.10 for the Mann-Whitney U tests, and 0.05 for the logistic regression.

Results

Significant differences between the ACL and healthy groups were seen for explode (p=0.08), drive (p=0.06), load:explode ratio (p=0.06), and explode:drive ratio (p=0.03). Explode and drive, when entered into the regression equation, showed the ability to predict injury, $\chi^2 = 6.8$, df = 2, $p=0.03$.

Conclusions

The vertical jump force plate variables were able to identify athletes who sustained an ACL injury within 66 days of testing. Athletes who sustained an ACL injury demonstrated altered kinetics and less ability to transmit forces during the vertical jump.
INTRODUCTION

Noncontact anterior cruciate ligament (ACL) injuries continue to be problematic in the athletic population, with more than 120,000 injuries occurring every year in the United States. These injuries most commonly occur in high school and college athletes. Although ACL injury prevention programs have grown in popularity, especially with the competitive athlete population, there continues to be an increase in the number of injuries every year, secondary to an increase in sport participation. Although contact ACL injuries may occur, over 70% of ACL injuries occur in a non-contact mechanism, with approximately 100,000 injuries per year within the NCAA alone. ACL injury can lead to short term disability and functional impairments, and often results in hastened knee articular cartilage destruction and osteoarthritis.

Extensive research on clinical movement screening assessments has been completed to identify athletes at risk for injury (e.g.: Y-balance, FMS, drop jump screening test, etc.). Current literature has questioned the validity, sensitivity, or internal consistency of such assessments as predictive modalities. Lab-based kinetic and kinematic measures during various jump – landing tasks have been found to be predictive of ACL injuries. Hewett and colleagues found that in female athletes, those who later sustained an ACL injury had a 2.5 times greater knee abduction moment, a 20% higher ground reaction force, and a 16% shorter stance time during a jump landing task than non-injured athletes. Several non-modifiable risk factors for ACL injuries have been identified in the literature; modifiable risk factors have also been identified, which puts injury risk detection at paramount importance. To this end, neuromuscular and biomechanical risk factors may be addressed through preventative training programs.

Lab-based biomechanical measures are the gold standard for detecting kinematic and kinetic deviations, force plate systems, which can also be utilized clinically or in training rooms, are reliable and valid measurement systems which can potentially be used for injury detection as well as performance enhancement. Force plate testing which involves vertical or drop jumps has been used in the literature primarily to detect asymmetries after lower extremity injuries. Drop landing mechanics have been investigated at time of return to sport in athletes status post (s/p) anterior cruciate ligament reconstruction (ACLR). Transverse plane hip kinetics, frontal plane knee kinematics during landing, sagittal plane knee moments at landing, and deficits in postural stability predicted a second injury in this population with excellent sensitivity (0.92) and specificity (0.88). In 2015, Baumgart and colleagues found that patients s/p ACL reconstruction showed ground reaction force asymmetries during unilateral and bilateral movements more than two years post-surgery. Three compensation strategies were found in patients with low subjective knee function: a reduced eccentric load, an interlimb compensation during bilateral movements, and the avoidance of high vertical impact forces. Kinematic differences have been found to persist 20 years after an ACLR. Evidence supports the use of force plate testing to quantify kinetics during rehabilitation after injury and recovery; however, there is limited current research regarding the role of jump kinetics for injury prevention or prediction purposes.

As no studies to date have used force plate variables from the vertical jump to predict ACL injuries, the purpose of this investigation was to identify whether the force-time variables from vertical jumps could predict ACL injuries in collegiate athletes.

METHODS

Approval was obtained from our institution’s institutional review board. Data were collected from 1/1/2015-6/1/19. Vertical jump testing was performed by all healthy varsity collegiate athletes at several intervals throughout the athletic year, using a commercially available force plate system (Sparta Science, Menlo Park, CA). After a standard warm-up, subjects were then adequately familiarized with the jump testing with two submaximal practice jumps before testing. The testing procedure consisted of each subject performing a series of six consecutive vertical jumps, with a 15-second rest period in between each jump. No other instruction was given on the technique to be used during the jumps. This testing protocol is used as the standard of practice for all varsity athletes as part of their strength and conditioning program.

Athletes who sustained a non-contact ACL injury between 1/1/15 and 6/1/19 were identified (n=18). Athletes were excluded if they did not perform the vertical jump testing within 10 weeks prior to their injury; 16 ACL injuries were included in the analysis. Injuries by sport were: field hockey (1), football (2), men’s lacrosse (4), men’s soccer (1), women’s lacrosse (5), women’s soccer (2), and wrestling (1). For the healthy cohort (n=262), exclusion criteria were athletes who later sustained a different lower extremity injury, a trunk/lumbar spine injury, or if they participated in a sport in which no athlete sustained an ACL injury. The purpose of excluding those sports was to improve the homogeneity of the healthy cohort by excluding sports in which non-contact ACL injuries were uncommon. If more than one jump trial was performed, the jump data included in the analysis was performed at the same time in the season as the injured athlete. Injuries were documented by the team athletic trainers directly into the software, then verified with the health care organization’s electronic medical documentation system.

Initial data analysis utilized the Sparta Science system software to analyze the force-time curve and breakdown the vertical jump into three components: load, explode, and drive. Load, explode, and drive were operationally defined as the average eccentric rate of force development, average relative vertical concentric force, and average relative vertical concentric impulse, respectively (Figure 1).
The purpose of this study was to identify whether the force-time variables from vertical jumps could predict ACL injuries in collegiate athletes using a commercially available force plate system. The results of the study demonstrated that the combination of variables used were effective in predicting athletes predisposed to ACL rupture, with explode and drive exhibiting independent predictive ability, in addition to revealing a significant deficiency in average relative concentric force in the injured group. The injured athletes were found to have imbalances: first, greater eccentric rate of force development compared to average relative concentric force; secondly, greater average relative concentric impulse compared to average relative concentric force. The medium effect sizes for the group differences for explode and drive indicate that if a larger sample size was used, a difference in these variables between groups would likely be seen, as well as in the regression analysis.

While a substantial body of evidence exists exploring kinetic and kinematic differences athletes exhibit post ACLR between limbs or compared to a healthy cohort post ACLR, there is a paucity of literature describing which functional tasks and/or variables are predictive of ACL injury.\textsuperscript{16,17} The results of this study suggest that a relationship exists between force-time variables from a vertical jump task and an ACL injury; thus, this is a viable option for prophylactically screening athletes who may be at high risk for an ACL tear.

When identified as susceptible to injury, training to increase in average relative concentric force (explode) could potentially eliminate any significant difference in force-time variables between limbs or compared to healthy individuals. Indeed, this study is the first to demonstrate a relationship between vertical jump performance and ACL injuries in collegiate athletes. The authors propose that elite athletes or those at high risk for ACL injuries should be screened for deficiencies in explode and drive, with athletes identified as susceptible to injury undergoing strength and power training specific to these variables to minimize the risk of ACL rupture.

### Table 1: Force Plate Vertical Jump Variable Means (SDs) and Group Differences

<table>
<thead>
<tr>
<th>Variable</th>
<th>Uninjured Mean (SD)</th>
<th>Injured Mean (SD)</th>
<th>Test Statistic</th>
<th>p-value</th>
<th>Effect Size (Cohen's $d$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>48.2 (8.5)</td>
<td>48.4 (9.5)</td>
<td>1792</td>
<td>0.05</td>
<td>0.02</td>
</tr>
<tr>
<td>Explode</td>
<td>49.4 (8.5)</td>
<td>45.0 (6.8)</td>
<td>1331</td>
<td>0.08*</td>
<td>0.52</td>
</tr>
<tr>
<td>Drive</td>
<td>52.0 (8.6)</td>
<td>57.3 (9.2)</td>
<td>2386</td>
<td>0.06*</td>
<td>0.61</td>
</tr>
<tr>
<td>Load:Explode</td>
<td>0.99 (0.20)</td>
<td>1.08 (0.19)</td>
<td>2373</td>
<td>0.06*</td>
<td>0.45</td>
</tr>
<tr>
<td>Explode:Drive</td>
<td>0.99 (0.32)</td>
<td>0.81 (0.19)</td>
<td>1181</td>
<td>0.03*</td>
<td>-0.57</td>
</tr>
<tr>
<td>Load:Drive</td>
<td>0.96 (0.28)</td>
<td>0.86 (0.20)</td>
<td>1552</td>
<td>0.33</td>
<td>-0.36</td>
</tr>
</tbody>
</table>

*significant difference at $p$ $<$ 0.10

### RESULTS

Sixteen athletes (8 females, 8 males) who sustained an ACL tear were included, with time to injury ranging from 1-66 days (mean: 17 days). The athletes who later sustained an ACL injury participated in field hockey (1), football (2), men (4) and women's (5) lacrosse, men's (1) and women's (2) soccer, and wrestling (1). Means (standard deviations), Mann-Whitney U results, and effect sizes are listed in Table 1.

Explode and drive, when entered into the regression equation, showed the ability to predict injury, $X^2 = 6.8, df = 2, p = 0.05$, with explode and drive independently showing significant prediction at $p=0.05$ and 0.03, respectively. Effect sizes (Cohen’s $d$) for load, explode, and drive had effect sizes of 0.02, 0.52, and 0.61, respectively, indicating medium effect sizes for both explode and drive. The logistic regression had an effect size of 0.32, indicating a small-medium effect size.

### DISCUSSION

The purpose of this study was to identify whether the force-time variables from vertical jumps could predict ACL injuries in collegiate athletes using a commercially available force plate system. The results of the study demonstrated that the combination of variables used were effective in predicting athletes predisposed to ACL rupture, with explode and drive exhibiting independent predictive ability, in addition to revealing a significant deficiency in average relative concentric force in the injured group. The injured athletes were found to have imbalances: first, greater eccentric rate of force development compared to average relative concentric force; secondly, greater average relative concentric impulse compared to average relative concentric force. The medium effect sizes for the group differences for explode and drive indicate that if a larger sample size was used, a difference in these variables between groups would likely be seen, as well as in the regression analysis.

While a substantial body of evidence exists exploring kinetic and kinematic differences athletes exhibit post ACLR between limbs or compared to a healthy cohort post ACLR, there is a paucity of literature describing which functional tasks and/or variables are predictive of ACL injury.\textsuperscript{16,17} The results of this study suggest that a relationship exists between force-time variables from a vertical jump task and an ACL injury; thus, this is a viable option for prophylactically screening athletes who may be at high risk for an ACL tear.

When identified as susceptible to injury, training to increase in average relative concentric force (explode) could potentially eliminate any significant difference in force-time variables between limbs or compared to healthy individuals. Indeed, this study is the first to demonstrate a relationship between vertical jump performance and ACL injuries in collegiate athletes. The authors propose that elite athletes or those at high risk for ACL injuries should be screened for deficiencies in explode and drive, with athletes identified as susceptible to injury undergoing strength and power training specific to these variables to minimize the risk of ACL rupture.

Figure 1: Force-time curve for (1) Load: average eccentric rate of force development; (2) Explode: average relative vertical concentric force; (3) Drive: average relative vertical concentric impulse.
plate means between injured and uninjured groups. While ACL injuries are multifactorial in origin and the described force plate variable jump analysis may not capture all potential deficiencies in force transmission, this study adds to current literature regarding ACL injury prediction via modifiable factors. Lower extremity proprioception, dynamic balance, hamstring strength, hamstring: quadriiceps force ratio and raising awareness of potential injury are some of the many modifiable characteristics that have demonstrated effectiveness in reducing non-contact ACL injury rates.  

This study demonstrates a novel usage of force-time variables that are predictive of ACL injury. Further exploration of the efficacy of intervention for at-risk athletes should be investigated to the ability to reduce primary ACL injury. Additionally, further insight into the relationship between abnormal isolated load, explode, or drive versus relative abnormalities will become essential when considering modification of athlete’s strength training. Continued study and application of force-plate variables may demonstrate more injury patterns of the lower extremity based on jump kinetics.

This study has several limitations. As only non-contact ACL injuries with a corresponding jump were included, the number of athletes in the injured group is small; however, the medium Cohen’s $d$ substantiates the results. The vertical jump task used for gathering kinematic variables was bilateral; thus, side-to-side differences and/or prediction of which lower extremity was at high injury risk could not be deduced from the data. As only Division I collegiate athletes were included, this limits generalizability to other populations; however, athletes participating in seven different sports were included. Lastly, other modifiable risk factors as potential confounders in this study were not assessed.

CONCLUSION

The kinetic variables collected from vertical jumps were able to identify athletes who later sustained an ACL injury, demonstrated by altered force-time variables. The injured athletes were found to have proportionately greater eccentric rate of force development compared to average relative concentric force, and proportionally greater average relative concentric impulse compared to average relative concentric force. These findings help validate the use of a force plate system in a clinical setting to identify athletes who are at higher risk for sustaining an ACL injury.

CONFLICTS OF INTEREST

No conflicts.

Submitted: October 31, 2019 CST, Accepted: July 24, 2020 CST
REFERENCES


Reliability of the Tuck Jump Assessment Using Standardized Rater Training

Kevin Racine, PT¹, Meghan Warren, PT, MPH, PhD¹, Craig Smith, PT, DPT², Monica R. Lininger, PhD, LAT, ATC¹ a

¹ Northern Arizona University, ² Northern Arizona University; Smith Performance Center
Keywords: screening, psychometrics, movement system, injury risk

BACKGROUND

The Tuck Jump Assessment (TJA) is a test used to assess technique flaws during a 10-second, high intensity, jumping bout. Although the TJA has broad clinical applicability, there is no standardized training to maximize the TJA measurement properties.

HYPOTHESIS/PURPOSE

To determine the reliability of the TJA using varied healthcare professionals following an online standardized training program. The authors hypothesized that the total score will have moderate to excellent levels of intra- and interrater reliability.

STUDY DESIGN

Cross-sectional reliability.

METHODS

A website was created by a physical therapist (PT) with videos, written descriptors of the 10 TJA technique flaws, and examples of what constituted no flaw, minor flaw, or major flaw (0,1,2) using published standards. The website was then validated (both face and content) by four experts. Three raters of different professions: a PT, an AT, and a Strength and Conditioning Coach Certified (SCCC) were selected due to their expertise with injury and movement. Raters used the online standardized training, scored 41 videos of participants’ TJAs, then scored them again two weeks later. Reliability estimates were determined using intraclass correlation coefficients (ICCs) for total scores of 10 technique flaws and Krippendorff’s α (K α) for the individual technique flaws (ordinal).

RESULTS

Eleven of 50 individual technique flaws were above the acceptable level (K α = 0.80). The total score had moderate interrater reliability in both sessions (Session 1: ICC²,² = 0.64; 95% CI (Confidence Interval) (0.34-0.81); Standard Error Measurement (SEM) = 0.66 technique flaws and Session 2: ICC²,² = 0.56; 95% CI (0.04-0.79); SEM = 1.30). Rater 1 had a good reliability (ICC²,² = 0.76; 95% CI (0.54-0.87); SEM = 0.26), rater 2 had a moderate reliability (ICC²,² = 0.62; 95% CI (0.24-0.80); SEM =0.41) and rater 3 had excellent reliability (ICC²,² = 0.98; 95% CI (0.97-0.99); SEM =0.01).

CONCLUSION

All raters had at least good reliability estimates for the total score. The same level of consistency was not seen when evaluating each technique flaw. These findings suggest that the total score may not be as accurate when compared to individual technique flaws and should be used with caution.

a Corresponding author: Monica R. Lininger, PhD, LAT, ATC Northern Arizona University PO Box 15094 Flagstaff, AZ 86011 928.523.7442 (phone) 928.523.4315 (fax) monica.lininger@nau.edu
LEVEL OF EVIDENCE:

3b

INTRODUCTION

Several clinical screening tests have been created to help identify individuals who are at high risk upon observation of jump-landing tasks. One of these tests is the 10-second Tuck Jump Assessment (TJA)\(^1,2\), which was developed as a “clinician-friendly” screening test to help identify lower extremity landing technique flaws in individuals during a high intensity, plyometric activity.\(^1,2\) One advantage of the TJA is that it is quick and inexpensive to administer, as it only requires athletic tape and two video cameras. The TJA may better simulate conditions faced in actual sporting activities than other anterior cruciate ligament (ACL) injury screening tools or jump-landing screening tests because it begins and ends from ground level while requiring maximum effort over multiple repetitive jumps.\(^3\) The TJA requires participants to jump with maximal effort over 10 seconds; this may also induce fatigue, which may expose jumping or landing technique flaws not seen with other tests that use one or two jumps.\(^3\) The TJA performance is scored qualitatively by a clinician based on 10 technique flaws using video recordings. The original TJA assessment has 10 technique flaws, which were scored on a dichotomous scale (0–1) as either flaw present (1) or absent (0).\(^1\) Previous literature reporting the intra- and interrater reliability of the TJA has yielded mixed results, ranging from poor to excellent.\(^3–5\)

Recently, because of the inconsistency in scoring interpretations, a modified scoring system of the TJA was developed.\(^5\) The modified system changed the scoring of the 10 technique flaws to an ordinal scale of 0–2 (0 = no flaw, 1 = small flaw, 2 = large flaw). Initial reliability testing of the modified TJA found both excellent interrater and intrarater reliability.\(^5\) However, significant limitations in the study by Fort-Vanmeehaeghe, et al.\(^5\) warranted caution when interpreting the results. Details of the type or the amount of training that raters received on the modified scoring of the TJA were not included.

Understanding the level of training and education of the raters could give important information on possible learning effect associated with scoring and would help with reproducibility.\(^5,6\) Additionally, the study used two raters who were both certified strength and conditioning coaches with five years of clinical experience; potentially limiting utility of the modified TJA by other professionals in the athletic performance community. Another reliability study of the modified TJA found excellent intrarater and good interrater reliability for total score, but lower reliability for individual technique flaws.\(^7\) However, this study also did not provide any details regarding the type or amount of training the raters received prior to scoring TJAs.

Currently, there is no standardized TJA training for raters, nor any standards of how much rater experience with the TJA produces reliable results. The purpose of this work was to determine the reliability of the TJA using varied healthcare professionals following an online standardized training program. The authors hypothesized that the raters would have moderate to excellent levels of intra- and inter-rater reliability.

METHODS

This cross-sectional reliability study was a secondary analysis of TJA videos obtained as part of a larger study. A website, www.tuckjumpassessment.com, was created by a physical therapist with videos and written descriptors of TJA technique flaws as examples of what constitutes no flaw, minor flaw, or major technique flaws (0, 1, 2, respectively). The website was created a tool to be included in standardized rater training. The website was then validated by four experts in the field (two athletic trainers (AT) and two physical therapists (PT)), who have scored over 50 TJAs and use the TJA clinically; two of these experts have also been authors of past TJA studies.\(^5\) These experts added both face and construct validity to the website by assessing the website using a standardized instrument and providing feedback based on whether or not the videos were accurate representations of scoring the technique flaws. Modifications to the training website were made based on the experts’ feedback.

To test intra- and interrater reliability between raters of varying educational and clinical background, our study design utilized three raters of different professions; a PT with a Doctorate of Physical Therapy degree and two years of clinical experience, an AT with five years of clinical experience and a Strength and Conditioning Coach Certified (SC-CC) with five years of experience. The PT and AT for this portion of the study were different from the experts involved in the validation process. These three raters were chosen because they represented professions associated with injury screening and athletic performance. Each rater independently scored videos of 41 participants after reviewing the website and reading details of the modified TJA.\(^5\) Raters were asked to complete two scoring sessions two weeks apart to reduce the likelihood of remembering scores completed during the first session.

Instructions to participants for performance of the TJA were the same as established by Myer, et al.\(^8\) which consisted of standing in an athletic position with feet shoulder width apart then swinging their arms while jumping straight in the air and pulling the knees up as high as possible while landing as softly as possible and repeating until told to stop at the end of 10 seconds or stopping if they could not complete the full 10 seconds. The 10 seconds of jumping were video recorded and each participant was scored on 10 established technique flaws.\(^5\) If the flaw was seen two or more times during the 10 second period, then it was counted and scored by a magnitude of 1 (small) or 2 (large).\(^5\) The complete scoring rubric can be seen in Table 1.

The videos of 41 study participants performing the TJA were part of a previous study.

The participants were between 18–30 year-old and recreationally active (participated in physical activity for at least 30 minutes three times a week for the prior five to six months and not participating in formal athletics competi-
The total score for the TJA was treated as continuous data and therefore traditional intraclass correlation coefficients (ICCs) from repeated measures analysis of variance, specifically a two-way random model with absolute agreement (ICC_{2,2}) was used. ICC values, measures of relative reliability, were classified as excellent (> 0.90), good (0.75-0.89), moderate (0.50-0.74), or poor (<0.50). Standard error of measure (SEM), a measure of absolute reliability, was calculated using \( SEM = SD \sqrt{1 - ICC} \). The individual technique flaws were ordinal (0,1,2) and therefore reliability was assessed using the Krippendorff α (K α), which allows for ordinal data with multiple raters. Values > 0.80 were considered acceptable. Ninety-five percent confidence intervals were constructed using a bootstrapping technique (n=1,000). These procedures were followed for both intrarater (individual rater across the two time points for either the individual technique flaw or the total score) and interrater (across 3 raters for either the individual technique flaw or the total score) reliability.

Level of agreement estimates were calculated using Fleiss’s kappa due to multiple raters and use of ordinal data. Fleiss’s kappa was classified as almost perfect agreement (≥ 0.81), substantial agreement (0.61-0.80), moderate agreement (0.41-0.60), fair agreement (0.21-0.40), and slight agreement (0.01-0.20). All analyses were conducted in SPSS version 25 (IBM SPSS, Inc.).

**RESULTS**

Rater 1 had a good reliability (ICC_{2,2} = 0.76; 95% CI (0.54 - 0.87); SEM = 0.26), rater 2 had a moderate reliability (ICC_{2,2} = 0.62; 95% CI (0.24 - 0.80); SEM =0.41) and rater 3 had excellent reliability (ICC_{2,2} = 0.98; 95% CI (0.97 - 0.99); SEM =0.01) for the total score. The raters had moderate levels of interrater reliability for the total score in both sessions (Session 1: ICC_{2,2} = 0.64; 95% CI (0.34 - 0.81); SEM =0.66 and Session 2: ICC_{2,2} = 0.56; 95% CI (0.04 - 0.79); SEM =1.30). Of all individual technique flaw reliability estimates (K α) for both intra- and interrater reliability, only 11 (50 total) were above the acceptable level (Tables 2 and 3). For

### Table 1. Scoring criteria for technique flaws of the Tuck Jump Assessment

<table>
<thead>
<tr>
<th>Technique Flaw</th>
<th>Score of 0</th>
<th>Score of 1</th>
<th>Score of 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower extremity valgus at landing</td>
<td>No valgus at landing</td>
<td>Slight valgus</td>
<td>Obvious valgus; both knees touch</td>
</tr>
<tr>
<td>Thighs do not reach parallel (peak of jump)</td>
<td>The knees are higher or at the same level as the hips</td>
<td>The middle of the knees are at a lower level than the middle of the hips</td>
<td>The whole knees are under the entire hips</td>
</tr>
<tr>
<td>Thighs not equal side to side</td>
<td>Thighs equal side to side</td>
<td>Thighs slightly unequal side to side</td>
<td>Thighs completely unequal side to side (one knee is over the other)</td>
</tr>
<tr>
<td>Foot placement not shoulder width apart</td>
<td>Foot placement exactly shoulder width apart</td>
<td>Foot placement mostly shoulder width apart</td>
<td>Both feet fully together and touch at landing</td>
</tr>
<tr>
<td>Foot placement not parallel</td>
<td>Foot (the end of the feet) placement parallel</td>
<td>Foot placement mostly parallel</td>
<td>Foot placement obviously unparallel (one foot is over half the distance of the other foot/leg)</td>
</tr>
<tr>
<td>Foot contact timing not equal</td>
<td>Foot contact timing equal side to side</td>
<td>Foot contact timing slightly unequal</td>
<td>Foot contact timing completely unequal</td>
</tr>
<tr>
<td>Does not land in same footprint</td>
<td>Lands in the same footprint</td>
<td>Does not land in same footprint, but inside the shape</td>
<td>Lands outside the shape</td>
</tr>
<tr>
<td>Excessive landing contact noise</td>
<td>Subtle noise at landing (landing on the balls of their feet)</td>
<td>Audible noise at landing (heels almost touch the ground at landing)</td>
<td>Loud and pronounced noise at landing (contact of the entire foot and heel on the group between jumps)</td>
</tr>
<tr>
<td>Pause between jumps</td>
<td>Reactive and reflex jumps</td>
<td>Small pause between jumps</td>
<td>Large pause between jumps (or double contact between jumps)</td>
</tr>
<tr>
<td>Technique declines prior to 10 seconds</td>
<td>No decline in technique</td>
<td>Technique declines after five seconds</td>
<td>Technique declines before five seconds</td>
</tr>
</tbody>
</table>
Table 2. Krippendorff alpha coefficients (K α (95% Confidence Interval)) for intrarater reliability estimates on individual technique flaws.

<table>
<thead>
<tr>
<th>Technique Flaws</th>
<th>Rater 1</th>
<th>Rater 2</th>
<th>Rater 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower extremity valgus at landing</td>
<td>0.65 (0.39, 0.85)</td>
<td>0.60 (0.35, 0.83)</td>
<td>0.78 (0.56, 0.95)</td>
</tr>
<tr>
<td>Thighs do not reach parallel</td>
<td>0.57 (0.30, 0.82)</td>
<td>0.66 (0.51, 0.82)</td>
<td>0.99 (0.99, 0.99)</td>
</tr>
<tr>
<td>Thighs not equal side-to-side</td>
<td>0.31 (0.05, 0.56)</td>
<td>0.48 (0.01, 0.99)</td>
<td>0.99 (0.99, 0.99)</td>
</tr>
<tr>
<td>Foot placement not shoulder width apart</td>
<td>0.41 (0.05, 0.74)</td>
<td>0.53 (0.24, 0.83)</td>
<td>0.96 (0.89, 0.99)</td>
</tr>
<tr>
<td>Foot placement not parallel</td>
<td>0.33 (0.01, 0.73)</td>
<td>0.18 (0.01, 0.66)</td>
<td>0.99 (0.99, 0.99)</td>
</tr>
<tr>
<td>Foot contact timing not equal</td>
<td>0.44 (0.12, 0.72)</td>
<td>0.27 (0.01, 0.85)</td>
<td>0.99 (0.99, 0.99)</td>
</tr>
<tr>
<td>Excessive landing contact noise</td>
<td>0.68 (0.47, 0.85)</td>
<td>0.41 (0.01, 0.99)</td>
<td>0.94 (0.85, 0.99)</td>
</tr>
<tr>
<td>Pause between jumps</td>
<td>0.80 (0.68, 0.90)</td>
<td>0.86 (0.69, 0.97)</td>
<td>0.98 (0.94, 0.99)</td>
</tr>
<tr>
<td>Technique declines prior to 10 seconds</td>
<td>0.14 (0.01, 0.49)</td>
<td>0.02 (0.01, 0.39)</td>
<td>0.88 (0.76, 0.97)</td>
</tr>
<tr>
<td>Does not land in same footprint</td>
<td>0.25 (0.01, 0.66)</td>
<td>0.36 (0.12, 0.85)</td>
<td>0.95 (0.84, 0.99)</td>
</tr>
</tbody>
</table>

Table 3. Krippendorff alpha coefficients (K α (95% Confidence Interval)) for interrater reliability estimates on individual technique flaws for each viewing session.

<table>
<thead>
<tr>
<th>Technique Flaws</th>
<th>Session 1</th>
<th>Session 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower extremity valgus at landing</td>
<td>0.64 (0.51, 0.76)</td>
<td>0.50 (0.32, 0.67)</td>
</tr>
<tr>
<td>Thighs do not reach parallel</td>
<td>0.54 (0.40, 0.67)</td>
<td>0.42 (0.30, 0.53)</td>
</tr>
<tr>
<td>Thighs not equal side-to-side</td>
<td>0.11 (0.01, 0.33)</td>
<td>0.24 (0.06, 0.41)</td>
</tr>
<tr>
<td>Foot placement not shoulder width apart</td>
<td>0.32 (0.15, 0.48)</td>
<td>0.31 (0.14, 0.47)</td>
</tr>
<tr>
<td>Foot placement not parallel</td>
<td>0.26 (0.06, 0.46)</td>
<td>0.15 (0.01, 0.41)</td>
</tr>
<tr>
<td>Foot contact timing not equal</td>
<td>0.12 (0.01, 0.27)</td>
<td>0.10 (0.01, 0.24)</td>
</tr>
<tr>
<td>Excessive landing contact noise</td>
<td>0.13 (0.01, 0.31)</td>
<td>0.03 (0.01, 0.22)</td>
</tr>
<tr>
<td>Pause between jumps</td>
<td>0.63 (0.50, 0.74)</td>
<td>0.62 (0.51, 0.72)</td>
</tr>
<tr>
<td>Technique declines prior to 10 seconds</td>
<td>0.06 (0.01, 0.23)</td>
<td>0.00 (0.00, 0.03)</td>
</tr>
<tr>
<td>Does not land in same footprint</td>
<td>0.15 (0.01, 0.32)</td>
<td>0.00 (0.00, 0.13)</td>
</tr>
</tbody>
</table>

level of agreement (Fleiss’s Kappa) (Table 4), within session 1, 3 individual technique flaws (lower extremity valgus at landing, thighs do not reach parallel, and technique declines prior to 10 seconds) had moderate agreement. Thighs not equal side-to-side had a fair level of agreement between raters in session 1. In Session 2, thighs do not reach parallel and technique declines prior to 10 seconds had moderate and fair agreement, respectively, among raters. All other assessments of agreement were within the slight agreement classification (0.01-0.20).

DISCUSSION

The primary objective of this study was to investigate the intra- and interrater reliability of the modified TJA when using a standardized training tool for raters of different clinical backgrounds who may be likely to use the modified TJA clinically. The main findings were the total scores had good, moderate, and excellent intrarater reliability, respectively, among the three different raters. Additionally, the total TJA scores had moderate interrater reliability between both scoring sessions.

When examining the intra- and interrater reliability for individual technique flaws, only 11/50 of the K α coefficients were above the acceptable level of 0.80. The level of agreement between raters for both scoring sessions using Fleiss’ kappa for the majority of individual items showed slight agreement (0.01-0.20). Fort-Vanmeerhaeghe, et al. found intra- and interrater reliability coefficients for the modified TJA scoring of individual technique flaws as good to excellent with 27/30 of the Fleiss’ kappa coefficients above 0.61, which was used as the cutoff for good defined in their statistical analysis. However, the findings of the current study are more aligned with Gokeler and Dingenen, which demonstrated poor level of agreement for the majority of individual technique flaws for both intra- and interrater reliability, using item analysis. One potential explana-
tion for the differences in results for individual flaw reliability could be the lack of clarity of the scoring descriptors. Two of the individual items that showed the lowest level of agreement between raters in both sessions were “excessive landing contact noise” and “pause between jumps.” The current scoring protocol for “excessive landing contact noise” is as follows: (0) subtle noise at landing (landing on the balls of their feet), (1) audible noise at landing (heels almost touch the ground at landing), and (2) loud and pronounced noise at landing (contact of the entire foot and heel on the ground between jumps). Concerns regarding the scoring of this specific technique flaw have been expressed by Smith, et al. In the work by Smith, et al., the team described the need to find means for quantifying landing noise via standardized volume calibration or by rephrasing the written descriptors regarding types of foot contact for each score. For example, it is possible that a person could land loudly, but on the balls of their feet, which would provide conflicting scoring options for raters. For the flaw “pause between jumps,” a similar issue regarding the written descriptors exists. The current scoring protocol for this flaw is: (0) reactive and reflex jumps, (1) small pause between jumps, and (2) large pause between jumps. With these descriptors, there is no way to delineate or quantify what constitutes a “small pause” versus a “large pause.” Smith, et al. proposed a change in the scoring protocol for this flaw to standardize a time-based cutoff for a small versus a large pause, for example 0.5 seconds, which could then be determined by watching the video frame by frame.

Another potential factor in the lack of consensus of individual flaw reliability could be due to inconsistency regarding the training of the TJA raters. One reason the original scoring system was revised into the modified version was that it was believed that the original version did not allow the rater to evaluate severity of dysfunction in the outlined criteria due to the dichotomous scoring nature (0,1). This dichotomous scoring system also made it difficult to determine improvement or reduction in an individual’s lower extremity landing techniques. The new modified scoring system was proposed to provide a more objective assessment on an individual’s risk of ACL injury. A reliability study of the original TJA conducted by Dudley, et al. included three raters who scored participants on two separate occasions and were analyzed for inter-rater reliability, which demonstrated a learning effect as ICC values increased from 0.52 to 0.66 between the first and second sessions. This demonstrated the potential need for scoring practice to be includ- ed as a standard in training assessors as a way to potentially improve reproducibility and reliability of the test. The need for training of raters is even more imperative for the current modified version of the TJA due to more scoring options on an ordinal scale. This ordinal scale results in slightly higher degrees of subjectivity, which is why standardized rater training was included in this study. To this research team’s knowledge, this is the first study to clearly outline and delineate the training procedures that TJA rates completed prior to scoring the TJA videos. The lack of consensus between the current study and previous studies of excellent reliability points to the need for further research to make a definitive conclusion about several important psychometric property of this test. In addition to a description of the TJA and the participate completing the test, future studies must include information about the experience of the raters with the TJA and other observational movement assessment tests, as well as the training specific to the TJA the raters received.

Initial reliability testing of the modified TJA scoring conducted by Fort-Vanneerhaeghe, et al. in a group of 24 athletes with two raters found excellent intrarater (ICC = 0.94; 95% CI = (0.88-0.97); ICC rater 2 = 0.96; 95% CI = (0.92-0.98)), as well as interrater (ICC = 0.94; 95% CI = (0.88-0.97)) reliability for total score. In a more recent study conducted by Gokeler and Dingener, excellent intrarater reliability for the total score (ICC rater 1 = 0.93; 95% CI = (0.78-0.98); ICC rater 2 = 0.96; 95% CI = (0.89-0.99)), and good interrater reliability for total score (ICC rater 1 = 0.85; 95% CI = (0.58-0.95); ICC rater 2 = 0.88; 95% CI = (0.66-0.96)) was reported. A lack of consensus in previous studies and the current study may be explained by differences in statistical methods. There are six different Shrout and Fleiss models for ICCs that are commonly used. So, if two separate researchers use two different models then the

Table 4. Fleiss’s Kappa for agreement of scores (Fleiss’s Kappa (95% Confidence Interval)) on individual technique flaws for each viewing session.

<table>
<thead>
<tr>
<th>Technique Flaws</th>
<th>Session 1</th>
<th>Session 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower extremity valgus at landing</td>
<td>0.56 (0.41, 0.70)</td>
<td>0.07 (-0.09, 0.24)</td>
</tr>
<tr>
<td>Thighs do not reach parallel</td>
<td>0.56 (0.41, 0.70)</td>
<td>0.43 (0.28, 0.58)</td>
</tr>
<tr>
<td>Thighs not equal side-to-side</td>
<td>0.33 (0.20, 0.46)</td>
<td>0.12 (-0.01, 0.25)</td>
</tr>
<tr>
<td>Foot placement not shoulder width apart</td>
<td>0.09 (-0.06, 0.24)</td>
<td>0.10 (-0.05, 0.25)</td>
</tr>
<tr>
<td>Foot placement not parallel</td>
<td>0.19 (0.04, 0.34)</td>
<td>0.19 (0.03, 0.34)</td>
</tr>
<tr>
<td>Foot contact timing not equal</td>
<td>0.15 (0.01, 0.29)</td>
<td>0.10 (-0.04, 0.24)</td>
</tr>
<tr>
<td>Excessive landing contact noise</td>
<td>0.01 (-0.16, 0.14)</td>
<td>0.01 (-0.21, 0.82)</td>
</tr>
<tr>
<td>Pause between jumps</td>
<td>0.02 (-0.11, 0.15)</td>
<td>0.01 (-0.20, 0.07)</td>
</tr>
<tr>
<td>Technique declines prior to 10 seconds</td>
<td>0.43 (0.30, 0.56)</td>
<td>0.35 (0.22, 0.48)</td>
</tr>
<tr>
<td>Does not land in same footprint</td>
<td>0.01 (-0.18, 0.11)</td>
<td>0.01 (-0.26, 0.01)</td>
</tr>
</tbody>
</table>

International Journal of Sports Physical Therapy
findings for reliability estimates might be slightly different. Gokeler and Dingenen\textsuperscript{7} used the same model (ICC\textsubscript{2,2}) as the current study, but Fort-Vanmeeraeghe, et al.\textsuperscript{5} did not provide which model was used. One suggestion for future TJA research would be to include which ICC model was used to calculate reliability estimates for replication and direct comparison of results.

Due to the lower individual item reliability and potential variability in scoring combinations, it is possible that the reported higher reliability results could be falsely inflated. For example, a total score of 8/20 could be highly variable and achieved in a variety of ways due to a combination of different scores for individual technique flaws. These findings align with those discovered in a recent critically appraised topic (CAT) of five TJA reliability studies which concluded that total scores are reliable, but individual technique flaws when examined individually are not reliable.\textsuperscript{14} Therefore, as previously stated by Gokeler and Dingenen\textsuperscript{7} it is advised to use caution when solely looking at total scores when interpreting injury risk.

This is the first study to provide a standardized protocol for training of raters prior to scoring any of the TJA videos. The website created for training purposes was validated by selected experts of the TJA, providing both face and construct validity to the website as a training platform for future scoring. One potential limitation of this study is that there was a fairly homogenous group of participants (college-aged, recreationally active) and the TJA was originally developed for use with athletes and not a recreationally active population.

CONCLUSION

Using standardized rater training, the modified TJA revealed moderate interrater reliability and moderate to excellent intrarater reliability for total scores, but only slight levels of agreement for the majority of individual technique flaws for both intra- and interrater reliability. These findings demonstrate that caution is warranted when solely interpreting total scores and also indicates the need for certain technique flaws such as “pause between jumps” and “excessive landing contact noise” to be further examined in terms of scoring descriptions and potentially modified to be more reproducible.

Dr. Warren is now working at the Patient-Centered Outcomes Research Institute (PCORI). All statements, findings, and conclusions in this publication are solely those of the authors and do not necessarily represent the views of the PCORI or its Board of Governors.

CONFLICT OF INTEREST

The authors have no conflicts of interest to report.

Submitted: January 17, 2020 CST, Accepted: May 23, 2020 CST
REFERENCES


Patients Walking Faster After Anterior Cruciate Ligament Reconstruction Have More Gait Asymmetry

Rachel J. Knobel, PT, DPT, MS¹,², Naoaki Ito, PT, DPT³, Elanna K. Arhos, PT, DPT³, Jacob J. Capin, PT, DPT, PhD⁴, Thomas S. Buchanan, PhD⁵, Lynn Snyder-Mackler, PT, ScD, FAPTA⁶

¹ Department of Physical Therapy, University of Delaware, ² Department of Physical Therapy/Biomechanics and Movement Science Program, University of Delaware, ³ Biomechanics and Movement Science Program, University of Delaware, ⁴ Department of Physical Medicine and Rehabilitation, University of Colorado; Eastern Colorado VA Geriatric Research Education and Clinical Center, ⁵ Delaware Rehabilitation Institute/Department of Biomedical Engineering, University of Delaware, ⁶ Department of Physical Therapy/Biomechanics and Movement Science Program/ Delaware Rehabilitation Institute/Department of Biomedical Engineering, University of Delaware

Keywords: walking speed, osteoarthritis, gait mechanics, anterior cruciate ligament reconstruction

10.26603/001c.18710

Background
Gait asymmetries after anterior cruciate ligament reconstruction (ACLR) may lead to radiographic knee osteoarthritis. Slower walking speeds have been associated with biomarkers suggesting cartilage breakdown. The relationship between walking speed and gait symmetry after ACLR is unknown.

Hypothesis/Purpose
To determine the relationship between self-selected walking speeds and gait symmetry in athletes after primary, unilateral ACLR.

Study Design
Secondary analysis of a clinical trial.

Methods
Athletes 24±8 weeks after primary ACLR walked at self-selected speeds as kinematics, kinetics, and electromyography data were collected. An EMG-driven musculoskeletal model was used to calculate peak medial compartment contact force (pMCCF). Variables of interest were peak knee flexion moment (pKFM) and angle (pKFA), knee flexion and extension (KEE) excursions, peak knee adduction moment (pKAM), and pMCCF. Univariate correlations were run for walking speed and each variable in the ACLR knee, contralateral knee, and interlimb difference (ILD).

Results
Weak to moderate positive correlations were observed for walking speed and all variables of interest in the contralateral knee (Pearson's r=.301-.505, p<0.01). In the ACLR knee, weak positive correlations were observed for only pKFM (r=.280, p=0.02) and pKFA (r=.263, p=0.03). Weak negative correlations were found for ILDs in pKFM (r=-.248, p=0.04), KEE (r=-.260, p=0.03), pKAM (r=-.323, p<0.01), and pMCCF (r=-.286, p=0.02).

Conclusion
Those who walk faster after ACLR have more asymmetries, which are associated with the development of early OA. This data suggests that interventions that solely increase walking speed may accentuate gait symmetry in athletes early after ACLR. Gait-specific, unilateral, neuromuscular interventions for the ACLR knee may be needed to target gait asymmetries after ACLR.

Corresponding author: Rachel Knobel, 540 S. College Ave, 210Z, Newark, DE 19713, USA. Email: rknobel@udel.edu.
INTRODUCTION

Over the past decade, the incidence of anterior cruciate ligament injury and reconstruction (ACLR) procedures in young adults has increased.1–3 Gait asymmetries persist for six months to one year after ACLR and have been associated with the development of early onset radiographic osteoarthritis (OA).4–7 Athletes who developed radiographic knee OA five years after ACLR walked with underloading of the medial compartment of the tibiofemoral joint of the ACLR knee compared to those who did not develop radiographic knee OA early after reconstruction.8 Slower walking speed may be a potential predictor for future OA development.8–12 An association between slower walking and greater serum collagen type II cleavage concentration, a biomarker associated with greater cartilage breakdown in the knee, have been found in individuals six months after ACLR.6,9

In healthy individuals, faster walking speeds are associated with larger joint moments and angles in the sagittal plane.11,13 Faster walking may promote joint loading, thus could be used as a potential intervention to prevent early onset OA. Faster walking speeds are also associated with lower incidences of knee OA in mid- to older-aged adults.10 The relationship between walking speed and knee joint moments and angles during gait after ACLR is unknown.

There are no interventions that fully restore gait symmetry early after ACLR. Perturbation training, weighted vest training, and sled towing have been trialed in the past but have been unsuccessful in restoring gait symmetry.14–19 Strength, agility, plyometric, and secondary prevention training and perturbation training interventions have been shown to help mitigate asymmetry in women two years after ACLR, but not at earlier timepoints.16 Real-time visual biofeedback with verbal cues suggest that individuals may be able to modulate medial compartment tibiofemoral contact forces, thereby improving symmetry.20,21 These bio-inspired technologies are, however, costly and time-consuming to implement in a clinical setting. Understanding the association between walking speed and knee biomechanics in athletes after ACLR may inform a clinically feasible intervention based on simply altering walking speed.

The purpose of this study was to determine the relationship between self-selected walking speed and gait biomechanics in athletes after ACLR. This study investigated the relationship between walking speed and knee biomechanics in the ACLR knee, in the contralateral knee, and for the interlimb differences (ILD = ACLR – contralateral knee). The first hypothesis was that faster walking speed would be related to larger knee kinematics, kinetics, and joint contact forces in both the contralateral and ACLR knees. The secondary hypothesis was that less asymmetry would be observed in gait biomechanics for those who walked faster.

METHODS

This study is a secondary analysis of prospectively collected data from a clinical trial (NCT01773317) approved by the University of Delaware institutional review board. Written informed consent was obtained from all participants and from parents/guardians for participants who were minors.

Seventy participants (21±8 years old) (Table 1) were included in this study.22 Participants were level I and II athletes (i.e. sports involving jumping, pivoting, and cutting),23,24 who participated in their sport at least 50 hours per year prior to injury, underwent primary, unilateral ACLR, and planned on returning to their pre-injury level of sport after surgery. Athletes were eligible for study enrollment 12 weeks after ACLR. Criteria were: minimal to no effusion,25 full and symmetrical knee range of motion, $\geq 80\%$ quadriceps index ($\textit{ACL}$ knee maximal volitional contraction (MVIC) / contralateral knee MVIC) x 100), initiation of a running progression, and ability to hop pain-free on each leg. Participants were excluded if they had a previous history of ACLR or other significant lower extremity injury or surgery on either knee, concomitant grade III knee ligament injury, or osteochondral defect $\geq 1\text{ cm}^2$.22 All participants from the parent clinical trial whose biomechanical testing data were able to be modeled were included in the present study.

MOTION ANALYSIS AND VARIABLES OF INTEREST

Motion capture and EMG (1080Hz) data were collected 24±8 weeks after ACLR. Commercial software (Visual3D; C Motion, Germantown, MD) was used to calculate kinematic and kinetic variables via inverse dynamics. Thirty-nine retroreflective markers were placed on both lower extremities, and kinematic data were captured at 120 Hz using an eight-camera motion analysis system (VICON, Oxford, UK). Kinetic data were recorded using an embedded force platform (Bertec Corporation, Columbus, OH) sampling at 1080 Hz. Five over-ground gait trials were collected at self-selected walking speeds maintained at $\pm 5\%$. Electromyography (EMG) was collected via electrodes placed bilaterally on the rectus femoris, medial and lateral vasti, medial and lateral hamstrings, and the medial and lateral gastrocnemii. We collected MVICs for each muscle group and data were normalized to each muscle’s MVIC. EMG data were high-pass filtered at 50 Hz using a 2nd order Butterworth filter and low-pass filtered at 6 Hz to create a linear envelope.

Variables of interest were external peak knee flexion (pKFM) and adduction moments (pKAM), peak knee flexion angle (pKFA), and knee flexion (KFE) and extension (KEE) excursion. KFE was defined as the change in knee flexion angle from initial contact to peak knee flexion. KEE was defined as the excursion between peak knee flexion angle and peak knee extension angle during the second half of stance. Joint moments were normalized by mass and height ($\text{kg}$·$\text{m}$).

pKFA and pKFM were normalized so that positive values reflect greater knee flexion angles and external knee flexion moments, respectively.
TABLE 1: Demographic Characteristics (SD) (n=70)

<table>
<thead>
<tr>
<th>Demographic Characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Since Surgery (weeks)</td>
<td>23.8 (7.7)</td>
</tr>
<tr>
<td>QI (%)</td>
<td>91.2 (8.8)</td>
</tr>
<tr>
<td>Walking speed (m/s)</td>
<td>1.55 (0.1)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.72 (0.1)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>77.5 (14.9)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>25.9 (3.3)</td>
</tr>
<tr>
<td>Age at Surgery (years)</td>
<td>21.5 (7.9)</td>
</tr>
<tr>
<td>Graft Type</td>
<td></td>
</tr>
<tr>
<td>Allograft</td>
<td>16</td>
</tr>
<tr>
<td>BPTB/Patellar Tendon</td>
<td>20</td>
</tr>
<tr>
<td>Hamstring</td>
<td>34</td>
</tr>
<tr>
<td>Medial Meniscus Pathology†</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>40</td>
</tr>
<tr>
<td>Partial Meniscectomy</td>
<td>12</td>
</tr>
<tr>
<td>Repair</td>
<td>12</td>
</tr>
<tr>
<td>Lateral Meniscus Pathology†</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>33</td>
</tr>
<tr>
<td>Partial Meniscectomy</td>
<td>23</td>
</tr>
<tr>
<td>Repair</td>
<td>8</td>
</tr>
<tr>
<td>Pre-injury Activity Level</td>
<td>64 level I, 6 level II</td>
</tr>
<tr>
<td>Sex</td>
<td>33 F, 37 M</td>
</tr>
</tbody>
</table>

Abbreviations: QI, quadriceps index; BMI, body mass index; BPTB, bone patellar bone
*Values are Mean (Standard deviation)
†Meniscal pathology not reported for all subjects due to missing operative reports for 6 subjects

MUSCULOSKELETAL MODELING

A validated, patient-specific EMG-driven model was used to calculate the primary variable of interest, medial tibiofemoral joint contact forces (pMCCF), which has been associated with early onset OA.4,5,28 The previously validated26,27 model uses a hill-type muscle fiber in series with an elastic tendon. EMG-derived forward estimations are used to create a knee flexion moment curve, which is then fit to the knee flexion moment curve generated through inverse dynamics calculated through motion capture and ground reaction forces. We then predicted each of the five trials per knee using muscle parameters and coefficients (penetration angle, fiber velocity, tendon strain, and muscle activation) from the other four trials. The three best-fitting predicted trials were selected by maximizing R² and minimizing root mean square error values. A frontal plane moment balance algorithm was used to calculate pMCCF, the modeling-derived variable of interest.22,26,27 pMCCF was normalized to body weight to allow comparison between individuals.

STATISTICS

Pearson’s correlation coefficients were computed for the variables of interest (contralateral knee, ACLR knee, and ILD) and walking speed. Linear regression was computed for all variables against walking speed to assess the linear relationship between each variable and walking speed. Alpha was set at 0.05 for all statistical analyses. Analyses were computed using SPSS version 25.0 (IBM Corporation, Armonk, NY).

RESULTS

CONTRALATERAL KNEE MECHANICS

There were weak to moderate positive correlations between walking speed and mechanics indicating larger values occurred at faster speeds in the contralateral knee. At faster speeds, pKFM (Pearson’s r=.505, p<0.01) (Figure 1), pKFA (r=.449, p<0.01), KEE (r=.379, p<0.01), pMCCF (r=.377, p<0.01) (Figure 2, Table 2), pKAM (r=.346, p<0.01) (Figure 3), and KFE (r=.301, p=0.01) were greater in the contralateral knee.

ACLR KNEE MECHANICS

There were weak positive correlations observed between walking speed and pKFM (r=.280, p=0.02) (Figure 1, Table 3) and pKFA (r=.263, p=0.03) in the ACLR knee. However, there were no statistically significant correlations between walking speed and pMCCF (r=.020, p=0.87) (Figure 2), pKAM (r=.080, p=0.49) (Figure 3), KFE (r=.065, p=0.59) and KEE (r=.226, p=0.06) suggesting no strong relationship between walking speed and gait mechanics in the ACLR knee.

INTERLIMB DIFFERENCE

There were weak negative correlations between walking speed and ILDs for KFE (r=-.260, p=0.03) (Table 4), pKAM (r=-.325, p<0.01), pMCCF (r=-.286, p=0.02) (Figure 4), and pKFM (r=-.248, p=0.04) indicating that more asymmetry oc-
curred at faster speeds. There were no correlations between walking speed and ILDs for pKFA (r=-.248, p=0.07) or KEE (r=-.172, p=0.15).

**DISCUSSION**

This study explored the relationship between self-selected walking speeds and gait biomechanics in athletes after ACLR. The first hypothesis, that faster walkers would have greater knee moments, angles, and joint contact forces, was supported in the contralateral knee but only partially and weakly supported in the ACLR knee. Only pKFM and pKFA in the ACLR knee were weakly correlated to walking speed. The secondary hypothesis, that there would be less asymmetry at faster walking speeds, was not supported. Greater asymmetry was observed for pKFM and KFE at faster walking speeds, and beyond 1.5 m/s in pMCCF (trending toward underloading) and pKAM. The ACLR knee does not present with the same characteristics as the contralateral knee at faster walking speeds, suggesting that healthy responses to faster walking may not be observed in the ACLR knee.

Gait asymmetries persist six months after ACLR in this and other cohorts. Given that previous research suggests that faster walking leads to larger angles and moments, especially in the sagittal plane, the hypothesis was that there would be similar trends in both the ACLR and contralateral knees. The findings in this study, conversely indicate that those who walk faster six months after ACLR, compared to those who walk more slowly, actually have more gait asymmetry. These results indicate that walking speed is more strongly associated with contralateral knee biomechanics than ACLR knee biomechanics. The varying strength of the relationships between each limb and walking speed may explain the underlying resultant asymmetry (i.e., underloading of the involved knee) observed for those patients walking faster after ACLR.

**FIGURE 1.**

Abbreviations: PKFM, peak knee flexion moment
In the contralateral knee, there was a moderate correlation between walking speed and PKFM (p < 0.01). In the ACLR knee, there was a weak correlation between walking speed and PKFM (p > 0.02).

**TABLE 2: Pearson’s r and R² values for the relationship between walking speed and biomechanics in the contralateral knee**

<table>
<thead>
<tr>
<th>Biomechanical Variable</th>
<th>Pearson’s r</th>
<th>R²</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Knee Flexion Moment (pKFM)</td>
<td>0.505</td>
<td>0.255</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Peak Knee Flexion Angle (pKFA)</td>
<td>0.449</td>
<td>0.202</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Knee Extension Excursion (KEE)</td>
<td>0.379</td>
<td>0.144</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Peak Medial Compartment Contact Force (pMCCF)</td>
<td>0.377</td>
<td>0.142</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Peak Knee Adduction Moment (pKAM)</td>
<td>0.346</td>
<td>0.120</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Knee Flexion Excursion (KFE)</td>
<td>0.301</td>
<td>0.091</td>
<td>0.01</td>
</tr>
</tbody>
</table>

**TABLE 3: Pearson’s r and R² values for the relationship between walking speed and biomechanics in the ACLR knee**

<table>
<thead>
<tr>
<th>Biomechanical Variable</th>
<th>Pearson’s r</th>
<th>R²</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Knee Flexion Moment (pKFM)</td>
<td>0.280</td>
<td>0.078</td>
<td>0.02</td>
</tr>
<tr>
<td>Peak Knee Flexion Angle (pKFA)</td>
<td>0.263</td>
<td>0.069</td>
<td>0.03</td>
</tr>
<tr>
<td>Knee Extension Excursion (KEE)</td>
<td>0.226</td>
<td>0.051</td>
<td>0.06</td>
</tr>
<tr>
<td>Peak Medial Compartment Contact Force (pMCCF)</td>
<td>0.020</td>
<td>0.000</td>
<td>0.87</td>
</tr>
<tr>
<td>Peak Knee Adduction Moment (pKAM)</td>
<td>0.083</td>
<td>0.007</td>
<td>0.49</td>
</tr>
<tr>
<td>Knee Flexion Excursion (KFE)</td>
<td>0.065</td>
<td>0.004</td>
<td>0.59</td>
</tr>
</tbody>
</table>

Bold p-values indicate statistically significant correlations.
TABLE 4: Pearson’s r and R² values for the relationship between walking speed and interlimb difference (ILD) in our biomechanical variables of interest

<table>
<thead>
<tr>
<th>Biomechanical Variable</th>
<th>Pearson’s r</th>
<th>R²</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Knee Flexion Moment (pKFM)</td>
<td>-0.248</td>
<td>0.062</td>
<td>0.04</td>
</tr>
<tr>
<td>Peak Knee Flexion Angle (pKFA)</td>
<td>-0.217</td>
<td>0.047</td>
<td>0.07</td>
</tr>
<tr>
<td>Knee Extension Excursion (KEE)</td>
<td>-0.172</td>
<td>0.030</td>
<td>0.15</td>
</tr>
<tr>
<td>Peak Medial Compartment Contact Force (pMCCF)</td>
<td>-0.286</td>
<td>0.082</td>
<td>0.02</td>
</tr>
<tr>
<td>Peak Knee Adduction Moment (pKAM)</td>
<td>-0.323</td>
<td>0.104</td>
<td>0.01</td>
</tr>
<tr>
<td>Knee Flexion Excursion (KFE)</td>
<td>-0.260</td>
<td>0.068</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Bold p-values indicate statistically significant correlations.

TABLE 5: Comparison of Pearson’s r for the relationship between walking speed and pMCCF in men, women, and pooled data

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th></th>
<th>Women</th>
<th></th>
<th>Pooled</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pearson’s r</td>
<td>p-value</td>
<td>Pearson’s r</td>
<td>p-value</td>
<td>Pearson’s r</td>
<td>p-value</td>
</tr>
<tr>
<td>ACLR knee</td>
<td>0.135</td>
<td>0.43</td>
<td>-0.025</td>
<td>0.89</td>
<td>0.020</td>
<td>0.87</td>
</tr>
<tr>
<td>Contralateral knee</td>
<td>0.382</td>
<td>0.02</td>
<td>0.376</td>
<td>0.03</td>
<td>0.377</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Interlimb difference</td>
<td>-0.196</td>
<td>0.25</td>
<td>-0.323</td>
<td>0.07</td>
<td>-0.286</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Bold p-values indicate statistically significant correlations.

who walked faster.

For all sagittal plane variables (PKFA, PKFM, KFE, and KEE), asymmetries were present regardless of walking speed, and were exaggerated for those who walked at faster speeds. The line of best fit for the association between walking speed and the ILD in pMCCF, the primary variable of interest associated with OA development,4,5,28 and between walking speed and the ILD in pKAM both crossed zero at approximately 1.5 m/s. Individuals who walked faster tended to exhibit greater underloading in the ACLR knee relative to the contralateral knee (Figure 4), an association that was driven primarily by changes in the contralateral limb (Figure 2, Table 2). As illustrated in Figure 4, clinically meaningful pMCCF underloading, as determined by ILDs exceeding the meaningful interlimb difference threshold of 0.4 BW,4 was more prevalent at faster speeds than was pMCCF overloading. These relationships were similar for men and women, as shown in secondary exploratory analyses (Table 5). Therefore, an intervention that manipulates walking speed alone for asymmetric gait mechanics after ACLR may result in continued gait asymmetry, perhaps even increasing the asymmetry. Future research, however, must manipulate walking speed within individuals after ACLR to determine its effect on walking symmetry.

The mechanism underlying the prolonged gait asymmetry following full functional recovery after ACLR is unknown. One possible explanation is neuroplastic changes after injury and reconstruction.32 Sigward et al. suggests that individuals three months after ACLR exhibit a mismatch between their loading patterns and abilities – termed “learned nonuse” – during bilateral tasks. Sit-to-stand and static standing are activities that are typically performed without attention to loading, similar to gait. Individuals in the Sigward et al. study exhibited asymmetry without cues during the tasks, but were able to load symmetrically (measured by vertical ground reaction force impulse) once real-time visual and verbal feedbacks were provided.33 Pizolato et al. found real-time visual biofeedback with verbal cues during gait may have short-term effects on restoring gait symmetry including variables such as medial compart-
ment tibiofemoral contact forces. These were short-term studies and visual feedback has not been shown to improve long-term learning or transfer to other environments. With repetition and targeted intervention, however, these changes may carry over into long-term gait symmetry. Given these findings, individuals early after ACLR may benefit from external feedback focusing on neuromuscular control in the ACLR knee in order to learn to load symmetrically during gait.

Interventions such as split-belt treadmill training may allow clinicians to unilaterally target the ACLR knee by decoupling the belts so that one limb moves faster than the other. Roper et al. found that split-belt training has the potential to increase hip adduction moment impulse of the fast limb. Therefore, targeting the ACLR knee using gait-specific, unilateral neuromuscular retraining early after ACLR may be promising for improving symmetry of knee moments, angles, and joint contact forces. Future research is warranted.

While the cause and effect of walking speed and underloading is unclear, both slower walking and tibiofemoral underloading of the ACLR knee at six months after ACLR have been associated with early OA development. In the present study, faster walkers tended to walk with tibiofemoral underloading of their ACLR knee at six months following ACLR. In contrast, slower walkers had more symmetrical medial compartment loading. These unexpected associations, however, were driven almost exclusively by the contralateral knee rather than the ACLR knee. Individuals who walked faster did not load their ACLR knee less than individuals who walked more slowly; they only underloaded their ACLR knee relative to the contralateral limb, which experienced higher loading at faster speeds. Optimal tibiofemoral joint loading and walking speeds early after ACLR remain unknown. Further follow-up including musculoskeletal imaging is necessary to elucidate the relationship between joint loading, walking speed, and long-term OA development.

This study was an explorative secondary analysis, so the interventions discussed are speculative in nature and should not be taken as clinical practice recommendations. The present study is limited by its cross-sectional, between-subjects design; walking speed was not manipulated. Additionally, correlations were weak to moderate. This sample may not be representative of the general ACLR population due to the stringent inclusion criteria (level I and II athletes, participated in their sport at least 50 hours/year prior to injury, primary, unilateral ACLR, and planned to return to pre-injury level of sport after ACLR). Lastly, this sample does not include long-term radiographic evidence of OA development.

CONCLUSION

The results of this study indicate that contralateral knee mechanics and loading were more strongly correlated to walking speeds (i.e., greater angles, moments, and loading with faster walking) than ACLR knee mechanics and loading. This difference may explain the larger gait asymmetries observed in faster walkers. Further research is warranted to study targeted interventions to improve gait symmetry for individuals after ACLR. These results suggest that those who walk faster demonstrate greater interlimb asymmetry, rather than less asymmetry. Therefore, manipulating walking speed alone as an intervention for targeting aberrant gait mechanics may accentuate, rather than mitigate, walking asymmetries among individuals after ACLR. Further research is necessary to understand the long-term effect of different walking speeds on gait biomechanics within the same individual. Gait-specific, unilateral, neuromuscular training for the ACLR knee may be necessary to improve symmetry in postoperative rehabilitation.

The Institutional Review Board of the University of Delaware approved this study, which was registered on IRB-
Net (ID 225014-15). This is a secondary analysis of a clinical trial which was registered at clinicaltrials.gov (NCT01773317). This study was supported by the National Institute of Arthritis and Musculoskeletal and Skin Diseases (R01-AR048212) and the National Institute of Child Health and Human Development (R37-HD037985, T32-HD007490, F30-HD096830). This study was funded in part by The Foundation for Physical Therapy Research Promotion of Doctoral Studies (PODS) Level I and II Scholarships (JJC), University of Delaware Doctoral Fellowship Award (JJC), Dissertation Fellowship Award (JJC), and Biomechanics and Movement Science (BIOMS) tuition scholarship (NI). JJC’s postdoctoral training is funded by an Advanced Geriatrics Fellowship from the Eastern Colorado Veterans Affairs Geriatric Research Education and Clinical Center. The authors certify that they have no financial disclosures or direct financial interest in the subject matter. The authors have no conflicts of interest to disclose.

Submitted: January 27, 2020 CST, Accepted: July 24, 2020 CST
Patients Walking Faster After Anterior Cruciate Ligament Reconstruction Have More Gait Asymmetry

REFERENCES


The Influence of Mode-of-Injury on Psychological Readiness for Return-To-Sport Following Anterior Cruciate Ligament Reconstruction: A Matched-Controlled Study

Jenifer Presley, PT, DPT, SCS, ATC¹, Lane Bailey, PhD, PT¹,³, Kevin Maloney, PT, DPT, SCS, ATC¹, Brian Duncan, PT, DPT, SCS, OCS¹, Mathew Reid, MD², Christopher Juneau, PT, DPT, SCS³, Walter R Lowe, MD²

¹ Memorial Hermann Ironman Sports Medicine Institute, Department of Sports Medicine & Rehabilitation, ² McGovern Medical School at UT Health, Department of Orthopaedic Surgery, ³ Reef Systems -US Air Force Special Warfare

Keywords: acl injury, return to sport, mode-of-injury, psychological readiness

Background
Self-efficacy and fear of re-injury have been documented as factors related to an athlete's ability to return-to-sport after anterior cruciate ligament (ACL) reconstruction. The purpose of this study was to compare psychological readiness between athletes injured in their primary mode of sport versus those injured outside of their primary sport following ACL reconstruction.

Hypothesis
Athletes sustaining 'in-sport' injuries will demonstrate poorer psychological readiness when compared to their matched counterparts injured outside of their primary sport.

Study Design
Case-Control Study

Methods
A single-surgeon database of 638 patients following ACL reconstruction was used to conduct a matched case-control analysis. Psychological readiness was examined 16-weeks postoperatively using the ACL-Return to Sport after Injury (ACL-RSI) questionnaire with subgroup analyses for the 'emotional', 'confidence' and 'injury risk' subscales. Subject matching was performed for baseline patient and surgical demographics. All statistical comparisons were performed using a one-way (group) analysis variance (ANOVA) at a significance level of \( \alpha = .05 \).

Results
Ninety-two matched patients (49 'in-sport' injuries, 43 'out-of-sport' injuries) were included in the final analysis. The 'in-sport' group exhibited significantly lower total ACL-RSI scores (55.3 ±12.9 versus 60.8 ±11.6, \( t = 2.747, P < .001 \)) when compared to the 'out-of-sport' group. Subscale comparisons indicated lower 'emotional' (\( P < .016 \)) and higher 'injury risk' (\( P < .001 \)) psychological constructs for 'in-sport' athletes versus 'out-of-sport' athletes. No differences were found between groups for the 'confidence' subscale (\( P = .987 \)).

Conclusions
Athletes sustaining 'in-sport' ACL injuries demonstrated poorer psychological readiness when compared to athletes injured outside their primary sport when in preparation for return-to-sport activities following ACL reconstruction.
Clinical Relevance
Clinicians should consider the potential impact of mode of injury on psychological readiness when returning athletes to sport after ACL reconstruction.

INTRODUCTION

There is an emerging body of evidence linking psychological factors to return-to-sport rates following ACL reconstruction.\(^1\)\(^–\)\(^5\) Previous research has reported that 52% of high school athletes and 50% of collegiate athletes who underwent ACL reconstruction chose not to return-to-sport due to fear of re-injury.\(^6\) These psychological factors also appear to have lasting consequences as athletes reporting a higher fear of reinjury display relatively lower return-to-sport rates for up to seven years following surgical reconstruction.\(^3\)\(^,\)\(^7\)\(^,\)\(^8\) In contrast, athletes who successfully return to their preinjury level of participation often exhibit more positive responses to psychological outcome measures, including higher knee-related quality of life,\(^9\) greater self-reported patient satisfaction,\(^10\) and a lower fear-avoidance behaviors when compared to those who are unable to return to their preinjury participation level.\(^11\)\(^,\)\(^12\) Furthermore, greater psychological readiness during rehabilitation has been shown to be a significant predictor of return to comparable level of performance.\(^13\)

Prior studies have demonstrated that traumatic injuries often lead to altered psychological responses which negatively impact the recovery process.\(^3\)\(^,\)\(^9\)\(^,\)\(^14\)\(^–\)\(^18\) The theory of contextual fear conditioning, also known as classical conditioning, states that a neutral stimulus can become conditioned when paired with an aversive unconditioned stimulus, such as pain.\(^19\) When an injury occurs, the activity at the time of injury can become a conditioned stimulus to the individual, resulting in a heightened fear response. Behaviorists have developed models based on this theory in which classically conditioned fear acts as a driver that motivates and reinforces activity avoidance behaviors.\(^19\) Based on this theory, patients participating in their respective sport at the time of injury would, theoretically, report a higher ‘fear of re-injury compared to those who were injured outside of their primary sport. For example, a collegiate soccer player who injures her ACL in soccer practice would potentially demonstrate an increased fear of re-injury when returning to soccer versus an American football player who sustains an ACL injury during a recreational basketball game. Unfortunately, no known clinical studies have been conducted to test this hypothesis in an ACL reconstruction population. Additionally, current literature suggests that psychological factors are potentially modifiable, and should be evaluated in athletes over time.\(^13\) This recommendation was supported by the work of Ardern and colleagues who demonstrated that lower Anterior Cruciate Ligament-Return to Sport after Injury scale (ACL-RSI) scores assessed at 16-weeks following surgical reconstruction was a sensitive predictor for determining successful return to sport at 12-months.\(^11\) Therefore, the purpose of this study was to determine whether athletes who sustain ‘in-sport’ ACL injuries exhibited poorer psychological readiness scores as assessed by the ACL-RSI scale when compared to matched subjects who sustain their injury outside their primary mode of sport following surgical reconstruction. The authors hypothesize that athletes who sustain an ‘in-sport’ ACL injury will display lower psychological readiness scores when compared to their ‘out-of-sport’ counterparts at 16-weeks following surgical reconstruction.

METHODS

STUDY DESIGN

A matched-case control study was conducted at the University of Texas Health Sciences Center examining a subset of patients enrolled within a larger prospective clinical trial. All eligible participants provided verbal and written consent that was approved by the University of Texas Health Sciences Center Institutional Review board. This study is registered at US National Institutes of Health (clinicaltrials.gov) as NCT # 03700996.

PARTICIPANTS

Recreational athletes with intentions of returning to their primary sport prior to undergoing ACL reconstruction were identified for study participation. Patients between 15 and 50 years of age were included if they received a unilateral ACL autograft reconstruction and regularly participated in level 1 or II sports (jumping, cutting, pivoting, and lateral movements) prior to surgery.\(^20\) Those undergoing multiple ligament reconstruction, revision ACL reconstruction, ACL repair, or complex concomitant meniscus and/or chondral procedures that would delay weight-bearing were excluded from participation. Subjects were regarded as ‘in-sport’ if they reported sustaining their ACL injury while participating in their self-reported primary mode of sport and ‘out-of-sport’ if they reported their injury occurring outside of their reported primary mode of sport.

PSYCHOLOGICAL ASSESSMENT

Psychological readiness was assessed using the ACL-RSI at 16-weeks following ACL reconstruction.\(^21\) This 12-item questionnaire evaluates three constructs of psychological involvement proposed to be associated with return-to-sport including confidence in performance, risk appraisal, and emotion. Previous studies have found the ACL-RSI scale to be valid, reliable, and predictive of return to preinjury level of sport following reconstruction surgery with a sensitivity of 0.97 and a specificity of 0.63.\(^10\)\(^,\)\(^22\)\(^,\)\(^23\) The 16-week assessment period was selected based on the work by Ardern and colleagues who examined the relationship between ACL-RSI scores and return-to-sport rates, discovering that athletes who scored lower than 56 on ACL-RSI at 16-weeks following reconstruction were less likely to return-to-sport at 12-months.\(^10\)
Table 1: Baseline Patient Demographics

<table>
<thead>
<tr>
<th></th>
<th>In-sport (n = 49)</th>
<th>Out-of-sport (n = 43)</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>25.5 ±10.8</td>
<td>26.4 ±13.0</td>
<td>.561</td>
</tr>
<tr>
<td>Gender (%)</td>
<td>28 Males (57%)</td>
<td>26 Males (60.5%)</td>
<td>.740</td>
</tr>
<tr>
<td>BMI</td>
<td>24.6 ±4.1</td>
<td>25.2 ±5.3</td>
<td>.472</td>
</tr>
<tr>
<td>Graft Type (n, %)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bone Patellar-Tendon Bone</td>
<td>45 (91.8%)</td>
<td>40 (88.6%)</td>
<td>.976</td>
</tr>
<tr>
<td>Hamstring</td>
<td>3 (6.1%)</td>
<td>2 (4.7%)</td>
<td></td>
</tr>
<tr>
<td>Quadriceps</td>
<td>1 (2.0%)</td>
<td>1 (2.3%)</td>
<td></td>
</tr>
<tr>
<td>Meniscus Repair (n, %)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>39 (79.6%)</td>
<td>35 (81.4%)</td>
<td>.984</td>
</tr>
<tr>
<td>MARX Scale (0-16)</td>
<td>10.7 ±5.0</td>
<td>10.4 ±5.2</td>
<td>.883</td>
</tr>
</tbody>
</table>

Data reported as mean ± standard deviation

STATISTICAL ANALYSIS

Case matching was performed using age, gender, body mass index (BMI), and preinjury activity level as determined by MARX scale with the 'out-of-sport' participants serving as the reference group due to the relatively fewer numbers of participants. Additionally, groups were matched by surgical characteristics including ACL graft type and frequency of meniscal involvement (e.g. meniscectomy/repair). Baseline patient demographics and surgical characteristics (graft type, meniscal injury) were analyzed using an independent t-test. Comparisons for ACL-RSI total scores and sub-scores between groups were analyzed using a univariate analysis of variance (ANOVA). An alpha level of .05 was selected to determine statistical significance, and IBM SPSS version 24 (Chicago, Ill, USA) was used for all statistical analyses.

RESULTS

From a cohort 638 patients undergoing ACL reconstruction, 187 met the inclusion criteria of the study, with 144 (29.3%) patients qualifying as an 'in-sport' injury and 43 (6.7%) patients sustaining 'out-of-sport' injuries (Figure 1). After patient matching the 'in-sport' contained 49 (7.7%) of similar age, gender and surgical profile (Table 1). A detailed list of activities in which patients had sustained their ACL injury is provided in Table 2.

Between-group differences at 16 weeks were observed for the 'out-of-sport' group demonstrating higher ACL-RSI scores (60.8 ±11.6 versus 55.3 ±12.4, t = 2.747, P < .001) when compared to the 'in-sport' group. Further analysis of the ACL-RSI subscales indicated that the 'out-of-sport' group demonstrated higher sub-scores on the 'emotional' (53.9 ±16.8 versus 45.9 ±17.2, t = 2.042, P < .016) and 'injury risk appraisal' (68.5 ±16.2 versus 61.3 ±14.7, t = 3.243, P < .001) subscales. There were no differences between groups for the 'confidence' subscale (65.2 ±11.6 versus 63.1 ±12.9, t = .018, P = .987) of the ACL-RSI.

DISCUSSION

The purpose of this study was to determine whether athletes who sustain 'in-sport' ACL injuries exhibited poorer psychological readiness when compared to matched controls who sustain their injury outside their primary mode of sport following surgical reconstruction at 16-weeks. In support of our hypothesis, the 'in-sport' group displayed lower ACL-RSI scores when compared to athletes who sustain their injury 'out-of-sport'. These results provide evidence to support the theory that 'mode of injury', specifically 'in-sport' injuries, can negatively impact psychological readiness scores at 16-weeks following ACL reconstruction.

The relationship between return-to-sport rates and the ACL-RSI has been well documented in previous studies. These studies have reported that the ACL-RSI was an effective measure with regard to its discriminative capabilities for determining return-to-sport readiness. Ardern and colleagues suggested that a score of less than 56 points when assessed at 16-weeks postoperatively was related to a higher likelihood of not returning to preinjury level of sport at 12 months and may help identify maladaptive psychological responses earlier in the recovery process. The average ACL-RSI score for "in-sport" injured athletes (55.3±12.4) in our study fell below the cutoff score, indicating that particular attention to psychological recovery may be warranted for individuals in this group. Similar work by Langford and coworkers concluded that patients who were able to return to their preinjury level of competition had an average ACL-RSI score of 72 when assessed 12-months after surgery. We recommend future investigators consider examining the differences between mode of injury at this timeframe to determine whether differences between groups persist out to a year. Regardless, when considering the link between low ACL-RSI scores and return-to-sport rates, clinicians should consider using strategies that enhance psychological readiness throughout all phases of rehabilitation.

The higher mean observed on the 'injury risk' subscale for 'in-sport' injuries was particularly interesting, and supports the theory of contextual fear conditioning. These data may be useful for future investigators and psychologists interested in the development of effective intervention strategies to potentially mitigate these negative psychological responses. Theoretically, if the impact of these negative responses could be avoided, it may potentially enhance the athletes' ability to return to their prior level of
Table 2: Mechanism of Injury

<table>
<thead>
<tr>
<th>Activity</th>
<th>In-Sport (n = 49)</th>
<th>Out-of-Sport (n = 43)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Football</td>
<td>13 (26.5)*</td>
<td>9 (20.9)</td>
</tr>
<tr>
<td>Basketball</td>
<td>7 (14.3)</td>
<td>3 (7.0)</td>
</tr>
<tr>
<td>Baseball/Softball</td>
<td>3 (6.1)</td>
<td>-</td>
</tr>
<tr>
<td>Soccer</td>
<td>10 (20.4)</td>
<td>3 (7.0)</td>
</tr>
<tr>
<td>Volleyball</td>
<td>3 (6.1)</td>
<td>3 (7.0)</td>
</tr>
<tr>
<td>Skiing/Snowboarding</td>
<td>1 (2.0)</td>
<td>10 (23.3)</td>
</tr>
<tr>
<td>Martial Arts</td>
<td>1 (2.0)</td>
<td>1 (2.3)</td>
</tr>
<tr>
<td>Running</td>
<td>1 (2.0)</td>
<td>2 (4.7)</td>
</tr>
<tr>
<td>Hockey</td>
<td>1 (2.0)</td>
<td>1 (2.3)</td>
</tr>
<tr>
<td>Rugby</td>
<td>1 (2.0)</td>
<td>-</td>
</tr>
<tr>
<td>Lacrosse</td>
<td>2 (4.1)</td>
<td>-</td>
</tr>
<tr>
<td>Dance</td>
<td>1 (2.0)</td>
<td>-</td>
</tr>
<tr>
<td>Badminton</td>
<td>1 (2.0)</td>
<td>-</td>
</tr>
<tr>
<td>Motocross</td>
<td>1 (2.0)</td>
<td>1 (2.3)</td>
</tr>
<tr>
<td>Trampoline</td>
<td>1 (2.0)</td>
<td>2 (4.7)</td>
</tr>
<tr>
<td>Field Events</td>
<td>2 (4.1)</td>
<td>1 (2.3)</td>
</tr>
<tr>
<td>Exercise</td>
<td>-</td>
<td>2 (4.7)</td>
</tr>
<tr>
<td>Bowling</td>
<td>-</td>
<td>1 (2.3)</td>
</tr>
<tr>
<td>Motor Vehicle Accident</td>
<td>-</td>
<td>1 (2.3)</td>
</tr>
<tr>
<td>Slip/Fall</td>
<td>-</td>
<td>3 (7.0)</td>
</tr>
</tbody>
</table>

*Data are presented as n (%)

Figure 1: Study Design
function; however, it is necessary to conduct these studies to confirm this hypothesis.

Considering that mode of injury may negatively influence the psychological profile of athletes, it is recommended to utilize the ACL-RSI to identify athletes subject to these deficits with the goal of implementing intervention strategies early within the rehabilitation process to mitigate the negative consequences of these injury mechanisms. While there is a paucity of research regarding the utilization of these interventions in an ACL population, previous studies have demonstrated their effectiveness in fear-avoidance behaviors found in patients with low back pain,17,18,28–30 chronic disease,29 musculoskeletal pain,31 and knee osteoarthritis.32 Beyond a psychological referral, rehabilitation professionals might consider utilizing techniques including education33–35 to reduce fear-avoidance beliefs, health coaching,17 quota-based exercise,18 on-field rehab,36 and exposure therapy.28,29,37 Graded exposure involves progressive exposure to a hierarchy of situations or activities that cause fear for the purpose of showing that these activities can be completed without causing harm.28,29,37 Della Villa et al. proposed the idea of incorporating on-field rehabilitation into the recovery process of an athlete returning to sport following ACL reconstruction.36 Specifically, the authors recommend a progression from graded exposure in the clinical setting to an on-field setting in order to potentially address the environmental component of contextual fear conditioning. Caution should be used when considering these treatment recommendations as future research is warranted to examine the clinical effectiveness of these interventions for improving return-to-sport rates following ACL injury.

There are several limitations to this study which should be considered when examining these results. Previous studies have reported varying ACL-RSI cut-scores for predicting successful return-to-sport following reconstruction ranging from 56 to 76 based on the assessment timeframe.22,23,38 In the current study, we selected a 16-week assessment not only based on the previous research, but also to serve as a pragmatic means of delivering treatment interventions to patients displaying poorer psychological readiness. However, this may be considered as a limitation as only one ACL-RSI score was used to evaluate the psychological profile of athletes along the athletes’ entire continuum of care. It is recommended that future research be conducted to examine the differences between ‘in-sport’ and ‘out-of-sport’ injuries at the time of return-to-sport, and subsequently return to prior level of performance in order to validate these measures. Lastly, this sample only includes patients from a high-volume, single surgeon ACL database which may potentially limit the generalizability of these results.

CONCLUSION

Athletes who suffer ACL injuries within their primary sport exhibit poorer emotional psychological constructs, and higher self-reported injury-risk when compared to those injured outside of their primary sport following ACL reconstruction. Clinicians should consider the contextual factors involving ‘mode of injury’ when investigating psychological variables of injured athletes attempting to return-to-sport.

CONFLICT OF INTEREST

Dr. Walter Lowe, MD is a paid consultant for DonJoy Inc. & Arthrex Inc. Neither DonJoy Inc. or Arthrex Inc had involvement with any phase of this study.

Submitted: October 22, 2019 CST, Accepted: July 24, 2020 CST
REFERENCES


Background

Patient adherence to home exercise programs (HEPs) is low, and poor patient self-efficacy is a barrier clinicians can influence. However, little evidence suggests that clinicians assess level of patient self-efficacy before prescribing HEPs.

Purpose

To determine the importance of patient self-efficacy to physical therapists (PTs) when addressing patient barriers, determine how PTs assess and use patient self-efficacy for HEPs, and describe the barriers facing PTs when assessing patient self-efficacy for HEPs.

Study Design

Survey.

Methods

Practicing PTs were recruited from the American Physical Therapy Association’s Orthopedic Section and emailed the electronic survey.

Results

Email invitations were sent to 17730 potential participants, and 462 PTs completed the survey over one month. PTs rated self-efficacy as "very" to "extremely" important for patient adherence (58%, 265/454). Most (71%, 328/462) reported assessing self-efficacy before prescribing HEPs and did so through verbal discussion and observation of the patient (50% and 38% respectively). Half of respondents individualized HEPs through self-efficacy related themes. PTs not assessing self-efficacy reported not knowing how (51%, 68/134), being unsure what to do with the information (24%, 32/134), or reporting other barriers (21%, 28/134).

Conclusions

Most PTs indicated that self-efficacy was important for patient adherence, but assessment strategies reported, such as verbal discussion and observation, may not be the most accurate. PTs who did not assess self-efficacy reported not knowing how or what to do with the information once collected. These findings suggest that there is a gap in knowledge related to how to evaluate self-efficacy for HEPs. Better assessment of self-efficacy may lead to more appropriate and effective implementation strategies.

Level of Evidence

Level II
INTRODUCTION

Rehabilitation is often required after musculoskeletal injury or surgery to return patients to normal function. Home exercise programs (HEPs) are one form of rehabilitation program that can contribute to patient outcomes and are a necessary part of recovery post injury or surgery. Although the benefits of rehabilitation are known, patient non-adherence with rehabilitation programs is 50%-70%. Lack of adherence is a significant issue because non-adherent patients have poorer outcomes than those who are adherent. Barriers to rehabilitation adherence include patient factors such as anxiety, depression, forgetfulness, lack of social support, low levels of activity at baseline, pain with exercise, and low self-efficacy. Addressing barriers to rehabilitation in clinical practice may produce more compliant patients and ultimately improve their outcomes.

From a healthcare and exercise perspective, low self-efficacy is a patient barrier to adherence that clinicians can positively influence. The concept of self-efficacy refers to the belief in one’s capability to perform given tasks. Albert Bandura theorized that 4 primary sources of information (mastery, verbal, vicarious, and physiologic/emotional state) can alter individuals’ beliefs about their capabilities. Mastery experience refers to one’s past successes, verbal or social persuasion involves encouragement or support from others, vicarious experiences refer to an individual’s observation of others’ success or failure, and lastly, physiological or emotional states are influenced by the body’s reaction to tasks or situations. Researchers have used a variety of measures to evaluate self-efficacy beliefs in general and for exercise and pain, for example the Pain Self Efficacy Scale. Further, many solutions and strategies have been studied to improve self-efficacy and adherence with rehabilitation programs. Despite the variety and availability of interventions known to improve self-efficacy and/or adherence for HEPs has not been reported. Low self-efficacy with rehabilitation exercise warrants study because of the value it may play in increasing patient adherence, improving patient outcomes, and reducing the cost associated with rehabilitation. This gap between assessing patient self-efficacy, self-efficacy interventions, and patient outcomes, may be due to lack of assessment or lack of knowledge of assessments in clinical practice.

Currently, it is unknown whether clinicians assess self-efficacy as a routine part of standard clinical practice, especially when prescribing HEPs. A better understanding of evaluation and intervention related to self-efficacy by clinicians is needed. Therefore, the purpose of the current study was to better understand clinicians’ approach to assessing patient self-efficacy when creating an HEP. Specifically, physical therapists (PTs) were surveyed to 1) determine the importance of patient self-efficacy when creating an HEP, 2) examine how PTs assess and use patient self-efficacy in HEP planning, and 3) describe the barriers perceived by PTs related to the assessment of patient self-efficacy for an HEP. It was hypothesized that PTs would not recognize self-efficacy as one of the top barriers to patient adherence, would use observation to assess self-efficacy at least 50% of the time, and would report “lack of time” as the most common barrier for not assessing patient self-efficacy.

METHODS

The current study used a cross-sectional survey design and was approved by the University of Kentucky Institutional Review Board. Study participants were recruited through the Academy of Orthopaedic Physical Therapy. To be included in data analysis, participants had to be practicing PTs who were willing and able to complete the electronic survey. The Academy of Orthopaedic Physical Therapy sent a single email invitation to potential participants. The email described the study and included a link to the survey that was open for one month. Participation was voluntary; consent to participate was implied when participants clicked “Yes” to begin the survey.

SURVEY DESIGN AND CONTENT

The survey was created specifically for the current study by the research team. The first step in the development of the survey was to identify relevant items. Over 30 items were generated to address the study aims. The research team reduced those items to approximately 20 items by eliminating similar or duplicate items and items considered unrelated to the aims. Using a judgmental approach, content validity was established with the research team and experts in the field. Pretesting of the mechanics of the survey was then conducted through the institution’s Survey Research Center to ensure that the survey was functioning as intended. Additional pretesting was performed using practicing clinicians (PTs, athletic trainers, and a self-efficacy expert) to determine content validity. Because the survey was designed to assess practice habits and to seek the diverse perspectives of clinicians, internal consistency was not evaluated. For these kinds of data, reliability analysis of internal consistency is difficult and not often performed. The final version of the electronic survey contained a minimum of 10 questions and used branching logic to populate 2-3 additional questions based on each respondent’s previous answers. Therefore, not all questions in the survey were necessarily completed by all respondents because the number of questions depended on an individual’s previous responses. A demographics section at the end of the survey asked participants to report their gender, date of birth, occupation, employment setting, years of experience, highest level of degree, and state of practice. The survey was administered through Qualtrics (Qualtrics, Inc, Provo, UT) and required 5-7 minutes to complete.

The survey included 3 questions to determine the importance of patient self-efficacy to PTs. The first question addressed the degree to which PTs believed that self-efficacy is important for patient adherence to exercise. Responses were rated on a 5-point Likert-like scale ranging from 0 (not important) to 4 (extremely important). The second question asked participants to select which patient barriers were typically related to patients not completing prescribed exercise. Specifically, PTs were asked to rank, in a drag and drop format, eight patient barriers (anxiety or depression, feelings of helplessness, forgetfulness, lack of time, lack of...
social support, low levels of activity at baseline, pain with exercise, and low self-efficacy), derived from the literature, on a scale from 1 (most often/common) to 8 (least often/common). The third question, stemming from the second, asked participants to rank the patient barriers they felt most negatively influenced patient adherence using a similar scale, 1 (most influential) to 8 (least influential). For both questions, a lower score represented greater influence.

Two questions were included in the survey to determine how PTs assess and use patient self-efficacy. One question dealt with methods of assessment and allowed respondents to select any forms of assessment used (verbal discussion, observation, patient-reported outcomes, and other). The second question was open-ended and asked PTs to report how they used patient self-efficacy information after collecting it (Based on a patient’s self-efficacy, how do you individualize treatment?).

Participants who indicated that they did not assess patient self-efficacy before prescribing HEPs were asked to identify what prevented them from doing so. Specifically, they were asked to select any barriers perceived from a list (e.g., not knowing how to assess, assessment would not change course of treatment, not sure what to do with the information after assessing, not knowing what self-efficacy is, time involved, or "other"). If the "other" option was selected, an open text box appeared to allow respondents to list additional barriers they encounter to assessing patient self-efficacy.

DATA ANALYSIS

Survey responses and demographic data were summarized descriptively [e.g., frequencies and percentages or mean (SD)]. A Friedman test was used to examine differences in participants’ rankings of the 8 barriers. A Wilcoxon signed rank test was used to determine where differences existed between and order of perceived and observed patient barriers. Seven pairwise comparisons were performed, therefore, the significance level was set to .007. Statistical analyses were performed in SPSS version 24.0 (IBM SPSS, Armonk, NY, USA).

Open ended responses were independently coded by two authors (KJP and ASV) according to their relevance to the four hypothesized sources of self-efficacy: mastery experience, verbal or social persuasion, vicarious experience, and physiological or emotional state. In this study, previous successes with rehabilitation exercise, a mastery experience, was thought to shape one’s beliefs in their abilities to achieve a goal. Lack of time was ranked as the most observed patient barrier to rehabilitation exercise adherence, followed by forgetting and having low levels of activity at baseline. Low self-efficacy was ranked fifth of the 8 patient barriers.

Regarding the importance of patient self-efficacy, 58% of PTs reported self-efficacy to be very (151/454) or extremely important (114/454) (Figure 1). Only 2% (9/454) reported self-efficacy as not at all important.

Physical therapists differed significantly in how they ranked the identified patient barriers to exercise adherence \((\chi^2 = 892.06, df = 7, p < .001)\). As indicated in Table 1, rankings differed significantly among patient barriers with few exceptions. Lack of time was ranked as the most observed patient barrier to rehabilitation exercise adherence, followed by forgetting and having low levels of activity at baseline. Low self-efficacy was ranked fifth of the 8 patient barriers.

Physical therapists also ranked the same set of patient barriers in terms of which had the most negative influence on exercise adherence. Again, their rankings differed significantly \((\chi^2 = 252.44, df = 7, p < .001)\) (see Table 3). Physical therapists ranked the presence of anxiety or depression as having the most negative influence on adherence \((p < .007)\). Statistically, there were no significant differences \((p > .001)\) between self-efficacy, low levels of activity at baseline, feelings of helplessness, and increased pain during exercises for the second rank.

Regarding how PTs assess and use patient self-efficacy, 71% (329/462) indicated that they assess patient self-efficacy for home exercise before prescribing an HEP (Figure 2). Half of the PTs reported using verbal discussion to assess patient self-efficacy. PTs also reported observing the pa-
Table 1: Participant characteristics (n = 462)

<table>
<thead>
<tr>
<th>Demographics</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>232</td>
</tr>
<tr>
<td>Male</td>
<td>228</td>
</tr>
<tr>
<td>Not reported</td>
<td>2</td>
</tr>
<tr>
<td>Level of education completed</td>
<td></td>
</tr>
<tr>
<td>Doctorate</td>
<td>340</td>
</tr>
<tr>
<td>Masters</td>
<td>66</td>
</tr>
<tr>
<td>Bachelors</td>
<td>35</td>
</tr>
<tr>
<td>Ph.D.</td>
<td>20</td>
</tr>
<tr>
<td>Not reported</td>
<td>1</td>
</tr>
<tr>
<td>Region of practice</td>
<td></td>
</tr>
<tr>
<td>Midwest</td>
<td>118</td>
</tr>
<tr>
<td>West</td>
<td>111</td>
</tr>
<tr>
<td>Northeast</td>
<td>98</td>
</tr>
<tr>
<td>Southeast</td>
<td>94</td>
</tr>
<tr>
<td>Southwest</td>
<td>33</td>
</tr>
<tr>
<td>South West</td>
<td></td>
</tr>
<tr>
<td>Southwest</td>
<td>33</td>
</tr>
<tr>
<td>South West</td>
<td>94</td>
</tr>
<tr>
<td>Not Reported</td>
<td>8</td>
</tr>
<tr>
<td>Setting of practice</td>
<td></td>
</tr>
<tr>
<td>Outpatient/private practice</td>
<td>393</td>
</tr>
<tr>
<td>Hospital</td>
<td>79</td>
</tr>
<tr>
<td>Education/research</td>
<td>20</td>
</tr>
<tr>
<td>Acute care</td>
<td>17</td>
</tr>
<tr>
<td>Home health</td>
<td>14</td>
</tr>
<tr>
<td>Professional sports</td>
<td>13</td>
</tr>
<tr>
<td>Government</td>
<td>12</td>
</tr>
<tr>
<td>Subacute care</td>
<td>11</td>
</tr>
<tr>
<td>Collegiate</td>
<td>11</td>
</tr>
<tr>
<td>Secondary school</td>
<td>8</td>
</tr>
<tr>
<td>Extended care</td>
<td>7</td>
</tr>
<tr>
<td>Industrial</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 2: Friedman test results of what physical therapists observe to be barriers to patient exercise adherence

<table>
<thead>
<tr>
<th>Barriers</th>
<th>N</th>
<th>Mean ranks</th>
<th>SD</th>
<th>Group differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of time</td>
<td>460</td>
<td>2.51</td>
<td>2.15</td>
<td>All</td>
</tr>
<tr>
<td>Forgetting</td>
<td>460</td>
<td>3.32</td>
<td>2.04</td>
<td>All</td>
</tr>
<tr>
<td>Low levels of activity at baseline</td>
<td>460</td>
<td>3.55</td>
<td>2.01</td>
<td>All</td>
</tr>
<tr>
<td>Pain with exercise</td>
<td>460</td>
<td>4.45</td>
<td>2.01</td>
<td>All</td>
</tr>
<tr>
<td>Low self-efficacy a</td>
<td>460</td>
<td>4.97</td>
<td>1.94</td>
<td>All, except b</td>
</tr>
<tr>
<td>Anxiety/depression b</td>
<td>460</td>
<td>5.32</td>
<td>1.94</td>
<td>All, except a &amp; c</td>
</tr>
<tr>
<td>Helplessness c</td>
<td>460</td>
<td>5.57</td>
<td>1.75</td>
<td>All, except b</td>
</tr>
<tr>
<td>Lack of social support</td>
<td>460</td>
<td>6.33</td>
<td>1.71</td>
<td>All</td>
</tr>
</tbody>
</table>

*A Wilcoxon Signed Rank test detected between which groups differences exist, this is indicated in the group-differences column. Three barriers were assigned a letter as indicated by the superscript.

**A higher score indicates lower importance.
Table 3: Friedman test results of what physical therapists believe the most negatively influential to patient exercise adherence

<table>
<thead>
<tr>
<th>Barriers</th>
<th>N</th>
<th>Mean rank</th>
<th>SD</th>
<th>Group differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anxiety/depression</td>
<td>458</td>
<td>3.54</td>
<td>2.12</td>
<td>All</td>
</tr>
<tr>
<td>Low levels of activity at baseline</td>
<td>458</td>
<td>3.99</td>
<td>2.17</td>
<td>All, except b, c, d</td>
</tr>
<tr>
<td>Helplessness b</td>
<td>458</td>
<td>4.20</td>
<td>1.90</td>
<td>All, except a, c, d</td>
</tr>
<tr>
<td>Pain with exercise c</td>
<td>458</td>
<td>4.26</td>
<td>2.21</td>
<td>All, except a, b, d</td>
</tr>
<tr>
<td>Low self-efficacy d</td>
<td>458</td>
<td>4.30</td>
<td>2.10</td>
<td>All, except a, b, c</td>
</tr>
<tr>
<td>Forgetting e</td>
<td>458</td>
<td>5.00</td>
<td>2.26</td>
<td>All, except f</td>
</tr>
<tr>
<td>Lack of time f</td>
<td>458</td>
<td>5.02</td>
<td>2.71</td>
<td>All, except e</td>
</tr>
<tr>
<td>Lack of social support</td>
<td>458</td>
<td>5.69</td>
<td>2.07</td>
<td>All</td>
</tr>
</tbody>
</table>

*A Wilcoxon Signed Rank test detected between which groups differences exist, this is indicated in the group differences column. All barriers were assigned a letter as indicated by the superscript.

**A higher score indicates less influence on patient exercise adherence.

tient (38%), using patient self-report questionnaires (10%), and using other methods (2%) to assess patient self-efficacy. Eighty-nine (27%) PTs identified using only 1 method to assess patients’ self-efficacy, whereas 186 (57%) PTs said they used 2 methods, and 53 (16%) said that they used 3 or more. Verbal discussion and patient observation were selected together most frequently; 91% of those selecting 2 methods reported assessing self-efficacy with these techniques. Only 10 (3%) participants reported using some other method to assess self-efficacy, and their responses were related to discussion with the patient or observing them complete the prescribed exercise.

Of the 328 PTs who reported assessing patient self-efficacy, 310 (94%) indicated how they individualized treatment after assessment by responding to the open-ended prompt. This open-ended prompt allowed participants to write freely to expand on all treatments they may use to address patient self-efficacy. From these open-ended responses, 362 treatments were extracted and 185 corresponded loosely to Bandura’s theorized sources of self-efficacy.8 Table 4 presents frequency counts based on common themes. Roughly half of participants’ responses were related to supporting patient self-efficacy through one or more of the sources of self-efficacy. Mastery experience (92/362, 25%) was the most common method followed by verbal persuasion (62/362, 17%), vicarious experience (19/362, 5%), and physiological state (12/362, 3%).

Of the open-ended responses, 49% could not be directly related to any of Bandura’s four8 sources of self-efficacy. Themes from these responses included individualization of HEPs based on patient preference or patient resources, modification of sets, repetitions, and type of exercise, or focused on nonspecific patient education. The other category consisted of statements regarding findings that would alter treatment, not methods of individualization that can be tied to Bandura’s sources of self-efficacy.

The last aim of the study was to examine factors that prevent PTs from assessing patient self-efficacy. In total, 134 respondents indicated they did not assess self-efficacy. Of those who reported barriers to assessing patient self-efficacy, 21% (28/134) reported more than one barrier (i.e., 21 participants identified two barriers, and 7 identified three or more barriers for an n=170 barriers reported). Of those, 39.4% (67/170) reported not knowing how to assess self-efficacy, 19% (32/170) were not sure what to do with the information once self-efficacy was assessed, 16.5% (28/170) reported other barriers to assessment, 14.1% (24/170) reported that assessing self-efficacy would not change their practice, 10% (17/170) indicated that assessing self-efficacy took too much time, and 1% (2/170) did not know what self-efficacy was (Figure 3). Of those who indicated that “other” barriers (21%, 28/170) prevented them from assessing patient self-efficacy, the most common response was assessment of self-efficacy was conducted at another time or they did not believe that self-efficacy is important enough to assess. When compared to those who do assess self-efficacy for HEPs, there were no statistically significant differences between groups for age, sex, or years of clinical experience.

DISCUSSION

The current study surveyed practicing PTs to determine their assessment and use of self-efficacy in musculoskeletal

International Journal of Sports Physical Therapy

Figure 2: Methods of self-efficacy assessment used by physical therapists

*458 participants indicated the y did not assess self-efficacy. Of those, 21% (28/134) reported more than one barrier (i.e., 21 participants identified two barriers, and 7 identified three or more barriers for an n=170 barriers reported). Of those, 39.4% (67/170) reported not knowing how to assess self-efficacy, 19% (32/170) were not sure what to do with the information once self-efficacy was assessed, 16.5% (28/170) reported other barriers to assessment, 14.1% (24/170) reported that assessing self-efficacy would not change their practice, 10% (17/170) indicated that assessing self-efficacy took too much time, and 1% (2/170) did not know what self-efficacy was (Figure 3). Of those who indicated that “other” barriers (21%, 28/170) prevented them from assessing patient self-efficacy, the most common response was assessment of self-efficacy was conducted at another time or they did not believe that self-efficacy is important enough to assess. When compared to those who do assess self-efficacy for HEPs, there were no statistically significant differences between groups for age, sex, or years of clinical experience.

DISCUSSION

The current study surveyed practicing PTs to determine their assessment and use of self-efficacy in musculoskeletal

International Journal of Sports Physical Therapy

Figure 2: Methods of self-efficacy assessment used by physical therapists

*458 participants indicated the y did not assess self-efficacy. Of those, 21% (28/134) reported more than one barrier (i.e., 21 participants identified two barriers, and 7 identified three or more barriers for an n=170 barriers reported). Of those, 39.4% (67/170) reported not knowing how to assess self-efficacy, 19% (32/170) were not sure what to do with the information once self-efficacy was assessed, 16.5% (28/170) reported other barriers to assessment, 14.1% (24/170) reported that assessing self-efficacy would not change their practice, 10% (17/170) indicated that assessing self-efficacy took too much time, and 1% (2/170) did not know what self-efficacy was (Figure 3). Of those who indicated that “other” barriers (21%, 28/170) prevented them from assessing patient self-efficacy, the most common response was assessment of self-efficacy was conducted at another time or they did not believe that self-efficacy is important enough to assess. When compared to those who do assess self-efficacy for HEPs, there were no statistically significant differences between groups for age, sex, or years of clinical experience.

DISCUSSION

The current study surveyed practicing PTs to determine their assessment and use of self-efficacy in musculoskeletal

International Journal of Sports Physical Therapy

Figure 2: Methods of self-efficacy assessment used by physical therapists

*458 participants indicated the y did not assess self-efficacy. Of those, 21% (28/134) reported more than one barrier (i.e., 21 participants identified two barriers, and 7 identified three or more barriers for an n=170 barriers reported). Of those, 39.4% (67/170) reported not knowing how to assess self-efficacy, 19% (32/170) were not sure what to do with the information once self-efficacy was assessed, 16.5% (28/170) reported other barriers to assessment, 14.1% (24/170) reported that assessing self-efficacy would not change their practice, 10% (17/170) indicated that assessing self-efficacy took too much time, and 1% (2/170) did not know what self-efficacy was (Figure 3). Of those who indicated that “other” barriers (21%, 28/170) prevented them from assessing patient self-efficacy, the most common response was assessment of self-efficacy was conducted at another time or they did not believe that self-efficacy is important enough to assess. When compared to those who do assess self-efficacy for HEPs, there were no statistically significant differences between groups for age, sex, or years of clinical experience.
Table 4: Themes extracted on how physical therapists individualize home exercise programs based on self-efficacy assessment

<table>
<thead>
<tr>
<th>Theme</th>
<th>Frequency (Out of 362 responses)</th>
<th>Example of participant response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mastery experience</td>
<td>92</td>
<td>“Try to make home exercises that I have observed them successfully perform within the therapy session.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Select exercises they can perform confident and successfully over time during visits; begin with 1 simple exercise to begin.”</td>
</tr>
<tr>
<td>Verbal/social persuasion</td>
<td>62</td>
<td>“Provide encouragement.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Reinstruct as needed.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Bring a family member in to help.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“...will follow up 24 hours later by email/phone.”</td>
</tr>
<tr>
<td>Vicarious experience</td>
<td>19</td>
<td>“I demonstrate a successful completion.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“…give written material with pictures and a web address for videos.”</td>
</tr>
<tr>
<td>Physiological state</td>
<td>12</td>
<td>“Prioritize based on symptom management.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Teach them how specific exercises can effect them.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Emphasis that they CANNOT do any harm that movement is good, they are not hurting anything.”</td>
</tr>
<tr>
<td>Other</td>
<td>177</td>
<td>“I may change visit frequency or modify number/type of exercises prescribed for home.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Limit the number of exercises.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Modify home exercise program in order for them to complete it on a regular basis, such as number of exercises, per day, work schedule, family demands.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Observe patient problem solve.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Make sure it can be completed with available or no equipment.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“2 week home exercise program trial to assess success.”</td>
</tr>
</tbody>
</table>

rehabilitation when prescribing HEPs. Just over half of participants found self-efficacy to be very to extremely important for patient adherence. Although the PTs surveyed in this study did not rank self-efficacy as the most important barrier to adherence (i.e., time contraints was ranked highest, and anxiety and depression was ranked as most adversely associated with adherence), almost three-quarters of the PTs participating in the study reported that they assess patients’ self-efficacy for HEPs before prescribing programs. Their assessments occur mainly through verbal discussions with or observations of the patient. However, over one quarter of participants reported that they did not assess self-efficacy. These findings suggest the need for better education of clinicians about the role of self-efficacy in guiding patient behavior.

Previous research has shown self-efficacy to be a moderate predictor of patient adherence and an influencer of patient behavior throughout the rehabilitation process. The clinical implications of such research suggest that clinicians should focus on patient self-efficacy to improve adherence and outcomes. Results of the current study support this evidence; the surveyed PTs believed self-efficacy was an important concept in musculoskeletal rehabilitation when prescribing HEPs. Just over half of participants found self-efficacy to be very to extremely important for patient adherence. Although the PTs surveyed in this study did not rank self-efficacy as the most important barrier to adherence (i.e., time contraints was ranked highest, and anxiety and depression was ranked as most adversely associated with adherence), almost three-quarters of the PTs participating in the study reported that they assess patients’ self-efficacy for HEPs before prescribing programs. Their assessments occur mainly through verbal discussions with or observations of the patient. However, over one quarter of participants reported that they did not assess self-efficacy. These findings suggest the need for better education of clinicians about the role of self-efficacy in guiding patient behavior.

Although anxiety and depression stood out in the rankings as the most negatively influential barrier hindering patient adherence, low self-efficacy ranked similarly with other barriers (e.g., pain while exercising, helplessness, and low lev-
els of activity at baseline) as next most influential. Physical therapists may not be able to treat anxiety or depression without additional training, but they do have the ability to influence patient self-efficacy. Ultimately, understanding which barriers clinicians can successfully address is important when trying to improve patient adherence to HEPs.

When PTs ranked the patient barriers to exercise that they observed most often, self-efficacy was ranked the same as 3 other barriers falling in at ranks 2-5; lack of time was ranked as the most prevalent barrier. Patients who are considered noncompliant have previously reported that they lacked time to exercise or the exercises did not fit into their daily schedules. As such, the PT should ask the patient about time constraints before prescribing an HEP. Medina-Mirapeix et al. examined adherence to HEPs with varying frequency and durations to identify whether adherence rates were different between patients with neck or back pain. They found prescribed exercises should be limited to 3 exercises or fewer because patients had lower odds of being adherent to their HEP when more exercises were prescribed. Another study examined the adherence of 15 older adults to HEPs consisting of 2, 5, or 8 exercises. The researchers found that older adults were more compliant with 2 exercises. Time constraints are likely to be associated with self-efficacy for HEP adherence. When patients are given too many exercise tasks, they may become unduly frustrated or fail to remember how to perform them. Therefore, clinicians should consider the patient’s time when trying to improve adherence to HEPs. Further, they should try to limit HEPs to 2-5 key exercises to facilitate adherence. Limiting exercises prescribed, as well as assessing patient self-efficacy for HEPs is of great importance for patient adherence.

In the current study, it was expected that patient observation would be the most common assessment method reported for assessing self-efficacy. However, verbal discussion with the patient was most commonly reported and often in combination with patient observation. In the literature, assessment of self-efficacy has typically included the use of self-report scales and questionnaires. A recent systematic review compiled methods of self-efficacy assessment to identify the variety of reliable and valid scales currently used in musculoskeletal rehabilitation. The authors did not identify verbal discussion or observation of the patient as reliable or valid methods of assessment. If PTs are not using assessment methods with sound psychometric properties, the quality of their results may be limited. As Bandura has noted, there are no strict behavioral markers for high or low self-efficacy. Clinicians can make incorrect inferences about a patient’s self-efficacy from verbal discussion and direct observation. Using these as the sole methods of self-efficacy assessment may not provide sufficient information about the patient’s cognitive self-judgment.

In the current study, only 10% of PTs reported using patient-reported scales or questionnaires. Because patient-reported outcome measures are increasingly used in clinical practice as a self-report of function, it is surprising that barriers to adherence would not be addressed using the same methodology. That is, until recently, there was not a scale designed to specifically assess patient self-efficacy for HEPs. Picha et al developed and established the psychometric properties of the Self-Efficacy for Home Exercise Programs Scale. This 12-item scale was designed to increase clinician assessment of patient self-efficacy for HEPs to enhance patient centered care. Clinicians should be aware of their options for assessment of patient self-efficacy to effectively track progress and improve patient care.

Although successful interventions to improve self-efficacy have been identified the results of this study suggest that PTs are not utilizing this evidence in practice. It may be that they are unfamiliar with such interventions. Three hundred and sixty two treatments were extracted from the open-ended responses addressing individualized treatment after assessment. Of those, half did not address self-efficacy as proposed by Bandura. This finding suggests that clinicians may not know how to effectively address or promote self-efficacy in their patients. Many of the responses were well removed from the construct of self-efficacy and primarily indicated that PTs individualized treatment based on other barriers. Individualizing treatments based on other patient barriers shouldn’t be perceived as incorrect, but speaks to the need for more education on the value of promoting self-efficacy to drive adherence. Given that previous studies have found promising results related to self-efficacy, incorporating the sources of self-efficacy into rehabilitation would be beneficial for those wanting to improve patient self-efficacy. For example, working with the patient to set goals, providing positive feedback, and including family or friends as additional social support can be effective strategies to improve self-efficacy.

Over a fourth of PTs in the current study reported they do not assess self-efficacy for HEPs. Of the PTs who did not assess self-efficacy, most report not knowing how to assess self-efficacy for HEPs and almost a quarter did not know what to do with the information once assessed. Perhaps the educational programs of these PTs did not cover this material sufficiently, or perhaps not knowing how to assess self-efficacy for HEPs arises from a lack of suitable instruments to assess it. In a systematic review, the authors were unable to find a self-efficacy scale that was task specific to HEPs. In another study, when a general exercise scale was used to evaluate self-efficacy for home exercise, no relationship between home exercise and adherence was found. Because self-efficacy is task and situation specific, scales need to reflect the tasks of interest and relevant to the context. One study examined the barriers to use of patient-reported outcomes and found that the most common barrier to assessment was time: time for patients to complete the assessment, and time for clinicians to analyze or score it. However, only 11% of respondents in the current study indicated time as a barrier to assessing patient self-efficacy.

Since most of the participants perceived patient self-efficacy as important, knowing how to assess self-efficacy for HEPs in an efficient and valid manner is important. Another reason clinicians have previously reported for not using patient-reported outcome measures is the belief that such measures are only useful for research purposes or that the results would not change their practice. Similarly, almost a fifth of participants indicated that assessing self-efficacy for HEPs would not change their practice. In a study by Stickler, PTs reported that self-efficacy does affect adherence, but they believed that gaining self-efficacy was the
patient’s responsibility. However, evidence suggests\(^6,7\) that self-efficacy is a barrier that can be influenced by the clinician and is a predictor of rehabilitation adherence. Therefore, PT education programs should stress the assessment of self-efficacy and interventions to improve it, especially for HEPs.

The current study had some limitations. The survey response rate was low. Practicing PTs were recruited from the Academy of Orthopaedic Physical Therapy as a sample of convenience; therefore, the results may be generalizable to only that population. These factors limit the external validity of the results. Physical therapists in other sections of the association or in other rehabilitation areas may have different perceptions of self-efficacy as a barrier and of the use of patient self-efficacy in practice. Additionally, this study does not address the overlap and direct correlations these 8 barriers have with each other. Self-efficacy specifically has direct correlations with depression\(^32\) and therefore, PT’s may not be equipped to address self-efficacy in combination with underlying mental health conditions. The selected data collection method provides a helpful, yet limited level of detail. Conducting lengthier conversations with clinicians would enable a more comprehensive understanding of how they can support patients’ self-efficacy.

CONCLUSION

Self-efficacy is an important construct influencing patient care. However, it may not be the most commonly observed or perceived as a largely influential patient barrier by PTs. The findings of this study suggested a few key concerns with current self-efficacy assessment and utilization when trying to improve patient adherence to HEPs. First, for this group of respondents, assessment of self-efficacy for HEPs was primarily performed through verbal discussion or observation of the patient; neither of these methods have been found to be reliable or valid for assessment. Second, about half of clinicians who reported assessing self-efficacy for HEPs may not be adequately addressing patient self-efficacy within their treatment plans. Although almost half of the PTs surveyed used a theorized source of self-efficacy in their treatment plans, just as many did not describe using one of the known strategies for changing patient self-efficacy. This provides a rich opportunity for PT professional development. Lastly, a number of PTs who reported not assessing self-efficacy for HEPs conveyed that they did not know how to assess this construct. This may be due to a lack of instrumentation or education. Future research should focus on utilization of self-efficacy instruments, such as the Self-Efficacy for Home Exercise Programs Scale, that assesses self-efficacy for HEPs in clinical practice and should work to improve implementation strategies for successful self-efficacy interventions.

The University of Kentucky IRB has approved this study.

CONFLICTS OF INTEREST

The authors report no conflicts of interest to disclose.

Submitted: March 15, 2020 CST, Accepted: October 10, 2020 CST
REFERENCES


Descriptive Strength and Range of Motion in Youth Baseball Players

Background
There are limited studies reporting descriptive strength and range of motion in youth baseball players 12 years of age or younger.

Purpose
To establish normative data for external (ER) and internal (IR) rotation range of motion (ROM), total arc range of motion (TROM), and isometric rotator cuff strength in youth baseball players, and to compare between the dominant throwing arm (D) to the non-dominant arm (ND).

Study Design
Cross-sectional

Methods
Patient population included 50 (5 to 12-year-old) uninjured, healthy athletes. ROM measurements were performed preseason using a goniometer for IR and ER in the supine position with the shoulder in 90 degrees of abduction (abd) with scapular stabilization. Isometric strength measurements for IR and ER were collected in both neutral and 90 degrees (deg) of abduction with the use of a hand-held dynamometer and recorded in pounds (lbs) utilizing a "make" test. Descriptive statistics were obtained for all measures.

Results
All data were analyzed as a single group (average age: 9.02). No significant difference in average total arc of PROM (ER+IR=Total Arc) on the D side compared to the ND side (136.7 ± 12.7 deg vs. 154.5 ± 12.3 deg). There were statistically significant differences between ER ROM (102.2 ± 7.7 deg vs. 96.8 ± 7.4 deg) and IR ROM (34.4 ± 9.0 deg vs. 37.5 ± 9.5 deg) between D versus ND arms (p=.000, .006 respectively). Mean ER strength in neutral (13.6 ± 3.4 and 12.8 ± 3.6 lbs) and 90 deg abduction (12.3 ± 3.4 and 12.5 ± 4.3 lbs) did were not significantly different between D and ND arms, respectively. Mean IR strength in neutral (18.0 ± 6.0 and 15.7 ± 4.7 lbs) and 90 deg abd (16.4 ± 5.6 and 15.0 ± 5.7 lbs) was significantly greater in the D arm vs ND arm, respectively (p=.000, .001).

Conclusion
These data can provide descriptive information for clinicians who treat very young baseball players. These data show sport specific adaptations occur at very young ages (5-12) and are similar to prior reports on adolescent, high school and professional baseball players regarding upper extremity ROM and rotator cuff strength.

Level of Evidence
3
INTRODUCTION

Glenohumeral joint range of motion (ROM) adaptations in IR and TROM have been identified in elite baseball and tennis players primarily in the direction of internal rotation (IR) and total rotational motion (TROM). These changes or adaptations in glenohumeral joint ROM have also been reported in other unilaterally dominant upper extremity sport athletes such as tennis, volleyball players and swimmers as well, but have been studied primarily in baseball pitchers.

It is well known that the overhead throwing athlete develops changes in shoulder ROM, specifically a loss of glenohumeral IR. This loss of IR ROM with an accompanying increase in external rotation (ER) ROM can place the overhead throwing athlete at risk of injury. Previous authors have specified that glenohumeral internal rotation deficit (GIRD) in itself is not necessarily considered deleterious to throwing motion or risk of injury. Rather a change in the total arc of motion between dominant (D) and non-dominant (ND) arms is when GIRD can be pathologic.

Total arc of motion is defined as the sum of ER and IR ROM (Figure 1) and has been reported to be a total of 160–180 degrees. Overhead throwing athletes notoriously have a shift in measured ER and IR ROM, with the D throwing arm presenting with limited IR and excessively increased ER in order to provide the necessary torque required to pitch. The ability to throw at high velocities requires adaptations to occur within the athlete’s shoulder complex that are not typically seen in the ND side of throwers, or in the shoulders of non-throwing individuals. For example, a baseball pitcher with a D arm total arc ROM (105 degrees of ER + 55 degrees of IR = 160° TROM) versus ND arm (90 degrees of ER + 70 degrees of IR = 160 degrees of TROM) would be considered to have an anatomic GIRD/adaptation and this athlete would not be considered at risk for further shoulder injury due to symmetrical TROM.

Pathologic GIRD is defined as when there is a loss of glenohumeral IR greater than 18° – 20° with a corresponding loss of total arc of motion greater than 5° when compared bilaterally. For example, a baseball pitcher with a D arm total arc ROM (110 + 50 = 160°) and ND arm total arc ROM (80 + 70 = 150°) would be considered pathologic and at risk for future shoulder or elbow injury.

In addition to changes in available ROM, muscle imbalances may occur of the rotator cuff and scapular stabilizers contributing to further asymmetry which relates to control of the throwing motion. Increased dominance of internal rotator muscles and impaired recruitment of external rotators, especially in eccentric control, may put throwing athletes at risk for injury. The late cocking phase and follow through phases are especially susceptible to excessive tensile load across shoulder structures. Dynamic control and proprioceptive input are critical in maintaining scapulothoracic and rotator cuff stability during the overhead throwing motion.

Muscle timing and recruitment are key components in maintaining proximal stability for distal mobility during arm motion. Researchers have shown decreased output of the scapular stabilizers (such as the serratus anterior) to occur with dominance of internal rotators (such as the pectoralis major and minor) along with impaired strength of the posterior rotator cuff needed for control and deceleration of the arm in throwing.

Most of the available research has demonstrated normative and descriptive data profiles for shoulder ROM and strength of the adult or older adolescent athlete, whereas minimal research is available for adolescent throwing athletes under the age of 12. Young athletes are often specializing in a single sport at earlier ages, dedicating their time year round to one sport and one position, despite the American Academy of Pediatrics recommending a minimum of two months off per year with a minimum of one day off per week to minimize overuse injuries in the adolescent athlete. Thus, the authors are aware of the fact that these overuse injuries are beginning to occur at younger and younger ages. We are less aware, however, of what age young overhead athletes begin to develop glenohumeral rotation deficits and rotational muscle imbalances. This information would be important to rehabilitation professionals working with young overhead athletes to perhaps reduce the risk for injury.

The purpose of this research was to establish descriptive data by measuring shoulder IR and ER ROM, total arc range of motion (TROM), and isometric strength and determine if differences exist between the D and ND extremity in athletes 12 years of age or younger. Research identifying the descriptive profile of total arc range of motion in healthy, uninjured youth baseball players will allow clinicians and scientists to better interpret findings of preventative evaluations and during the examination of youth baseball players. It was hypothesized that youth baseball athletes aged 5–12 years old would show throwing-related adaptations in shoulder strength and ROM in the D versus the ND arm.

METHODS

Study participants were recruited from a local youth baseball league during opening day festivities prior to the start of the season. Subjects were included if they were between...
the ages of 5 and 12 and had no current shoulder pain or injury, and no history of shoulder or elbow surgery in either upper extremity. Participants were also excluded if they had any shoulder injury in the prior year that prevented baseball competition or training.

PROCEDURES

All participants were measured on opening day of the 2012 baseball season. Before data collection, the parent/guardian read and signed the informed consent form approved by the institutional review board of Physiotherapy Associates, Exton, PA. Subjects were assigned a number that represented their involvement in this study. This number was used in lieu of their name to minimize the risk and ability of their identity being disclosed to persons other than the primary investigator. After informed consent was signed demographic information was collected (age, arm dominance). Participants were then instructed to report to either a strength or range of motion testing location for evaluation based on convenience. Subjects were measured bilaterally in a random order to prevent any effects of bias for both ROM and strength measures.

For ROM measurement, participants were placed supine on a portable treatment table without a pillow under their head, with the arm in 90 degrees of shoulder abduction and 90 degrees of elbow flexion. Subjects were asked to retract their scapulae bilaterally and then lie in a relaxed position for the duration of the testing. The superior border of the scapula was stabilized in a relaxed position by one hand of the examiner using a thumb on the coracoid process (Figure 3) to prevent/minimize scapular substitution. From this position the examiner passively moved the subject’s extremity into external rotation until first resistance was encountered (Figure 2). There was no overpressure applied to the extremity at any time. Gravity was used as a constant force to maintain the end-point position similar to the method used by the authors during measurement of glenohumeral joint internal rotation. From neutral rotation the examiner then moved the extremity into internal rotation until first resistance was encountered (Figure 3) using the exact procedure employed for external rotation measurement. A standard method was used with the same therapist collecting all of the ROM and strength measurements. An analog goniometer was then placed along the axial midline of the humerus with one arm vertical representing 0 degrees and the other arm of the goniometer parallel to the lateral border of the ulna. One trial of measurement was utilized to represent the subjects’ ER and IR ROM for this investigation. Bilateral measurement was performed using identical procedures.

Strength measurements were obtained with the use of a hand held dynamometer (Microfet 2, Hoggan Health Industries, Salt Lake City, UT- Figure 4) and recorded in pounds utilizing a “make” test. The strength tests were performed with the subjects in a standing position with a 3” ½ foam roll under the subjects’ axilla to provide sufficient spacing between arm and body. D and ND sides were randomly chosen and tested using a coin toss to determine which side was tested first. Internal and external rotation strength were tested in this position in neutral shoulder rotation by the same examiner. The hand-held dynamometer was positioned proximal to the wrist on the dorsal and volar aspect of the distal forearm for external and internal rotation strength testing, respectively. The process was completed bilaterally and recorded in a Microsoft Excel spreadsheet. In a random fashion, external and internal rotation strength in 90 degrees of abduction was also tested with the shoulder placed in the coronal plane. Testing took place in a standing position with the shoulder in 90 degrees of ER and 90 degrees of abduction bilaterally.

Data were stored on a Microsoft Excel sheet and SPSS was used to calculate descriptive statistics as well as compare differences between extremities using dependent
Table 1: Descriptive Demographics - Youth Baseball Players (total n=50, all were male)

<table>
<thead>
<tr>
<th>Age</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
</tr>
</tbody>
</table>

Arm Dominance

<table>
<thead>
<tr>
<th>Right</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>45</td>
</tr>
</tbody>
</table>

| Left  | 5  |

Table 2: Shoulder Internal (IR), External (ER), and Total Rotation Range of Motion, mean ± SD, reported in degrees.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dominant Arm</th>
<th>Non-Dominant Arm</th>
<th>t</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER ROM @ 90 AB</td>
<td>102.2±7.7</td>
<td>96.8±7.4</td>
<td>4.42</td>
<td>0.000</td>
</tr>
<tr>
<td>IR ROM @ 90 AB</td>
<td>34.4±9.0</td>
<td>37.5±9.5</td>
<td>-2.88</td>
<td>0.006</td>
</tr>
<tr>
<td>Total Rotation ROM @ 90</td>
<td>136.7±12.7</td>
<td>134.3±12.3</td>
<td>1.67</td>
<td>0.100</td>
</tr>
</tbody>
</table>

AB= abduction

RESULTS

Fifty youth male baseball players age 5-12 years old, mean age 9.02 years ± 1.6 were measured in this cross-sectional study. Table 1 presents the available descriptive demographics for the youth baseball study participants.

RANGE OF MOTION

Table 2 presents the IR, ER, and TROM data from the 50 subjects included in this study. ER ROM was 102.2±7.7 degrees for the D and 96.6±7.4 degrees for the ND extremity. IR ROM was 34.4±9.0 and 37.5±9.5 for the D and ND extremity respectively. In a similar cross-sectional study of healthy baseball players aged 6-18, Hibberd et al.31 also found intergroup ROM differences in players aged 6-10, 11-13, 14-16, and 16-18. Mean TROM was 136.7 ± 12.7 degrees and 154.3 ± 12.3 degrees for the D and ND extremity respectively. There was no significant difference between extremities for TROM. These data produced significantly greater ER (p<.001) and less IR (p<.006) ROM for the D as compared to the ND extremity.

Figure 4: Hand held dynamometer used for strength measures.
Table 3: Shoulder Internal (IR) and External (ER) Rotation Strength measured with a Handheld Dynamometer, displayed at mean ± standard deviation in pounds

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dominant Arm</th>
<th>Non-Dominant Arm</th>
<th>t</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder ER (Neutral)</td>
<td>13.6±3.4</td>
<td>12.89±3.6</td>
<td>1.50</td>
<td>0.136</td>
</tr>
<tr>
<td>Shoulder IR (Neutral)</td>
<td>18.0±6.0</td>
<td>15.7±4.7</td>
<td>4.50</td>
<td>0.000</td>
</tr>
<tr>
<td>Shoulder ER (90 AB)</td>
<td>12.3±3.4</td>
<td>12.5±4.3</td>
<td>-5.5</td>
<td>0.584</td>
</tr>
<tr>
<td>Shoulder IR (90 AB)</td>
<td>16.4±5.6</td>
<td>15.0±5.7</td>
<td>3.60</td>
<td>0.001</td>
</tr>
<tr>
<td>ER/IR Ratio (Neutral)</td>
<td>0.76</td>
<td>0.82</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ER/IR Ratio (90 AB)</td>
<td>0.75</td>
<td>0.83</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

AB= abduction; ER/IR Ratio calculated as ER strength / IR strength

MUSCULAR STRENGTH

Table 3 displays the internal and external rotation strength data for both the neutral and 90-degree abducted testing positions. Mean strength measurements in neutral were 13.6 ± 3.4 and 12.8 ± 3.6 lbs for ER, and 18.0 ± 6.0 and 15.7 ± 4.7 lbs for IR for the D and ND extremities respectively. Mean strength measurements at 90 degrees abduction were 12.3 ± 3.4 and 12.5 ± 4.3 pounds for ER, with 16.5 ± 5.6 and 15.0 ± 5.7 pounds for IR for the D and ND extremities respectively. No significant differences were found in ER strength in the neutral or 90 degree abducted position between the D and ND extremities. In contrast, significantly greater (p<0.001) IR strength was found on the D arm in both neutral and 90 degrees of glenohumeral joint abduction. External rotation/ internal rotation strength ratios (ER/IR ratio) of the D extremity were 0.76 and 0.75 at neutral and 90 degrees of abduction, respectively. ER/IR ratio for the ND extremity was 0.82 and 0.83 at neutral and 90 degrees of abduction, respectively.

DISCUSSION

Increased glenohumeral external rotation ROM, decreased internal rotation ROM, and maintenance of total rotation of the D throwing arm compared to ND arm in uninjured baseball players has been consistently documented at the professional,8-10,13,28,32-35 collegiate,36,37 high school,31,38,39 and little league levels.11,31,40,41 A consolidated summary of shoulder range of motion in healthy baseball and tennis players from other authors can be found in Table 4.3-5,11,15,28,31,33,34,37-48 In this study, there was no significant difference in TROM in D vs. ND arms but significantly higher ER ROM and lower IR ROM of the D arm (p= .000, .006 respectively). The shoulder ROM findings of this study on youth baseball players with a mean age of 9 are consistent with the established pattern of increased ER and decrease IR. While such ROM characteristics are present in younger age groups, as youth baseball players mature there appear to be gradual yearly alterations in shoulder ROM documented using cross-sectional observations of such populations. Meister et al11 found average external, internal, and total rotational ROM to decrease in both D and ND arms as age increased in healthy youth baseball players aged 8-16. For example, at 8 years of age, Meister et al11 found ER to be 152 and 145 deg, IR as 39 and 42 deg, and TROM as 191 and 187 deg in D and ND respectively, while at 16 years of age ER to be 143 and 137 deg, IR as 35.9 and 41.8 deg, and TROM as 179 and 178 deg in D and ND arms respectively (Table 4). This study confirms the findings of Meister et al regarding asymmetrical total rotational motion quantities despite ER and IR ROM differences between D and ND arms. With the exception of ER of the D arm, all rotational shoulder measures were significantly lower in the 16-18-year-old group versus the 6-10-year-old group (Table 4). Additionally, in a study considering the influence of age and skeletal maturity on shoulder ROM in healthy aged baseball players aged 8-28, Levine et al39 found ER, IR and TROM of D arm to peak in quantity in the 15-14 year group, who were considered to be at a point of maximal growth during skeletal immaturity, versus both the 8-12 and 15-28 age groups. With such ROM measures consistently changing as a youth baseball player matures, the influence of bony and/or soft-tissue structures on shoulder ROM is important to consider.

Multiple studies considering the effect of humeral retroversion on shoulder rotational motion in groups of baseball players of varying skeletal maturity have been conducted, which demonstrate the presence of bony adaptations that account for changes in GIRD, external rotation gain, and TROM.10,28,31,36,37,48 In skeletally immature baseball players, Hibbard et al51 found both GIRD and humeral retroversion to increase with age and concluded humeral retroversion to be a primary source of age-related increases in GIRD. Similar findings in studies of healthy college,36,37 and professional baseball players,10,28 have led to general agreement on bony morphology as the primary influencer of side-to-side shifts in rotational shoulder motion.

This study found no significant differences in isometric ER strength with the shoulder positioned in both neutral and 90 degrees of abduction in the D versus ND throwing arms. Conversely, IR strength in the D arm was 13% higher in neutral and 9% higher in 90 degrees abduction compared with the ND arm (p=.000, 0.001). In a study of risk factors for elbow injury in baseball players aged 9-12, Harada et al49 found no significant differences in ER or IR strength (neutral and 90 deg. abduction) between D and ND arms but did find ER strength exceeding 80N and IR strength exceeding 100N to be risk factors for elbow pain (Odds ratios: 4.11,
In a comparison of baseball players (average age 15.7) with and without history of shoulder or elbow pain in the previous season, Trakis et al.\textsuperscript{50} found the group with injury history showed increased IR strength of D arm versus ND arm (19% vs. 6%, \( p < .05 \)). In a population of 11-12 year old baseball players with throwing-related pain, there were no side to side differences in strength or ROM.\textsuperscript{51}

To the authors knowledge, there is little published normative data regarding rotator cuff muscle strength in healthy youth baseball players aged 5-12 and the findings of this study can serve to inform clinicians of descriptive values for such a population.

ER/IR strength ratios have been used as a means for studying rotator cuff muscle balance in the comparison of strength characteristics within throwers D and ND extremities, and between D extremities in groups of throwers.\textsuperscript{17,42,52–60} In the present study of healthy male youth baseball players aged 5-12, D and ND arms were found to have different ER/IR ratios at neutral and 90 degrees of abduction (0.76 vs. 0.82 and 0.75 vs. 0.83 in neutral, 90 abd for D and ND arms respectively). These findings align with the ratios published by Ellenbecker et al.\textsuperscript{56} in a study of healthy elite junior tennis players aged 12-17. Ellenbecker et al found isokinetic ER/IR strength ratios at 90 degrees abduction of 0.69 for the D arm and 0.82 for the ND arm.\textsuperscript{56} With no significant differences found between ER strength in D versus ND arms in the present or Ellenbecker et al.\textsuperscript{56} studies, dissimilar ER/IR strength ratios in the extremities is explained by relative increase of IR strength in the D compared to ND extremity. Byram et al.\textsuperscript{53} reports the majority of studies of throwers D arm ER/IR strength ratios to range from 0.60-0.80, although research on professional baseball pitchers reveal higher ratios ranging from 0.83-1.19.\textsuperscript{17,52,58–60}
<table>
<thead>
<tr>
<th>Author</th>
<th>Average Age</th>
<th>N</th>
<th>DER</th>
<th>NDER</th>
<th>DIR</th>
<th>NDIR</th>
<th>DTROM</th>
<th>NDTROM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown et al.</td>
<td>27</td>
<td>18 Professional Baseball Pitchers</td>
<td>141</td>
<td>132</td>
<td>83</td>
<td>98</td>
<td>224</td>
<td>230</td>
</tr>
<tr>
<td>Brown et al.</td>
<td>27</td>
<td>23 Professional Position Players</td>
<td>132</td>
<td>124</td>
<td>85</td>
<td>91</td>
<td>217</td>
<td>215</td>
</tr>
<tr>
<td>Chou et al.</td>
<td>16.2</td>
<td>24 High School Baseball Players</td>
<td>138</td>
<td>119</td>
<td>49</td>
<td>66</td>
<td>186</td>
<td>185</td>
</tr>
<tr>
<td>Chou et al.</td>
<td>20.3</td>
<td>24 College Baseball Players</td>
<td>138</td>
<td>119</td>
<td>36</td>
<td>50</td>
<td>173</td>
<td>168</td>
</tr>
<tr>
<td>Crockett et al.</td>
<td>20.1</td>
<td>25 Professional Baseball Pitchers aged 18-35</td>
<td>128</td>
<td>119</td>
<td>62</td>
<td>71</td>
<td>189</td>
<td>189</td>
</tr>
<tr>
<td>Downar et al.</td>
<td>20</td>
<td>27 Professional Baseball Players</td>
<td>109</td>
<td>102</td>
<td>57</td>
<td>69</td>
<td>166</td>
<td>170</td>
</tr>
<tr>
<td>Ellenbecker et al.</td>
<td>22.6</td>
<td>46 Professional Baseball Players</td>
<td>103</td>
<td>95</td>
<td>42</td>
<td>52</td>
<td>146</td>
<td>147</td>
</tr>
<tr>
<td>Hibberd et al.</td>
<td>8.3</td>
<td>52 Youth Baseball Players aged 6-10</td>
<td>122</td>
<td>120</td>
<td>52</td>
<td>55</td>
<td>174</td>
<td>175</td>
</tr>
<tr>
<td>Hibberd et al.</td>
<td>11.9</td>
<td>52 Junior High Baseball Players aged 11-13</td>
<td>126</td>
<td>123</td>
<td>54</td>
<td>57</td>
<td>180</td>
<td>179</td>
</tr>
<tr>
<td>Hibberd et al.</td>
<td>14.6</td>
<td>70 Junior Varsity Baseball Players aged 14-16</td>
<td>123</td>
<td>116</td>
<td>46</td>
<td>55</td>
<td>169</td>
<td>171</td>
</tr>
<tr>
<td>Hibberd et al.</td>
<td>16.9</td>
<td>113 Varsity Baseball Players aged 16-18</td>
<td>123</td>
<td>115</td>
<td>45</td>
<td>53</td>
<td>168</td>
<td>168</td>
</tr>
<tr>
<td>Hurd et al.</td>
<td>16</td>
<td>210 High School Baseball Players aged 14-18</td>
<td>130</td>
<td>120</td>
<td>60</td>
<td>75</td>
<td>190</td>
<td>195</td>
</tr>
<tr>
<td>Levine et al.</td>
<td>10.3</td>
<td>100 Youth Baseball Players aged 8-12</td>
<td>96</td>
<td>94</td>
<td>33</td>
<td>37</td>
<td>129</td>
<td>131</td>
</tr>
<tr>
<td>Levine et al.</td>
<td>13.5</td>
<td>100 Youth Baseball Players aged 13-14</td>
<td>115</td>
<td>105</td>
<td>40</td>
<td>49</td>
<td>155</td>
<td>154</td>
</tr>
<tr>
<td>Levine et al.</td>
<td>18.1</td>
<td>98 Baseball Players aged 15-28</td>
<td>109</td>
<td>94</td>
<td>38</td>
<td>54</td>
<td>147</td>
<td>148</td>
</tr>
<tr>
<td>Meister et al.</td>
<td>25</td>
<td>25 Youth Baseball Players age 8</td>
<td>152</td>
<td>145</td>
<td>39</td>
<td>42</td>
<td>191</td>
<td>187</td>
</tr>
<tr>
<td>Meister et al.</td>
<td>28</td>
<td>28 Youth Baseball Players age 9</td>
<td>146</td>
<td>142</td>
<td>42</td>
<td>44</td>
<td>188</td>
<td>186</td>
</tr>
<tr>
<td>Meister et al.</td>
<td>44</td>
<td>44 Youth Baseball Players age 10</td>
<td>144</td>
<td>141</td>
<td>41</td>
<td>44</td>
<td>184</td>
<td>186</td>
</tr>
<tr>
<td>Meister et al.</td>
<td>36</td>
<td>36 Youth Baseball Players age 11</td>
<td>146</td>
<td>142</td>
<td>40</td>
<td>43</td>
<td>185</td>
<td>186</td>
</tr>
<tr>
<td>Meister et al.</td>
<td>35</td>
<td>35 Youth Baseball Players age 12</td>
<td>142</td>
<td>138</td>
<td>38</td>
<td>43</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td>Meister et al.</td>
<td>52</td>
<td>52 Youth Baseball Players age 13</td>
<td>143</td>
<td>135</td>
<td>36</td>
<td>45</td>
<td>179</td>
<td>180</td>
</tr>
<tr>
<td>Meister et al.</td>
<td>35</td>
<td>35 Youth Baseball Players age 14</td>
<td>141</td>
<td>131</td>
<td>29</td>
<td>40</td>
<td>170</td>
<td>171</td>
</tr>
<tr>
<td>Meister et al.</td>
<td>24</td>
<td>24 Youth Baseball Players age 15</td>
<td>133</td>
<td>125</td>
<td>27</td>
<td>32</td>
<td>159</td>
<td>157</td>
</tr>
<tr>
<td>Meister et al.</td>
<td>15</td>
<td>15 Youth Baseball Players age 16</td>
<td>132</td>
<td>122</td>
<td>21</td>
<td>33</td>
<td>159</td>
<td>155</td>
</tr>
<tr>
<td>Meister et al.</td>
<td>12</td>
<td>294 Youth Baseball Players aged 8-16</td>
<td>143</td>
<td>137</td>
<td>36</td>
<td>42</td>
<td>179</td>
<td>178</td>
</tr>
<tr>
<td>Myers et al.</td>
<td>21.2</td>
<td>11 College/Semi-Professional Baseball Players</td>
<td>121</td>
<td>116</td>
<td>51</td>
<td>62</td>
<td>172</td>
<td>178</td>
</tr>
<tr>
<td>Oliver et al.</td>
<td>11.3</td>
<td>26 Youth Baseball Players</td>
<td>110</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>145</td>
<td>145</td>
</tr>
<tr>
<td>Osbahr et al.</td>
<td>19.1</td>
<td>19 College Baseball Pitchers aged 18-21</td>
<td>127</td>
<td>115</td>
<td>79</td>
<td>91</td>
<td>206</td>
<td>206</td>
</tr>
<tr>
<td>Oyama et al.</td>
<td>16.5</td>
<td>791 High School Baseball Players</td>
<td>117</td>
<td>113</td>
<td>43</td>
<td>51</td>
<td>161</td>
<td>165</td>
</tr>
<tr>
<td>Reagan et al.</td>
<td>19.3</td>
<td>54 College Baseball Players aged 18-23</td>
<td>116</td>
<td>106</td>
<td>43</td>
<td>51</td>
<td>160</td>
<td>158</td>
</tr>
<tr>
<td>Reuther et al.</td>
<td>22.5</td>
<td>30 Professional Baseball Pitchers</td>
<td>99</td>
<td>96</td>
<td>50</td>
<td>61</td>
<td>148</td>
<td>157</td>
</tr>
<tr>
<td>Sauers et al.</td>
<td>22</td>
<td>99 Professional Baseball Players</td>
<td>95</td>
<td>88</td>
<td>41</td>
<td>50</td>
<td>136</td>
<td>136</td>
</tr>
<tr>
<td>Shanley et al.</td>
<td>15.6</td>
<td>103 High School Softball Players aged 13-18</td>
<td>124</td>
<td>122</td>
<td>60</td>
<td>67</td>
<td>184</td>
<td>189</td>
</tr>
<tr>
<td>Shanley et al.</td>
<td>15.8</td>
<td>143 High School Baseball Players aged 13-18</td>
<td>126</td>
<td>118</td>
<td>54</td>
<td>61</td>
<td>180</td>
<td>179</td>
</tr>
<tr>
<td>Shanley et al.</td>
<td>23.4</td>
<td>33 Professional Baseball Players</td>
<td>127</td>
<td>121</td>
<td>46</td>
<td>50</td>
<td>172</td>
<td>171</td>
</tr>
<tr>
<td>Shanley et al.</td>
<td>24.4</td>
<td>33 Professional Baseball Players</td>
<td>139</td>
<td>126</td>
<td>38</td>
<td>51</td>
<td>175</td>
<td>177</td>
</tr>
<tr>
<td>Takeuchi et al.</td>
<td>10.9</td>
<td>65 Youth Baseball Players</td>
<td>115</td>
<td>113</td>
<td>41</td>
<td>49</td>
<td>156</td>
<td>161</td>
</tr>
<tr>
<td>Author</td>
<td>Average Age</td>
<td>N</td>
<td>DER</td>
<td>NDER</td>
<td>DIR</td>
<td>NDIR</td>
<td>DTROM</td>
<td>NDTROM</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td>--------------------</td>
<td>-----</td>
<td>------</td>
<td>-----</td>
<td>------</td>
<td>-------</td>
<td>--------</td>
</tr>
<tr>
<td>Wilk et al.\textsuperscript{13}</td>
<td>25.6</td>
<td>369 Professional Baseball Pitchers</td>
<td>132</td>
<td>127</td>
<td>52</td>
<td>63</td>
<td>184</td>
<td>190</td>
</tr>
<tr>
<td>Wilk et al.\textsuperscript{8}</td>
<td></td>
<td>170 Professional Baseball Pitcher Seasons</td>
<td>136</td>
<td>129</td>
<td>48</td>
<td>59</td>
<td>184</td>
<td>188</td>
</tr>
</tbody>
</table>

Abbreviations: DER=Dominant External Rotation, NDER=Non-Dominant External Rotation, DIR=Dominant Internal Rotation, NDIR=Non-Dominant Internal Rotation, DTROM=Dominant Total Rotational Motion, NDTROM=Non-Dominant Total Rotational Motion

-Range of motion (DER-NDTROM) values are all provided in degrees
Currently, there is minimal published data to inform clinicians of normative values of bilateral shoulder external and internal rotation ROM and strength in youth baseball players 12 years of age and younger.\textsuperscript{11,31} As stated earlier, shoulder ROM among throwers takes on a consistent pattern across baseball players of all ages with a characteristic ER gain, IR loss, and TROM maintenance in the dominant arm of such athletes. The findings of this study on youth baseball players with a mean of nine years of age, help to strengthen understanding of the age ranges such ROM patterns can be expected to present clinically. If a youth athlete should present with throwing-related pain, routine ROM measures can help to guide intervention strategies including ROM restoration programs including stretching and manual therapies if indicated.

The use of hand-held dynamometers in the evaluation of isometric rotator cuff strength testing is clinically feasible, time efficient, and offers an objective means of tracking strength changes. For youth baseball players, clinicians may expect increased IR and equivalent ER muscle strength of the throwing arm versus non-throwing arm. These characteristics may be quantified using ER/IR ratio calculations to identify throwers falling outside of the accepted 0.60-0.80 strength ratio. Rotator-cuff specific strengthening programs can be employed to increase ER/IR ratios and have been shown to be effective for such goals.\textsuperscript{54} Additionally, the monitoring of ER/IR ratios may guide clinicians on appropriate timing of return to throwing following throwing-related injury.\textsuperscript{53}

The limitations of this study include a relatively small sample size of 50 participants ranging from 5-12 years of age. As a result, the authors were unable to run ROM and strength analyses of specific age groups within this broad age range of athletes up to seven years apart. Additionally, the influence of descriptive information including height, weight, years of baseball experience, and injury history on the ROM and strength measures collected is unknown. All strength and ROM measures were taken in a single trial which may increase the risk of measurement error.

**CONCLUSION**

The results of the current study indicate that youth baseball players with a mean age of 9.02 years (age range 5-12) demonstrated no significant difference in total rotation ROM between extremities, however had significantly greater dominant arm ER and significantly less dominant arm IR. There were no significant differences in ER isometric strength between extremities both in neutral and in 90 degrees of abduction. However, significant increases in dominant arm IR isometric strength were identified in both neutral and 90 degrees of abduction. These results are consistent with findings reported in many other studies in older, more developed and mature overhead throwing athletes, indicating sport specific ROM and strength adaptations. These data can assist clinicians who work with athletes in this population and age range to inform prevention and treatment of overuse throwing injuries.

**CONFLICTS OF INTEREST**

The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in this article.

**ACKNOWLEDGEMENTS**

The authors would like to thank Jessica Endo, DPT, Sports Resident at Los Gatos Orthopedic Sports Therapy for her contribution with helping us bring this to publication. Without her work, effort and persistence, we would not have been able to accomplish the endeavor.

Submitted: November 05, 2019 CST, Accepted: July 24, 2020 CST
REFERENCES


International Journal of Sports Physical Therapy


International Journal of Sports Physical Therapy
Comparison of the Effects of Static-Stretching and Tubing Exercises on Acute Shoulder Range of Motion in Collegiate Baseball Players

Andrew M Busch, EdD, CSCS
1, Jackson Browstein1, Richard Ulm, DC, CSCS
2

1 Department of Health and Human Kinetics, Ohio Wesleyan University, 2 Columbus Chiropractic & Rehabilitation Center

Keywords: static stretching, movement system, glenohumeral joint, dynamic exercise, baseball

Background
The overhead throwing motion repetitively stresses the dominant arm in baseball players, frequently altering normal range of motion (ROM) in multiple directions. Baseball players regularly perform a combination of static stretches (SS) and dynamic tubing (DT) resistance exercises in pre-throwing warm-up routines intended to improve shoulder ROM and reduce injuries.

Purpose
The purpose of this study was to compare acute changes in dominant shoulder ROM improvements between SS and DT warm-up exercise protocols. The DT exercises were hypothesized to elicit greater improvements in shoulder ROM.

Study Design
Two-way crossover study.

Methods
Twenty-five healthy collegiate baseball players (mean age = 19.8 ±1.0 years) presenting with glenohumeral internal rotation deficit (GIRD) >20° and total rotational range of motion (TRROM) losses >5° completed the SS and DT interventions on different days. Dominant arm internal rotation (IR), external rotation (ER) and TRROM were measured before, immediately after, 30-minutes after, and 60-minutes after each treatment session. A two-way repeated measures analysis of variance (ANOVA) compared the effect of SS and DT over time on IR, ER, and TRROM.

Results
IR improved on average 10.68 ± 0.82° (p < .001) post intervention, 11.18 ± 0.79° (p < .001) 30-min post intervention, and 9.03 ± 0.95° (p < .001) 60-min post intervention. ER improved on average 8.60 ± 0.67° (p < .001) post intervention, 8.25 ± 0.85° (p < .001) 30-min post intervention, and 6.65 ± 0.91° (p < .001) 60-min post intervention. TRROM improved on average 19.28 ± 1.09° (p < .001) post intervention, 19.43 ± 1.36° (p < .001) 30-min post intervention, and 15.68 ± 1.55° (p < .001) 60-min post intervention. There were no significant differences between the main effects of treatment and time for IR, ER, and TRROM. For IR, SS improved by an average of 1.73 ± 0.55° (p = .005) more than DT. For ER and TRROM, there were no differences between SS and DT.

Conclusion
Both SS and DT exercises improve glenohumeral IR, ER and TRROM up to one-hour post intervention, with no significant differences noted between interventions for treatment or time. Baseball players can benefit equally from performing SS or DT exercises to acutely improve shoulder ROM.
INTRODUCTION

The baseball throwing motion repetitively creates large translational forces and rotational moments on the shoulder and elbow as the arm dynamically moves through susceptible end-range positions.\(^1\) It has been well established in studies investigating shoulder range of motion (ROM) in baseball players that differences exist between arms, such that external rotation (ER) tends to increase while internal rotation (IR) typically decreases in the dominant arm compared to the non-dominant arm.\(^2–4\) One common adaptation is known as glenohumeral internal rotation deficit (GIRD),\(^2,5–7\) which is the excessive loss of IR in the glenohumeral joint compared to the opposite arm.\(^5–7\) Bilateral differences of 10-15° are considered normal for IR or ER\(^8\), whereas deficits > 20° are a cause for concern and increase injury risk in baseball players.\(^5,9\) In addition to GIRD, total rotational range of motion (TRROM), the sum of glenohumeral IR and ER, has consistently been demonstrated to fall within 5° bilaterally\(^9\) and thought to provide even greater relevance when assessing shoulder ROM in baseball players within clinical settings.\(^9\) It is unclear however which measurement is more important when attempting to reduce injuries.

Alterations of shoulder ROM in response to throwing are multifactorial, as bony and soft tissue adaptations contribute to commonly observed changes.\(^8\) Bone tissue can adapt to repetitive loading, and two common adaptations include increased humeral retrotorsion (HRT), which is the angle of rotation in the epiphyseal axis relative to the greater and lesser humeral tubercles,\(^7,8,10\) and increased glenohumeral retroversion (GRV),\(^8\) which is the angle subtended by the glenoid line relative to a perpendicular scapular line on the posterior aspect of the scapula.\(^11\) Collegiate baseball players exhibit greater HRT in their dominant arms when compared to age-matched controls with no history of overhead sport participation.\(^12\) Professional pitchers who present with GIRD have also displayed greater side-to-side differences in HRT when compared to pitchers without GIRD,\(^5\) and those who demonstrate >20° GIRD are twice as likely to become injured compared to pitchers without GIRD.\(^13\) The relationship of increased HRT and GRV are not fully understood, but seem to be coupled during maturation.

Soft tissue adaptations can also occur in the capsule or muscular structures of the shoulder.\(^14\) The repetitive stress throwing places on the anterior shoulder capsule is theorized to lead to tightening of the posterior capsule.\(^15\) Several studies have revealed patients who present with injuries such as labral tears and impingement-syndrome also demonstrate GIRD and tight posterioinferior shoulder capsules.\(^5,13,16\) In addition to capsular thickening, a shortening response and stiffening of the rotator cuff muscles can occur due to the exposure history of those muscles with throwing.\(^8,14\)

A recent systematic review of randomized controlled trials of studies to improve GIRD and posterior shoulder tightness, found that most stretching interventions only performed a single intervention. Six articles only utilized passive stretching, four utilized active stretching, two compared passive to active stretching, and four articles used control groups with no interventions.\(^17\) While passive and active stretching have been shown to acutely improve shoulder ROM, baseball players tend to perform more dynamic exercises immediately prior to competition, and performing dynamic exercises after a pitching session have been shown beneficial in restoring normal shoulder ROM in professional pitchers.\(^4\) Much of the research aimed to improve shoulder ROM typically measure only pre- and post-intervention, yet it is unclear how long improvements in ROM last after completing the different interventions used. Understanding the duration ROM improvements last would help coaches and athletes optimally time warm-up routines prior to competition. The purpose of this research was to compare acute changes in IR and TRROM improvement between commonly performed static stretches (SS) and dynamic tubing (DT) exercises in the dominant shoulders of collegiate baseball players. A crossover design was utilized to compare three post-intervention measurements over the course of one hour. It was hypothesized that DT exercises would elicit a greater overall improvement in shoulder ROM for both IR and TRROM.

METHODS

PARTICIPANTS

A sample of twenty-five healthy male NCAA Division III collegiate baseball players (age = 19.8 ± 1.0 years) were recruited from a local university (descriptive statistics are provided in Table 1). All participants were listed on the active roster, and free of injury at the time of screening. Participants were excluded from the study if they had reported a previous elbow or shoulder surgery within the past 12 months. Distribution of the participants by position and dominant arm were: pitchers (n = 11), catchers (n = 3), infielders (n = 5), outfielders (n = 6), right-handed (n = 22, 88%), left-handed (n = 3, 12%). The academic year of the participants were: freshmen (n = 9), sophomores (n = 9), juniors (n = 6), and seniors (n = 1). All participants provided written informed consent prior to testing, and the study was approved a university institutional review board: IRB Protocol # 1902.004.

All participants received an email with a detailed description of the study, and completed an athletic and injury history questionnaire prior to testing. Participants met at a university exercise lab on two days, separated by one week during the spring 2019 preseason. At the time of the study, the baseball team had been practicing for 5 weeks, and the competitive season was set to begin in 2 weeks. All pitchers were tested at least two days after throwing off a mound, to prevent any delayed soreness or stiffness from affecting results. Upon arrival the first day, participants were randomly assigned to first perform either the static stretching (SS) intervention, or the dynamic tubing (DT) exercise intervention, and completed the opposite protocol the second day.
Table 1: Descriptive statistics of participants (Mean ± Standard Deviation)

<table>
<thead>
<tr>
<th>Participants</th>
<th>Age (y)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All (n = 25)</td>
<td>19.8 ± 1.0</td>
<td>181.8 ± 4.4</td>
<td>84.4 ± 7.1</td>
</tr>
<tr>
<td>Pitchers (n = 14)</td>
<td>19.4 ± 0.9</td>
<td>181.9 ± 4.8</td>
<td>86.8 ± 7.5</td>
</tr>
<tr>
<td>Position Players (n = 11)</td>
<td>20.3 ± 1.1</td>
<td>181.5 ± 4.0</td>
<td>81.2 ± 5.3</td>
</tr>
</tbody>
</table>

of testing. All participants refrained from throwing prior to data collection on testing days, and were instructed to simply wait patiently for each measurement time during the post-intervention hour.

SHOULDER RANGE OF MOTION ASSESSMENT

Glenohumeral IR and ER was passively measured for each participant lying supine on an examination table (Figure 1). TRROM was calculated from the sum of IR and ER values. A single examiner collected all measures using a digital inclinometer (model ACU001: Lafayette Instrument Company, Lafayette, IN), while a second examiner stabilized the scapula at the coracoid process with the shoulder abducted at 90°. The examiners were blinded to which intervention the participants were assigned. Intrarater reliability for ROM measures were established on 10 individuals a priori. Strong intraclass correlation coefficients (ICC's) were demonstrated for both IR (ICC (3,1) = 0.98, SEM= 1.36, 95% CI = 0.956-0.993) and ER (ICC (3,1) = 0.96, SEM= 1.10, 95% CI = 0.904-0.984).

Baseline glenohumeral IR and ER was initially measured on both testing days in both arms prior to the interventions, to determine ROM deficits. Three post-intervention measurements were collected: immediately after, 30-minutes post, and 60-minutes post-intervention (Figure 2). All ROM measures post-intervention were only collected in the dominant arms.

STATIC STRETCHING

The static stretching intervention included: Shoulder extension, doorway stretch, shoulder flexion, cross-body stretch, overhead triceps, and IR @ 90° stretch. These exercises were chosen due to their practicality for on-the-field recommendations because they do not require athletes to lay on the ground or a table. The cross-body stretch has commonly been in research when targeting posterior shoulder tightness and GIRD, and has demonstrated effectiveness in multiple studies. The IR @ 90° stretch was used to target IR, and was described by Escamilla et al. The remaining four stretches: doorway, overhead triceps, flexion & extension were utilized due to their common use among baseball players. Participants were instructed to hold each position where they felt a strong stretch for a total of 30 seconds (Figure 3).

DYNAMIC TUBING EXERCISES

Baseball players commonly perform many different rubber-tubing resistance exercises as part of their warm up routines in attempt to prevent throwing-related injuries. These exercises are usually performed in the dugout or bullpen prior to throwing. The six exercises chosen included: ER at 90°
Table 2: Dominant arm glenohumeral range of motion (ROM) for static stretching and dynamic tubing interventions. All are reported in degrees.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Intervention</th>
<th>Baseline mean (SD)</th>
<th>Post Intervention mean (SD)</th>
<th>30-min Post Intervention mean (SD)</th>
<th>60-min Post Intervention mean (SD)</th>
<th>Effect Size**</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Rotation</td>
<td>Static Stretching</td>
<td>49.0 (6.27)</td>
<td>60.28 (6.15)</td>
<td>60.78 (4.19)</td>
<td>59.39 (4.77)</td>
<td>0.742</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td></td>
<td>Dynamic Tubing</td>
<td>48.55 (6.98)</td>
<td>58.63 (6.22)</td>
<td>59.13 (5.96)</td>
<td>56.23 (4.83)</td>
<td>0.758</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>External Rotation</td>
<td>Static Stretching</td>
<td>89.91 (6.84)</td>
<td>97.92 (5.37)</td>
<td>97.0 (4.99)</td>
<td>95.49 (4.14)</td>
<td>0.568</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td></td>
<td>Dynamic Tubing</td>
<td>90.31 (6.64)</td>
<td>99.49 (5.68)</td>
<td>99.71 (4.87)</td>
<td>98.03 (4.91)</td>
<td>0.774</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>TRROM</td>
<td>Static Stretching</td>
<td>138.91 (10.88)</td>
<td>158.20 (9.47)</td>
<td>157.78 (7.07)</td>
<td>154.88 (7.58)</td>
<td>0.786</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td></td>
<td>Dynamic Tubing</td>
<td>138.85 (11.76)</td>
<td>158.12 (9.29)</td>
<td>158.84 (7.8)</td>
<td>154.25 (6.48)</td>
<td>0.841</td>
<td>&lt;.001*</td>
</tr>
</tbody>
</table>

TRRM = total rotational range of motion. Note: Values are degrees of passive ROM
*Statistically significantly different observed (p < .05)
**Effect size = Partial eta squared (η²)

of abduction, shoulder flexion, shoulder extension, throwing acceleration, throwing deceleration, and low-scapular rows. These specific exercises were chosen due to research previously demonstrating that moderate electromyography (EMG) activation occurs in a majority of the muscles responsible for throwing (rotator cuff, scapular stabilizers, and primary humeral head movers) during those exercises. Participants completed 10 repetitions of each exercise at a moderate, self-selected tempo (Figure 4).

STATISTICAL ANALYSIS

Descriptive statistics were calculated for all variables. Data are mean ± standard deviation, unless otherwise stated. A two-way repeated measures analysis of variance (ANOVA) was run to determine the effect of SS and DT over time on IR and TRROM. Main effects were run for treatment and time, and post hoc tests when necessary. Data analysis showed there was normality, as assessed by the Shapiro-Wilk test of normality with no outliers, as assessed by no studentized residuals greater than ± 3 standard deviations. Power analysis, using G*Power 3.1, indicated a 90% chance of detecting a medium effect size of 0.5 in 10 subjects with statistical significance determined a priori at p < .05 (one tailed). Data analyses were conducted with the Statistical Package for the Social Sciences (SPSS version 26.0 for Mac; IMB Corp, Armonk, NY).

RESULTS

There was no history of shoulder or elbow surgeries in any of the subjects reported in the previous 12 months. Descriptive statistics are presented for all shoulder ROM data in Table 2. Data are mean ± standard deviation, unless otherwise stated. There were no statistically significant interactions between treatment and time for IR: (F(3, 72) = 1.93, p = .152), ER: (F(1.59, 38.08) = 2.37, p = .118), or TRROM: (F(2.18, 52.43) = 0.48, p = .64). Therefore, main effects are reported.

For IR, the main effect of time showed a statistically significant difference between time points, (F(3, 72) = 120, p < .001). Post hoc analyses revealed improvements in ROM on average 10.68 ± 0.82° (95% CI, 8.32 to 13.04, p < .001) 30-min post intervention, 11.18 ± 0.79° (95% CI, 8.91 to 13.46, p < .001) 60-min post intervention, and 9.03 ± 0.95° (95% CI, 6.31 to 11.76, p < .001) 60-min post intervention (Figure 5).
The main effect of treatment also showed a statistically significant difference between SS and DT, \(F(1,24) = 9.77, p = .005\). Post hoc analyses revealed SS improved by an average 1.73 ± 0.55° (95% CI, 0.58 to 2.87), \(p = .005\) more than DT.

For ER, the main effect of time showed a statistically significant difference between time points, \(F(1.47, 35.53) = 77.72, p < .001\). Post hoc analyses revealed improvements in ROM on average 8.60 ± 0.67° (95% CI, 6.66 to 10.54, \(p < .001\)) post intervention, 8.25 ± 0.85° (95% CI, 5.80 to 10.70, \(p < .001\)) 30-min post intervention, and 6.65 ± 0.91° (95% CI, 4.04 to 9.27, \(p < .001\)) 60-min post intervention (Figure 6). The main effect of treatment did not show a statistically significant difference between SS and DT, \(F(1,24) = 3.04, p = .09\).

For TRROM, the main effect of time showed a statistically significant difference between time points, \(F(1.39, 35.39) = 152.84, p < .001\). Post hoc analyses revealed improvements in ROM on average 19.28 ± 1.09° (95% CI, 16.14 to 22.45, \(p < .001\)) post intervention, 19.45 ± 1.56° (95% CI, 15.51 to 23.34, \(p < .001\)) 30-min post intervention, and 15.68 ± 1.55° (95% CI, 11.22 to 20.15, \(p < .001\)) 60-min post intervention (Figure 6). The main effect of treatment did not show a statistically significant difference between SS and DT, \(F(1,24) = 0.005, p = 0.96\).

**DISCUSSION**

The results of this study support the use of both SS and DT exercises as part of a pre-throwing warm-up routine in collegiate baseball players. These findings demonstrate acute changes can be experienced in shoulder ROM through different methods, which can last up to one hour post intervention.

Even though significant IR, ER and TRROM improvements were noted in both interventions, the amount of IR improvement was not enough to categorically de-classify any participant from having GIRD (commonly suggested as > 20° deficit).\textsuperscript{2,5,9} There was a statistically significant difference between interventions for IR, as the SS intervention showed slightly greater mean improvement compared to DT across all post-measurements, but the difference of only 1.73 ± 0.55° is probably not clinically relevant due to the amount of GIRD that was present at baseline. The mean baseline measurements for IR were 49.0 ± 6.27° on the SS day, and 48.55 ± 6.98° on the DT day. Despite substantial improvements during both interventions, all participants still retained > 20° IR deficits during all post-intervention measurements. However, the large increases observed in TRROM was enough to de-classify many as ‘at-risk’, due to the normalization of the dominant arm TRROM compared to the non-dominant arm (suggested as < 5° deficit). The de-classification of at-risk participants using TRROM was most likely due to the improvement in ER with both interventions. The common measurements used to classify injury risk have clinically shown different findings, which can change how a clinician interprets injury risk based on shoulder ROM differences.\textsuperscript{9} These findings illustrate the difficulty often noted when attempting to classify injury risk in shoulders of overhead athletes. One way to strengthen the interpretation of shoulder rotational values is to account for HRT in addition to IR, ER and TRROM, which could better explain clinical findings, yet the use of ultrasound or other imaging may not always be an option for clinicians or team trainers.

There are several mechanisms possibly responsible for the ROM adaptations observed in the dominant arm of baseball players. It has often been suggested that decreased IR results from posterior capsular tightness, however, there is evidence demonstrating no significant differences exist in glenohumeral posterior translation between dominant and non-dominant arms in professional baseball players.\textsuperscript{19,20} A more likely explanation for why IR deficits remained, despite significant improvements, have to do with osseous adaptations leading to increased HRT and GRV. It is common for athletes across a range of overhead sports to have an average 12° more HRT in their dominant arm compared to the non-dominant arm.\textsuperscript{20}
to their non-dominant arms. At birth, the humeral head of both arms are actually in marked HRT, and the normal maturation process involves a period of de-rotation of the humeral head during the pediatric and adolescent years, most rapidly occurring from 0-8 years. The asymmetrical retrotorsion commonly seen in adult baseball players is believed to exist from greater throwing stress placed on the shoulder during this skeletally immature time period, while growth plates are likely open. In collegiate pitchers with a history of elbow injuries, greater limb difference in HRT (mean of 7.2°) has been noted compared to pitchers with no history of injuries. While improvements in bony adaptations such as HRT or GRV can only be addressed through surgery, soft-tissue adaptations from throwing did seem to acutely improve in participants of this study, however it is unknown whether those changes were due more to capsular or muscular properties.

Completing SS before athletic performances involving muscular strength and power has thought to exhibit detrimental effects due to altered length-tension relationships, decreased motor unit activation, and reduced muscle spindle activity. In lower body muscles, where most research literature focuses, static stretching can negatively affect performance outcomes in comparison to dynamic exercises. However, adverse effects of SS may be negated when coupled with dynamic activity. In a few studies measuring upper body performance, Torres et al found no short-term effect of stretching on upper body muscular performance, regardless of stretch type, which may be due to allowing a minimum of five minutes or longer after stretching. Knudson et al found no significant effect of SS on the overhand tennis serve when measuring velocity and accuracy in various ages and ability levels. Similarly, a study investigating specifically DIII baseball players, the same population used in the current study, found no differences in average velocity or maximal pitch velocity after performing six different SS, which suggests that acute SS does not deleteriously affect pitching performance.

The improvement in IR in the SS group is most likely due to biomechanical mechanisms such as changes in viscoelastic properties of the muscle-tendon-unit (MTU). The similar improvement observed in the DT group may come from multiple neurological mechanisms. There is likely a level of post-activation potentiation (PAP), wherein activation of the muscles involved in the tested movement improves its contractile performance and function. Alternatively, it could be due to improved motor control in the shoulder, secondary to increased proprioception, as improvements in hip ROM have been demonstrated in the absence of stretching, simply through the use of stabilization exercises. Another explanation for improved ROM could be due to proximal stability of the scapula. If instability exists within the shoulder, possibly from inadequate strength in muscles responsible for deceleration during throwing, past injuries, overuse, etc., the shoulder may be protectively guarded by neurologically tightening the posterior-inferior capsule. Such guarding could become the symptomatic tight capsule and measurable GIRD. Shoulder rehabilitation protocols have long focused on these aspects of improving shoulder strength and endurance through exercises for the scapular stabilizers and rotator cuff muscles. By focusing on neuromuscular control during the DT exercises, appropriate proximal stabilizing strategies may have been reinforced. These findings seem to demonstrate some unappreciated neurological components involved in dynamic ROM.

This study is not without limitations. Strength-training routines, and the amount of throwing in the days prior to testing was not recorded. Although pitchers were required to have a minimum of two days’ rest between their last bullpen session and each testing day, throwing loads could have varied in each participant between testing days. It is unknown at what point in time, beyond one-hour, ROM improvements possibly return to baseline in this sample. Baseball players often perform both types of the interventions used in this study as part of normal warm-up routines; yet further research is warranted to determine if the order in which they perform such exercises matter. Future research should seek to better understand these effects on upper body performance, as most objective performance tasks measured (pitch speed/ serve speed) are full-body, multi-joint movements where the integration of lower body and core muscles may compensate for small upper body changes that possibly occur within the muscle. The effects of long-
term stretching outcomes on shoulder ROM is unknown, along with different dosing of the SS and DT exercises, or even a combination of both protocols could possibly result in greater ROM improvements.

CONCLUSIONS

After completing both SS and DT exercises, passive gleno-humeral IR, ER and TRROM can improve for up to one-hour in collegiate baseball players exhibiting shoulder ROM deficits. Both interventions demonstrated statistically significant mean improvements for IR, ER and TRROM in all three post-intervention measurements. The SS intervention demonstrated a greater mean improvement (1.73 ± 0.55°) for IR than DT, although probably not clinically significant, as neither intervention improved IR enough to reduce GIRD. There were no differences in the mean improvements in ER or TRROM between the SS and DT groups. This data extends knowledge for therapists, trainers, coaches and athletes who can incorporate either type of warm-up drills to improve shoulder ROM in a time-efficient manner.

ETHICAL STATEMENT

This study was approved by the Ohio Wesleyan University institutional review board: IRB Protocol # 1902.004, and all participants signed an informed consent prior to testing.

CONFLICT OF INTEREST AND SOURCE OF FUNDING

There are no conflicts of interest to report and no funding was received for this study.

Submitted: April 04, 2020 CST, Accepted: October 10, 2020 CST

This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY-NC-ND-4.0). View this license's legal deed at https://creativecommons.org/licenses/by-nc-nd/4.0 and legal code at https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode for more information.
REFERENCES


Original Research

Pre-Operative Scapular Rehabilitation for Arthroscopic Repair of Traumatic Rotator Cuff Tear: Results of a Randomized Clinical Trial

Luane Landim de Almeida, PT, MSc1, Adriano Fernando Mendes Júnior, MD, MSc2, José da Mota Neto, MD, MBA3, Leandro Furtado De Simoni, MD, MBA4, Karine Helena Souza Lopes, PT, MSc5, Paloma Carvalho Guimarães, PT6, Brenda Iasmin de Oliveira Valério, PT7, Aaron Sciascia, PhD, ATC, PES, SMTC, FNAP6

1 Hospital e Maternidade Therezinha de Jesus; Espaço Maria Inês, Centro de Fisioterapia e Condicionamento Físico, 2 Hospital Universitário da Universidade Federal de Juiz de Fora, 3 Hospital e Maternidade Therezinha de Jesus; Hospital Universitário da Universidade Federal de Juiz de Fora, 4 Hospital e Maternidade Therezinha de Jesus, 5 Faculdade de Ciências Médicas e da Saúde de Juiz de Fora; Espaço Maria Inês, Centro de Fisioterapia e Condicionamento Físico, 6 Eastern Kentucky University

Keywords: movement system, scapular stabilization, rotator cuff, preoperative rehabilitation, arthroscopy

10.26603/001c.18654

International Journal of Sports Physical Therapy
Vol. 16, Issue 1, 2021

Background
Pre-operative rehabilitation aims to improve the functional capacity of the individual to enable him/her to prepare for the period of inactivity associated with the surgical procedure.

Objective
To evaluate the impact of preoperative scapular rehabilitation before arthroscopic repair of traumatic rotator cuff injury, regarding pain, range of motion of the shoulder, and functional activity.

Study Design
Randomized Clinical Trial (RCT) – pilot.

Methods
Twenty adult individuals (age range: 47–69 years), with a diagnosis of traumatic rotator cuff tear and arthroscopic surgical repair, were randomized and allocated into two groups: experimental (EG) (n = 10) and control group (CG) (n = 10). All participants underwent preoperative rehabilitation for six weeks, consisting of mobility exercises of the cervical spine, elbow, wrist, and hand, and analgesics education. The EG also performed scapular and core stabilization exercises, which were not performed by the CG. Exercise instruction was performed by the same physiotherapist and the surgical team was blinded to group participation in the preoperative period. After arthroscopic repair, the patients followed the same protocol of postoperative rehabilitation for 16 weeks, and functional evaluation was conducted after three months and in a follow-up of at least one year.

Results
Compared to the CG, the EG presented with a significant decrease in pain between the preoperative period and after one year (p < 0.05). In relation to the preoperative period, flexion and external rotation increased significantly in both groups after three months (p<0.05), and abduction was significantly higher in the EG (p < 0.05). Compared to CG, the EG presented a significantly higher SF-12 physical component after three months (48.47 vs. 40.33, p < 0.05), and a significantly lower Western Ontario Rotator Cuff Index (WORC) total after one year (85.00 vs. 1130.00, p < 0.05).

Conclusion
Preoperative scapular rehabilitation had a positive impact on recovery after arthroscopic repair.

Corresponding author: Luane Landim de Almeida Avenida Olegario Maciel - Paineiras, number 1667, Apartment 402. Email: lua_landim@hotmail.com
repair of traumatic rotator cuff injury, in the assessment of pain, range of motion of the shoulder, and quality of life.

Levels of Evidence

Level 1

INTRODUCTION

Rotator cuff lesion (RCL) is a common disorder of the shoulder that can exist from unknown etiology or be associated with mechanisms such as trauma or progressive degeneration of the tendon. In general, traumatic RCLs are associated with higher energy injury mechanisms and result in complete or extensive ruptures, while atraumatic RCLs originate from pre-existing partial ruptures, which can eventually progress to total lesions. Traumatic RCLs are primarily treated surgically and good functional results can be achieved if surgery is performed within a period of up to six months after the initial trauma has occurred.

The Danish National Clinical Guideline on Shoulder Injuries recommends, following surgical repair of RCLs, immediate immobilization and rehabilitation. The negative impacts of immobilization during the injury period may be minimized by a comprehensive rehabilitation program (restoration of mobility, scapular stability, shoulder strength, and muscle endurance), increasing the probability of success after surgery and ensuring a return to functional activities with a better quality of life. Scapular rehabilitation has important clinical relevance in the alignment and function of the glenohumeral (GH) and acromioclavicular joints. Imbalance in the scapular stabilizing muscles, such as high upper trapezius muscle activity, low activation of the middle trapezius and lower trapezius, and serratus anterior insufficiency, may be associated to abnormal scapular movement and pain in the shoulder. As such, scapular rehabilitation is a critical component of the post-surgical comprehensive rotator cuff rehabilitation regimen.

Pre-operative physiotherapy was reported in 1980 by Noyes in individuals with chronic anterior cruciate ligament (ACL) deficiency, to promote the restoration of function prior to surgery, maximize dynamic muscle stabilization prior to reconstruction, and facilitate post-operative recovery. Pre-operative lower extremity rehabilitation is widely used in clinical practice, and studies have shown its effectiveness in muscle stabilization prior to reconstruction, improved stability, and in some cases possibly avoiding surgery. In a preoperative rehabilitation program for ACL rupture, data showed that the pre-operative group presented a significant post-operative improvement in quadriceps strength, static balance, agility, and subjective performance, compared to the control group.

Pre-operative scapular rehabilitation before shoulder surgery has also been described. Düzgün et al. opined that pre-operative scapular rehabilitation program aims to reduce pain, restore the normality of scapular movements, and strengthen the periscapular muscles, providing painless movement in the shoulder. However, publications on scapular rehabilitation prior to surgical treatment of traumatic rotator cuff injuries are scarce. The aim of this study was to evaluate the impact of preoperative scapular rehabilitation before arthroscopic repair of traumatic rotator cuff injury, regarding pain, range of motion of the shoulder, and functional activity. The hypothesis is that the individuals who participated in the pre-operative scapular exercises would develop better range of motion with less pain than those in the control group.

METHODS

This was a pilot randomized clinical trial (RCT) experimental study, of 22 adult individuals, with a history of shoulder pain after trauma, and diagnosed with RCL by an orthopedic shoulder surgeon, through clinical examination (full passive range of motion of the shoulder, positive tests for rotator cuff tear: Jobe or full can test; Infraspinatus test: External Rotation Lag Sign, Patte, Drop arm; Subscapularis test: Gerber, Belly Press or Bear Hug) and confirmed by magnetic resonance imaging (MRI). All had a medical indication for surgical treatment with arthroscopic repair of their lesions, and a pre-operative scapular rehabilitation program would be evaluated as an intervention. Those who had previous fractures or pre-existing shoulder conditions such as adhesive capsulitis, joint instability, or labral lesions were excluded.

The individuals who agreed to participate in the study provided informed consent prior to the start. The study was approved by the Ethics and Research Committee of the institution (Opinion No. 421.569). After inclusion in the study, all underwent a physiotherapist assessment consisting of history and physical examination, including goniometry to assess joint range of motion (ROM), and the visual analog scale (VAS) for assessing pain. Two patients did not attend the assessment and were excluded, with an initial group totaling 20 individuals. Because this was a pilot study, the individuals were recruited by convenience from a group of patients who were already waiting for the surgical procedure, without previous calculating of the sample size. Randomization was accomplished through the RANDOM.ORG program, and the participants were allocated into two groups: experimental (EG) and control (CG), with a numerical code assigned according to arrival order (Figure 1).

Participants in the EG received an exercise booklet and were instructed by physiotherapists to perform, in the home environment, exercises for scapular and core stabilization, mobility of the cervical spine, elbow, wrist, and hand, as well as exercises to improve shoulder proprioception, and on pain control (Appendix 1). CG members also received a home exercise booklet, but only with exercises involving mobility of the cervical spine, elbow, wrist, and hand, and analgesics guidelines. Each study participant received verbal guidance and training on the execution of each exercise to be performed. Individuals were challenged to perform all exercises in the booklet, three times a day (once in the morning, once in the afternoon and once at night), 10 repetitions of each exercise, or according to availability and pain...
tolerance. In case of pain during or after the exercises, they were instructed to perform analgesic procedures with local cryotherapy for 20 minutes. The groups followed the pre-operative routine for six weeks, with reassessments by the same physiotherapist every two weeks, in which they were asked about the execution of exercises and perception of pain, either in person (among those who could present to the rehabilitation center) or via telephone. After six weeks, with the surgeons blinded as to the individuals’ participation in the rehabilitation program, the patients underwent arthroscopic repair of the rotator cuff lesions using standard procedures, performed by one of the three orthopedic surgeons co-authors (Table 1).

The post-operative rehabilitation protocol (Appendix 2) was the same for both groups and began one week after surgery. All individuals were reassessed in the third month and in the one-year post-operative follow-up, using theVAS, ROM, the Disabilities of the Arm, Shoulder and Hand Questionnaire (DASH), the Western Ontario Rotator Cuff Index (WORC), and 12-item health survey (SF-12). This study was conducted in accordance with the CONSORT guidelines for clinical trials.

**Figure 1. Flowchart of study patients**

---

**STATISTICAL ANALYSIS**

A descriptive and exploratory analysis of the data was conducted. The analysis of the comparisons between the groups regarding the characteristics of the patients was performed using Fisher’s exact test for the qualitative variables and the Student’s t-test for the quantitative variables. To determine the normality of the data, the Shapiro-Wilk test was used. Taking into account the assumptions of a parametric analysis, a methodology of mixed models for measurements repeated over time, ANOVA and Tukey-Kramer test, was applied. Data unsuitable for a parametric analysis were analyzed using the Mann Whitney (comparison between groups) and Wilcoxon (comparison between timeframes) tests. VAS and goniometry measurements (flexion, abduction, internal and external rotation) were analyzed using mixed models for measurements repeated over time and the Tukey-Kramer test. For the abduction data, since there was a significant difference between the groups in the pre-operative period, the analysis was rerun considering the pre-operative period as a covariate. The WORC data (physical symptoms, sports/recreation, work, lifestyle, emotions, and total score), DASH, and the SF-12 domains...
Table 1. Demographic Characteristics of Patients

<table>
<thead>
<tr>
<th>Patient</th>
<th>Sex*</th>
<th>Age</th>
<th>Evolution time **</th>
<th>Associated procedures</th>
<th>Surgical repair features</th>
<th>RCT Size***</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>47</td>
<td>13</td>
<td>TND</td>
<td>SE (SR, 01 anchor, 1 MMA)</td>
<td>Small</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>69</td>
<td>34</td>
<td>TND</td>
<td>SE and IS (SR, 02 anchors, 02 MMA)</td>
<td>Massive</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>65</td>
<td>5</td>
<td>TNT</td>
<td>SE and IS (SR, 2 anchor, 2 MMA)</td>
<td>Small/Medium</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>69</td>
<td>19</td>
<td>TNT</td>
<td>SE and IS (SR, 2 anchor, 2 MMA, 1 MC)</td>
<td>Massive</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>65</td>
<td>4</td>
<td>TNT</td>
<td>SE and IS (SR, 1 anchor, 1 MMA)</td>
<td>Small/Medium</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>58</td>
<td>7</td>
<td>TND</td>
<td>SE (MSR, 2 anchors, 1 MMA, 2 SIS, 1 MC); IS (1 anchor, 2 SIS)</td>
<td>Massive</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>59</td>
<td>8</td>
<td>TNT + ACP</td>
<td>SE and IS (SR, 2 anchors, 4 SIS, 1 MC)</td>
<td>Massive</td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>64</td>
<td>12</td>
<td>TNT</td>
<td>SE and IS (SR, 2 anchors, 4 SIS, 1 MC, SS (superior two thirds); 2 anchors, 4 Mattress)</td>
<td>Massive</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>65</td>
<td>6</td>
<td>TND + Anterior capsulotomy</td>
<td>SE and IS (1 anchor, 2 SIS, 2 MC)</td>
<td>Small/Medium</td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>65</td>
<td>20</td>
<td>TNT</td>
<td>SE irreparable (GU arthrosis outrebridge 3 in the glenoide); IS (advanced with 1 anchor, 2 SIS)</td>
<td>Massive</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>47</td>
<td>2</td>
<td>TND + ACP + Anterior capsulotomy</td>
<td>SE (1 anchor, 2 SIS)</td>
<td>Small</td>
</tr>
<tr>
<td>12</td>
<td>M</td>
<td>61</td>
<td>6</td>
<td>TNT + ACP</td>
<td>SE (1 anchor, 2 SIS)</td>
<td>Massive</td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>59</td>
<td>9</td>
<td>TNT</td>
<td>SE and IS (2 MC, 3 anchors, 3 MMA)</td>
<td>Massive</td>
</tr>
<tr>
<td>14</td>
<td>M</td>
<td>52</td>
<td>11</td>
<td>TNT + ACP</td>
<td>SE (1 anchor, 2 SIS, 1 MC)</td>
<td>Small/Medium</td>
</tr>
<tr>
<td>15</td>
<td>F</td>
<td>58</td>
<td>7</td>
<td>TNT + ACP + Anterior capsulotomy</td>
<td>SE and IS (2 anchors, 1 MC, 2 MMA)</td>
<td>Massive</td>
</tr>
<tr>
<td>16</td>
<td>M</td>
<td>63</td>
<td>9</td>
<td>TNT</td>
<td>SE (partial repair, MSR, 1 anchor, 2 SIS); IS (advanced with 1 anchor, 2 SIS); SS (partial tear) debriment</td>
<td>Massive</td>
</tr>
<tr>
<td>17</td>
<td>M</td>
<td>49</td>
<td>3</td>
<td>Excluded (Use of anticoagulant)</td>
<td>--------</td>
<td>Massive</td>
</tr>
<tr>
<td>18</td>
<td>F</td>
<td>65</td>
<td>4</td>
<td>TNT</td>
<td>SE (SR, 1 anchor, 2 SIS)</td>
<td>Small</td>
</tr>
<tr>
<td>19</td>
<td>F</td>
<td>65</td>
<td>5</td>
<td>TNT + ACP</td>
<td>SE (SR, 1 anchor, 2 SIS); SS (partial) debriment</td>
<td>Medium</td>
</tr>
<tr>
<td>20</td>
<td>M</td>
<td>58</td>
<td>12</td>
<td>TNT + ACP</td>
<td>SE (MSR, 2 anchors, 4 SIS); SS (partial) debriment</td>
<td>Massive</td>
</tr>
</tbody>
</table>

SE= Supraspinatus; IS= Infraspinatus; SS= Subscapularis; ACP=acromioplasty; TND=Long Head Biceps Tenodesis with Paulus technique; TNT: Long Head of Biceps Tenotomy;
SR=Single Row; MSR= Medialized Single Row; MMA=Modified Mason Allen suture; SIS=Single suture; MC=Margin convergence; RCT: Rotator Cuff Tear.
*Sex classified in M for Male and F for Female
**Time in months from initial injury to surgery
*** Size of the tear, according to Coffield’s and/or Gerber’s classification.

(physical and mental) did not meet the assumptions and were analyzed using the Mann Whitney (comparison between groups) and Wilcoxon (comparison between timeframes) tests. The analyses were performed in the SAS and R programs, with a p-value of 0.05.

RESULT

From the initial sample of 20 participants with traumatic RCL, in the EG group one patient did not perform surgical repair and one was lost to follow up; one patient in the CG group was lost to follow up, and the final sample for analysis consisted of 17 individuals According to their characteristics, as shown in Table 2 and Table 3, there were no significant differences between the groups regarding gender and age, however there was a significant difference between the two groups for subscapular lesion, as 66.7% of the CG and 12.5% of EG presented with this lesion (p < 0.05).

The results of the goniometry measurements are presented in Table 4. In relation to the pre-operative period, flexion and external rotation increased significantly in both
Table 2. Description of patients’ qualitative characteristics by group.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>4 (44.4%)</td>
<td>3 (37.5%)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>5 (55.6%)</td>
<td>5 (62.5%)</td>
<td></td>
</tr>
<tr>
<td>Tendon affected</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>9 (100.0%)</td>
<td>8 (100.0%)</td>
<td></td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>5 (55.6%)</td>
<td>4 (50.0%)</td>
<td></td>
</tr>
<tr>
<td>LHB</td>
<td>7 (77.8%)</td>
<td>5 (62.5%)</td>
<td></td>
</tr>
<tr>
<td>Subscapular</td>
<td>6 (66.7%)</td>
<td>1 (12.5%)*</td>
<td></td>
</tr>
<tr>
<td>Size of the lesion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small or medium</td>
<td>2 (22.2%)</td>
<td>4 (50.0%)</td>
<td></td>
</tr>
<tr>
<td>Large and/or extensive</td>
<td>7 (77.8%)</td>
<td>4 (50.0%)</td>
<td></td>
</tr>
<tr>
<td>Dominant extremity /</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right/Right</td>
<td>9 (100.0%)</td>
<td>5 (62.5%)</td>
<td></td>
</tr>
<tr>
<td>Affected extremity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right/Left</td>
<td>0 (0.0%)</td>
<td>3 (37.5%)</td>
<td></td>
</tr>
</tbody>
</table>

* Differs from the control group (p<0.05);

Table 3. Mean values of patients’ quantitative characteristics by group.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td></td>
<td>61.7 (3.9)</td>
<td>59.4 (8.4)</td>
</tr>
<tr>
<td>Time from trauma to diagnosis (months)</td>
<td></td>
<td>5.4 (2.2)</td>
<td>7.6 (9.0)</td>
</tr>
<tr>
<td>Time of progression until surgery (months)</td>
<td></td>
<td>9.4 (4.4)</td>
<td>13.0 (10.8)</td>
</tr>
</tbody>
</table>

There were no significant differences between groups (p>0.05)

groups after three months (p < 0.05). The abduction was significantly higher in the experimental group than in the control group (p < 0.05), after three months and at the one-year follow-up (Figure 2). Regarding internal rotation, there was no significant difference between the groups, nor between the two post-operative reassessment points (p > 0.05).

Regarding the pain assessment (VAS), it was noted that in the CG there was a significant decrease between the three-month and the one-year timeframe (p < 0.05), and in the EG, a significant decrease between the pre-operative period and after one year (p < 0.05). Regarding functional results the WORC total in the EG, after one year, presented scores significantly lower than in the control group (p < 0.05), however, the DASH scores were not significantly different between the groups or between the timeframes (p > 0.05). Analysis of the SF-12 (Figure 3) showed that after three months, the EG presented significantly higher scores than the CG in the physical component domain of the SF-12 (p < 0.05), (Table 5).

Results from the WORC domains (Figure 4) show that after three months the EG presented values significantly lower than the CG for physical symptoms, work, and emotions (p < 0.05). After one year, the EG presented scores significantly lower than the CG for physical symptoms, sports/recreation, lifestyle, emotions, and WORC total score (p < 0.05).

DISCUSSION

Pre-operative rehabilitation aims to improve the functional capacity of the individual to enable him/her to prepare for the period of inactivity associated with the surgical procedure. Described in the literature as having the potential to improve post-operative function, it decreases shoulder stiffness, which is considered a common complication of rotator cuff repair, leading to pain and frustration in pa-
Table 4. Mean (standard deviation) for goniometric measurements (in degrees), by group and timeframe.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Timeframe</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>108.44 (35.85)</td>
<td>124.38 (35.50)</td>
</tr>
<tr>
<td></td>
<td>Preoperative</td>
<td>$^{1}$146.55 (21.15)</td>
<td>$^{1}$160.88 (21.59)</td>
</tr>
<tr>
<td></td>
<td>3 months post-op</td>
<td>$^{1}$143.78 (26.41)</td>
<td>$^{1}$160.50 (35.24)</td>
</tr>
<tr>
<td>Flexion</td>
<td>1 year post-op</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abduction</td>
<td>Preoperative</td>
<td>90.00 (38.89)</td>
<td>*108.75 (42.24)</td>
</tr>
<tr>
<td></td>
<td>3 months post-op</td>
<td>$^{1}$112.33 (15.86)</td>
<td>$^{1}$155.50 (26.55)</td>
</tr>
<tr>
<td></td>
<td>1 year post-op</td>
<td>$^{1}$120.00 (32.79)</td>
<td>$^{1}$153.75 (31.14)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Rotation</td>
<td>Preoperative</td>
<td>56.33 (27.81)</td>
<td>45.63 (25.13)</td>
</tr>
<tr>
<td></td>
<td>3 months post-op</td>
<td>47.22 (9.44)</td>
<td>70.25 (16.36)</td>
</tr>
<tr>
<td></td>
<td>1 year post-op</td>
<td>60.89 (14.35)</td>
<td>61.25 (19.43)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External Rotation</td>
<td>Preoperative</td>
<td>38.50 (26.36)</td>
<td>46.25 (21.00)</td>
</tr>
<tr>
<td></td>
<td>3 months post-op</td>
<td>$^{1}$58.80 (15.42)</td>
<td>$^{1}$66.88 (14.87)</td>
</tr>
<tr>
<td></td>
<td>1 year post-op</td>
<td>$^{1}$55.11 (18.39)</td>
<td>$^{1}$72.13 (17.34)</td>
</tr>
</tbody>
</table>

*Differs from the control group in the same timeframe (p<0.05); $^{1}$Differs from the preoperative timeframe (p<0.05).

Table 5. Median (minimum, maximum) scores for pain, WORC total, SF-12, and DASH, by group and timeframe.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Timeframe</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain (VAS)</td>
<td>Preoperative</td>
<td>7.00 (4.00; 10.00)</td>
<td>7.00 (4.00; 9.00)</td>
</tr>
<tr>
<td></td>
<td>3 mo. post-op</td>
<td>7.00 (5.00; 9.00)</td>
<td>3.50 (0.00; 9.00)</td>
</tr>
<tr>
<td></td>
<td>1 yr. post-op</td>
<td>$^{1}$3.00 (0.00; 10.00)</td>
<td>$^{1}$0.00 (0.00; 7.00)</td>
</tr>
<tr>
<td>WORC total</td>
<td>3 mo. post-op</td>
<td>1,095.00 (170.00; 1,905.00)</td>
<td>237.50 (65.00; 1,480.00)</td>
</tr>
<tr>
<td></td>
<td>1 yr. post-op</td>
<td>1,130.00 (140.00; 1,958.00)</td>
<td>$^{1}$235.00 (0.00; 1,325.00)</td>
</tr>
<tr>
<td>SF-12 - PCS</td>
<td>3 mo. post-op</td>
<td>40.33 (32.76; 48.42)</td>
<td>$^{1}$48.47 (32.83; 63.95)</td>
</tr>
<tr>
<td></td>
<td>1 yr. post-op</td>
<td>$^{1}$47.93 (33.96; 55.72)</td>
<td>53.10 (25.40; 60.85)</td>
</tr>
<tr>
<td>SF-12 - MCS</td>
<td>3 mo. post-op</td>
<td>49.81 (25.26; 63.57)</td>
<td>52.46 (30.29; 64.08)</td>
</tr>
<tr>
<td></td>
<td>1 yr. post-op</td>
<td>42.69 (25.34; 64.39)</td>
<td>53.88 (22.78; 62.48)</td>
</tr>
<tr>
<td>DASH</td>
<td>3 mo. post-op</td>
<td>31.67 (10.00; 66.67)</td>
<td>15.00 (5.00; 47.50)</td>
</tr>
<tr>
<td></td>
<td>1 yr. post-op</td>
<td>25.83 (6.60; 66.67)</td>
<td>15.42 (0.00; 46.60)</td>
</tr>
</tbody>
</table>

VAS: Visual Analog Scale for pain; WORC: Western Ontario Rotator Cuff Index; SF-12: 12-Item Health Survey; PCS: Physical Composite Scale; MCS: Mental Composite Scale; DASH: Disabilities of the Arm, Shoulder and Hand.

*Differs from the control group in the same timeframe (p<0.05); $^{1}$Differs from the preoperative timeframe (p<0.05); $^{2}$Differs from the 3 month post-op timeframe (p<0.05).

The results showed a significant improvement in pain in the experimental group, between the pre operative period and one year after, with a significant increase in relation to goniometry of flexion and external rotation in both groups, after three months, and significantly higher values for abduction in the experimental group after three months and one year.

The six-week pre-operative rehabilitation program as described by Seyahi et al.\textsuperscript{22} provided, after arthroscopic cuff repair, faster recovery of shoulder ROM, scapular muscle and rotator cuff strength, diminished scapular dyskinesis, improved quality of life, and better results in the VAS, DASH, and Constant scores than those who did not utilize the program. In the present study, those receiving education specifically on scapular-focused exercise outperformed on EVA, WORC total, and physical component of the SF-12 in relation to the control group, corroborating the data in the literature. Analyzing the relationship between quality...
of life (QOL) and WORC, in the evaluated post-operative periods, there were better values of the physical component of SF-12 in the experimental group compared to the control group. However, there was no statistical correlation between WORC and the QOL score, which may be due to the small sample size of this pilot study.

Exercises that focus on the scapula are beneficial to patients with many types of shoulder disorders. Saito et al.,\textsuperscript{23} showed that in adults with subacromial impingement syndrome, scapula-focused exercises could improve pain and shoulder function in the short-term. In the present study, the group that underwent pre-operative rehabilitation with a focus on scapular stabilization presented better results for abduction ROM in the follow-up at three months and one year, and lower WORC values. Baskurt et al.,\textsuperscript{24} investigating the efficacy of scapula stabilization exercises in patients with subacromial impingement syndrome, found that ROM measurements and quality of life improved statistically in both groups after treatment (p < 0.05), but the group who underwent the six-week scapular stabilization exercise program had a significant improvement in abduction ROM, scapular muscle strength, lower WORC score, and better scapulohumeral rhythm after treatment (p < 0.05).

The purpose of the current study was to analyze the post-operative clinical effects of scapular and core activation before the treatment of a traumatic injury with surgery. These activation with exercises were guided by a physical therapist, who described their execution and frequency. In this sense, the authors believe that the role of this professional in guiding the exercises had a positive impact on the adherence of participants and its clinical results.

The current study was conducted on patients diagnosed with traumatic RCL with surgical treatment indicated, and even with the presence of the lesion, the pre-operative rehabilitation program had patient adherence, and the results of pain control, range of motion of the shoulder, and quality of life were significant. This is similar to the study by Björnsson et al.,\textsuperscript{25} in which they evaluated the function of 42 shoulders after repair of traumatic lesion of the rotator cuff and showed significantly better scores for the WORC while finding no significant difference for the DASH. In the present study, the EG had lower WORC scores in the three-month period and in the one-year follow-up (p < 0.05), with no significant difference in the DASH between groups.

Düzgün et al.,\textsuperscript{16} described an accelerated rehabilitation protocol consisting of a pre-operative rehabilitation program of four to six weeks and for 24 weeks post-operatively. The accelerated protocol was associated with less pain during activities and at night, after the fifth week, being superior to the slow protocol in terms of functional activity level, as determined by the DASH (p < 0.05). However, they did not determine which variable of the accelerated protocol was responsible for the improvement of the symptoms and the score, unlike the present study where the experiment was pre-operative and both groups followed the same post-operative protocol. The authors believe that pre-operative scapular exercises improve the scapula stability, re-establishing the roles of the scapula\textsuperscript{9} such as favoring the optimal position of the humerus in the subacromial space and the recovery of shoulder function, which was evidenced by the results of abduction and reduced pain in the patients of the intervention group.

The analysis of the WORC score of the groups showed that the experimental group had better results in the period of one year, which was not observed in the control group, whose value was worse in one year than in three months, with no statistically significant difference. This occurrence may have something to do with the lack of preoperative scapular exercises in the control group.

The post-operative rehabilitation protocol in the present study was the same for both groups, with emphasis on joint mobility gain through passive and active mobilizations, and strengthening of the shoulder girdle, core, and rotator cuff musculature (Appendix II). It is known that post-operative rehabilitation has an important role in functional improvement after rotator cuff repair.\textsuperscript{26} It is suggested that rehabilitation should include the re-establishment of ROM, shoulder function, and muscle strength, taking into account the healing time of the repaired tendon.\textsuperscript{27} However, considering the post-operative rotator cuff protocol was effective at aiding the recovery for both groups, the likely factor that positively influenced the experimental group’s results compared to the control group’s results was the inclusion of the pre-operative scapular strengthening program. This suggests that addressing the roles of the scapula\textsuperscript{9} prior to surgery could benefit rotator cuff function following surgery.

This study presented has limitations such as small sample size (because it was a pilot study), the non-blinding of the evaluator in the post-operative period, and the uncertainty about the patients’ adherence regarding performance of the home based exercises. Despite this, there was a uniform sample of patients in which one physiotherapist came into frequent contact during the preoperative period to both groups and performed the postoperative rehabilitation exercises in the same manner in all participants. Regarding the positives, the study shows that the preoperative rehabilitation significantly improved the physical parameters, demonstrated through the ROM and the functional scores in the follow-ups evaluated. In light of these results, a next study is planned with greater control of these variables. Using the results of WORC for the purpose of calculating the sample size, with a power of 80% and a signifi-

Figure 3. Boxplot of SF-12 scores by component, group, and timeframe
CONCLUSION

Pre-operative scapular rehabilitation had a positive impact on the ROM and pain outcomes of individuals who underwent arthroscopic repair of traumatic rotator cuff injury, contributing to good clinical recovery of the patients, as demonstrated by the results of ROM, SF-12 physical component after three months of intervention, and WORC after one year of follow-up. The authors recommend performing pre-operative scapular rehabilitation, focusing on periscapular muscular activation, for patients who will undergo surgical repair of a traumatic rotator cuff lesion.

CONFLICTS OF INTEREST

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Submitted: October 08, 2019 CST, Accepted: June 16, 2020 CST
REFERENCES


SUPPLEMENTARY MATERIALS

Appendix 1

Appendix 2
Original Research

An Alternative Model of Care for the Treatment of Adolescent Athletes with Extension-Based Low Back Pain: A Pilot Study.

Mitchell Selhorst, DPT, PhD, OCS\textsuperscript{1,2}, Richard Rodenberg, MD\textsuperscript{2}, Nick Padgett, DPT, OCS\textsuperscript{1}, Anastasia Fischer, MD, FACSM\textsuperscript{2}, Reno Ravindran, MD\textsuperscript{2}, James MacDonald, MD, MPH\textsuperscript{2}

\textsuperscript{1} Sports and Orthopedic Physical Therapy, Nationwide Children's Hospital, \textsuperscript{2} Division of Sports Medicine, Nationwide Children's Hospital

Keywords: spondylolysis, low back pain, athlete, adolescent

10.26603/001c.18715

International Journal of Sports Physical Therapy

Vol. 16, Issue 1, 2021

Background and Purpose

Half of adolescent athletes report low back pain (LBP) and there is a significant risk of vertebral injury in this population. The current model of care for adolescent athletes with LBP is to first confirm a medical diagnosis of spondylolysis which frequently requires advanced imaging. However, routine use of advanced imaging increases cost, delays treatment, and can expose the athlete to radiation.

Purpose

The purpose of this pilot study was to assess the viability of a physical therapist guided functional progression program to manage low back pain (LBP) in adolescent athletes.

Study Design

Non-randomized, controlled clinical trial.

Methods

Sixteen adolescents (15 ± 1.8 years, 50% female) with extension-based LBP were assigned to the biomedical model or physical therapy first model. The biomedical model sought to determine a spondylolysis diagnosis to guide treatment. In the physical therapy first model, patients began early therapeutic exercise and their ability to functionally progress determined the course of care. Dependent variables were change in Micheli Function Score, use of imagining, days out of sport, and ability to return to sport. Adverse events were monitored in order to assess safety. Descriptive statistics were completed to assess the viability of the alternative model.

Results

Both models had similar improvements in pain and function. The physical therapy first model reduced use of advanced imaging by 88% compared to the biomedical model. Patients in the biomedical model who did not sustain a vertebral injury returned to sport sooner than the physical therapy first model (3.4 days versus 51 days), while those with a vertebral injury took longer in the current model (131 days versus 71 days). All of the patients in the physical therapy first model and 88% of patients in the current model made a full return to sport. Two adverse events occurred in the biomedical model, and none were noted in the physical therapy first model.

Conclusion

This pilot study demonstrated that the physical therapist guided functional progression program may be a viable method for treating young athletes with LBP and further research is warranted.
Level of Evidence
3b

INTRODUCTION

Low back pain (LBP) is a common complaint among adolescent athletes, and the incidence is increasing.\(^1\) The most common cause of specific LBP in this population is an ischemic spondylolysis, which has previously been reported to occur as frequently as 47% in some populations of young athletes.\(^2\) However, outcomes of larger studies suggest that the prevalence of spondylolysis is likely closer to 14-30% among adolescent athletes reporting LBP.\(^3,4\) Repetitive lumbar extension and rotation motions have been associated with increased risk of spondylolysis.\(^5\) Sports involving these repetitive motions, such as baseball and gymnastics, have rates of spondylolysis as high as 47-58% among symptomatic athletes.\(^2,5\) Given this high prevalence, spondylolysis should be given high priority as a diagnostic hypothesis in young athletes presenting with LBP.\(^6\)

The current model of care for adolescent athletes with LBP is a biomedical model which seeks to identify a specific pathoanatomical cause of LBP using advanced imaging.\(^6\)-\(^9\) Imaging is necessary to accurately distinguish spondylolysis from non-specific LBP, as there is no method to reliably identify a spondylolysis using physical examination and history.\(^10,11\) The most well-known clinical test to screen for spondylolysis, the single-leg hyperextension test, is neither sensitive nor specific for detecting spondylolysis.\(^12,13\) Consequently, diagnostic imaging is frequently obtained for this population. In adolescent athletes presenting with LBP, two-view radiographs are recommended as the first initial study.\(^14\) However, the sensitivity of radiographs is low and advanced imaging is typically necessary to obtain an accurate diagnosis.\(^14\)

The outcomes of adolescent athletes following treatment using the biomedical model are not ideal.\(^15\)-\(^17\) Diagnosis of adolescent LBP is associated with exposure to significant radiation and high imaging costs.\(^18\) Adolescent athletes with LBP may have a worse prognosis regarding function than their nonathletic counterparts.\(^19\) Moreover, 65% of adolescent athletes with non-specific LBP had continued pain or a recurrence of symptoms within six months.\(^16\) In patients with a spondylolysis, 42% had a poor clinical outcome and one in eight had to stop or reduce sport participation at long-term follow-up.\(^15,17\) These findings become particularly important because the more days an adolescent experiences LBP, the higher the risk for chronic LBP as an adult.\(^20\) The suboptimal clinical outcomes in adolescent athletes with LBP demonstrate the need to improve the model of care.

An additional problem with the biomedical model of care for this population is the high cost and potential radiation exposure of diagnostic imaging.\(^18\) Single photon emission computed tomography (SPECT) with computed tomography (CT) scan, long considered the gold standard for diagnosing spondylolysis, has recently fallen out of favor due to heightened concerns over the long-term risk of malignancies associated with exposure of children to radiation.\(^14,21\) Magnetic resonance imaging (MRI) is becoming more popular for identifying spondylolysis, as MRI has good diagnostic accuracy without exposing the patient to ionizing radiation.\(^22\) Challenges to the use of MRI remain, however, with issues of cost, insurance coverage, access, and variable quality of imaging in different centers. In contrast to the current recommendations to first obtain a specific diagnosis, Miller et al.\(^18\) suggested that extensive imaging is neither needed nor advisable in adolescents with LBP, arguing that advanced imaging should not be performed until the patient returns with continuing or unresolved pain following physical therapy patient management.\(^18\)

The majority of LBP in adolescent athletes can be divided into two groups; non-specific LBP and spondylolysis (and other bone stress injuries).\(^3,4\) The primary difference between current treatment of non-specific LBP and spondylolysis is the need for relative rest from sport.\(^5,23,24\) Thus, the authors propose a physical therapist guided functional progression program which uses pain-free functional progress in rehabilitation in order to guide care. This model has been specifically designed to address the needs of adolescent athletes with LBP and to treat adolescent athletes without the use of advanced imaging. Patients who are able to progress back to sport without pain are believed to be stable and safe enough to do so, while those having persistent pain warrant further evaluation and perhaps need a period of rest to allow their injury to heal. Subsequently, the purpose of this pilot study was to assess the viability of a physical therapist guided functional progression program to manage LBP in adolescent athletes.

METHODS

This pilot study was a non-randomized, controlled trial using a sample of convenience. Adolescent athletes with low back pain that is increased during lumbar extension presenting to participating sports medicine physicians at Nationwide Children’s Hospital (Columbus, Ohio) were considered for participation. The institutional review board approved this study prior to recruitment and data collection. All patients and guardians provided written informed consent prior to participation. This study was registered at ClinicalTrials.gov (Identifier number NCT02861456).

PARTICIPANTS

Patients were eligible if they were an adolescent athlete (12-19 years) who reported acute LBP (< 3 months) which increased during lumbar extension. To be considered an athlete, patients had to participate in sport activity at least two times a week prior to the onset LBP. Patients were excluded if they (1) already had advanced imaging performed, (2) demonstrated red flags (bowel or bladder problems, saddle anesthesia, progressive neurological deficits, recent fever of infection, unexplained weight loss, unable to change symptoms with clinical testing) (3) previously rested from sport for >4 weeks due to LBP, (4) reported other injury or conditions which would alter the plan of care for
LBP (i.e. pregnancy, concomitant ACL tear), or (5) history of lumbar surgery.

**TREATMENT ALLOCATION**

This study was not randomized and the intervention the patient received was based upon their co-investigating physician. Patients either received treatment based on the proposed physical therapist guided functional progression program (PT First) or a biomedical model of care (Figure 1). Consecutive patients treated by two co-investigating physicians (AF and RR) were treated using the PT First program, while patients treated by the other two co-investigating physicians (JM and RR) were treated using a biomedical model of care. Both interventions used a pragmatic approach.

**INTERVENTIONS**

**PHYSICAL THERAPIST GUIDED FUNCTIONAL PROGRESSION PROGRAM (PT FIRST)**

Patients in the PT First group had radiographs but did not immediately have advanced imaging obtained to determine diagnosis and instead were placed on rest from sport and began the physical therapist guided functional progression program. Therapy in the PT First group was performed twice a week and followed a three-phase program (Table 1). Progression through the physical therapy program was based on achieving specific criteria, as opposed to a time-based protocol. Patients performed Phase I of the physical therapy program and progressed to phase II after meeting the specified criteria without an increase in pain. The criteria to progress to the next phase was assessed at each session. Patients who met the criteria to pass Phase I and II within a designated three-week period progressed into the third phase of physical therapy to begin return to sport activity. Patients who progressed into Phase III at this time were given additional physical therapy visits. Patients who progressed well in this third phase, and met the return to sport criteria, were released to return to sport and were discharged from physical therapy with a home exercise program. Patients who failed to meet the criteria of Phase I and II within three weeks and Phase III after a total of five weeks were considered to have an inability to progress.

Patients who had an inability to progress during the initial course of physical therapy were either treated as a presumed spondylolysis or had advanced imaging performed as a shared decision of the patient, family, and physician. Patients who had advanced imaging ordered after failing to meet the criteria were treated based upon the imaging results. Patients treated as a presumed vertebral injury were placed on rest for two months from all activities except activities of daily living and their physical therapy home exercise program. Following the two months of rest the patient then completed physical therapy care before returning to sport.

**BIOMEDICAL MODEL OF CARE**

Adolescents with LBP in the control group received care based upon the biomedical model. The biomedical model consisted of the physician first attempting to determine if the adolescent athlete had a spondylolysis or non-specific LBP. Advanced imaging was obtained to diagnose the injury when the physician had sufficient suspicion of a vertebral injury in the athlete with low back pain. If there was no identifiable cause of the patient’s LBP, the patient was sent to physical therapy and was allowed to progress to sport.
immediately. If the patient was diagnosed with a bony or spondylolytic injury, care would consist of a preliminary two to three month rest from activity, bracing if the physician thought it was necessary, followed by four to six weeks of physical therapy. Physical therapy was performed twice per week and interventions were individualized based on the patient’s presentation.

OUTCOMES

Use of advanced imaging, cost of care, and clinical outcomes were the main outcomes of interest. Clinical outcomes included pain, function, ability to return to sport, and time to return to sport. Pain and function were assessed at baseline and discharge using the Micheli Functional Scale (MFS), as traditional adult patient reported outcome measures are notably less reliable in high functioning individuals. The MFS is a self-report measure designed to assess pain and functional ability of adolescent athletes with LBP on a 0-100 scale with 0 being no disability and 100 representing maximum disability. This scale has been found to have validity (concurrent validity r = 0.90), and reliability (item reliability α = 0.79-0.90) in young athletes with LBP. The patient’s ability to participate in sport was assessed using a self-report question reporting one of the following: 1) I am at the same or higher level of sport than I was prior to treatment, 2) I am still in my sport but at a lower level due to my low back injury, 3) I am currently unable to participate in sport due to my low back injury or 4) I am currently not participating in sport, but my low back was not a factor. Time to return to sport was the number of days from when the physician instructed the patient to rest from sport to when the patient was cleared to return to sport. If the patient was not instructed to rest from sport, time to return to sport was zero days.

SAFETY

Safety of the PT First program was assessed by monitoring adverse events in both groups. An adverse event was defined as 1) lumbar symptoms increasing enough to cause an unplanned visit to a physician, 2) the patient being placed on hold from therapy during the episode of care due to increased low back pain, or 3) there was a significant delay (>4 weeks) in diagnosis of non-mechanical low back pain which could have been made by use of advanced imaging.

BLINDING

No blinding was performed in this pilot trial as it was not feasible to blind either the clinicians or the patient to the treatment cohort.

SAMPLE SIZE

A sample of eight participants in each group was recruited for this pilot trial. This number was deemed sufficient to provide estimates of outcomes to guide future research studies.

DATA ANALYSIS

To assess the viability of a physical therapist guided functional progression program to treat young athletes with extension-oriented LBP descriptive statistics of the patient.

### TABLE 1. Physical Therapy First- Physical Therapy Program

<table>
<thead>
<tr>
<th>Phase I Protected Phase</th>
<th>Criteria to begin Phase II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core strengthening in neutral spine</td>
<td>1. Good core stability in neutral spine during exercises (clinician judgement)</td>
</tr>
<tr>
<td>Treat directional preference if identified</td>
<td>2. Pain free repeated standing extension x10</td>
</tr>
<tr>
<td>Hip strengthening</td>
<td>3. Pain free repeated standing flexion x10</td>
</tr>
<tr>
<td>Peri-scapular strengthening</td>
<td>Flexibility exercises</td>
</tr>
<tr>
<td>Manual Therapy as needed</td>
<td>Modicities for pain (use sparingly)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phase II Functional Exercise Phase</th>
<th>Criteria to begin Phase III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core strengthening in functional range</td>
<td>1. 0% score on ADL and Pain subsections (B and C) of Micheli Functional Scale</td>
</tr>
<tr>
<td>Hip and peri-scapular strengthening</td>
<td>2. Pain free for 2 consecutive visits during functional extension, rotation, and flexion exercises</td>
</tr>
<tr>
<td>Flexibility exercises</td>
<td>Light Running</td>
</tr>
<tr>
<td>Manual Therapy (use sparingly)</td>
<td>Jumping</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phase III Return to Sport Phase</th>
<th>Return to sport criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Return to sport activity with focus on functional return to all aspect of sport.</td>
<td>1. Pain free at end range of all lumbar motions</td>
</tr>
<tr>
<td></td>
<td>2. Completed 2 weeks of return to sport activity in physical therapy without pain.</td>
</tr>
<tr>
<td></td>
<td>3. 0% score on Micheli Functional Scale</td>
</tr>
</tbody>
</table>

### TABLE 2. Demographics and Baseline Variables. Data are presented as means (SD) or numbers (%)

<table>
<thead>
<tr>
<th></th>
<th>All Patients (n=16)</th>
<th>Physical Therapy First Model (n=8)</th>
<th>Biomedical Model (n=8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>15.0 ± 1.8</td>
<td>14.5 ± 12.1</td>
<td>15.5 ± 1.4</td>
</tr>
<tr>
<td>Gender (% female)</td>
<td>8 (50%)</td>
<td>5 (62%)</td>
<td>3 (38%)</td>
</tr>
<tr>
<td>Micheli Functional scale</td>
<td>46.8 ± 14.5</td>
<td>40.0 ± 11.3</td>
<td>53.5 ± 14.8</td>
</tr>
<tr>
<td>Unable to play</td>
<td>13 (81%)</td>
<td>6 (75%)</td>
<td>7 (88%)</td>
</tr>
<tr>
<td>Pain</td>
<td>5.2 ± 2.3</td>
<td>4.8 ± 2.5</td>
<td>5.6 ± 2.2</td>
</tr>
</tbody>
</table>

### TABLE 3. Course of Care. Data are presented as means (SD)

<table>
<thead>
<tr>
<th></th>
<th>All Patients (n=16)</th>
<th>Physical Therapy First Model (n=8)</th>
<th>Biomedical Model (n=8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of Care (days)</td>
<td>62 ± 32</td>
<td>59 ± 21</td>
<td>65 ± 41</td>
</tr>
<tr>
<td>Physical therapy visits</td>
<td>8.9 ± 4.6</td>
<td>11.5 ± 3.2</td>
<td>6.5 ± 4.6</td>
</tr>
<tr>
<td>Physician visits</td>
<td>3.2 ± 1.8</td>
<td>2.8 ± 1.2</td>
<td>3.6 ± 2.3</td>
</tr>
</tbody>
</table>

### TABLE 4. Clinical Outcomes. Data are presented as means (SD)

<table>
<thead>
<tr>
<th></th>
<th>All Patients (n=16)</th>
<th>Physical Therapy First Model (n=8)</th>
<th>Biomedical Model (n=8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in Micheli</td>
<td>33.5 ± 17.6</td>
<td>30.5 ± 14.9</td>
<td>36.5 ± 20.5</td>
</tr>
<tr>
<td>Change in Pain</td>
<td>4.3 ± 2.4</td>
<td>4.1 ± 2.3</td>
<td>4.4 ± 2.6</td>
</tr>
<tr>
<td>Full return to sport</td>
<td>15 (94%)</td>
<td>8 (100%)</td>
<td>7 (88%)</td>
</tr>
<tr>
<td>Global Rating of Change</td>
<td>5.4 ± 1.3</td>
<td>5.6 ± 1.2</td>
<td>5.1 ± 1.4</td>
</tr>
</tbody>
</table>

demographics and outcome variables were calculated using SPSS 24. This was a pilot study and is underpowered for inferential statistics, therefore only descriptive statistics were used to assess the viability of the PT first program.30

**RESULTS**

Sixteen patients were recruited for this pilot study and were assigned to either the biomedical model (n=8) or the PT First program (n=8) group. Eligible patients were recruited from August through December of 2016. Twenty-eight consecutive patients who presented to the participating sports medicine physicians with low back pain were screened for inclusion (Figure 2). Baseline variables were similar between the two models of care based upon comparison of descriptive statistics (Table 2). Eight advanced imagining procedures were performed in the biomedical model group and only one was performed in the PT First group. In the biomedical model group, five of the patients (63%) were diagnosed with non-specific low back pain, two of the patients (25%) were diagnosed with spondylolysis and one patient (12%) with a herniated disc. A definitive diagnosis in the PT First program was not made for patients as per protocol, but based on the patient’s ability to improve, six (75%) were able to make a full return to sport and activity directly from the program. Two patients (25%) did not progress through the program without pain. Advanced imaging was obtained with one patient, while the other was treated as a presumed vertebral injury and requiring a period of rest to make a full return to sport.

The course of care differed between both models of care (Table 3). Use of advanced imaging was 88% lower in the PT First program. On average, nearly twice as many physical therapy visits were used in the PT First program, while slightly more physician visits were used in the biomedical model. Both models of care had a similar duration of care. The median billed cost for the PT First program was 19% lower than in the biomedical model ($3885.00 versus $4774.00).

Both models of care made similar improvements in clinical outcomes (Table 4). Overall, 94% of the patients between the groups (n=15) were able to make a full return to sport in an average of 49 days (± 43 days). In this pilot study, the duration of care for vertebral injuries (101 ± 20 days) was longer than for non-specific LBP (49 ± 23 days). Patients in the biomedical model group with non-specific LBP were cleared to return to sport much sooner than the PT First program (3.4 days versus 51 days). However, those with a diagnosed vertebral injury took longer to be cleared to return to sport in the biomedical model group than those with a presumed vertebral injury in the PT First group (131 days versus 71 days).
Two adverse events were noted in the biomedical model group, and none occurred in the PT First group. The relative risk of adverse events was not calculated due to the nature of this pilot study. One patient initially had a SPECT scan which revealed no vertebral injury, and physical therapy was prescribed. The patient did not attend her physical therapy evaluation, and two weeks later had a significant worsening of LBP with tingling in the right leg. Clinical examination revealed no myotomal weakness of the lower extremities, intact deep tendon reflexes and decreased sensation to light touch in the right medial foot. The patient’s co-investigating physician ordered an MRI which revealed a herniated disc at L4. The patient and family sought a referral to neurology and opted to have a microdiscectomy. She was the only patient who reported being unable to return to sport. Another patient was diagnosed initially with a bilateral spondylolysis at L4 and started physical therapy after 10 weeks of rest, had a significant worsening of LBP during care requiring her to stop participation. She subsequently had repeat advanced imaging which revealed no additional significant findings.

**DISCUSSION**

The purpose of this pilot study was to assess an alternative way to manage LBP in adolescent athletes in a safe manner without exposing the patient to unnecessary and expensive testing. This study demonstrated that by using the physical therapist guided functional progression (PT First) program there is the potential to safely reduce the need for advanced imaging by 88% in adolescents with LBP. Although a specific diagnosis was not obtained in the PT First group, all of the participants were able to return to sport, despite two patients (25%) requiring a period of rest from the treatment protocol before returning to progress back to sport. Only one of these two patients required advanced imaging. Early advanced imaging, as seen in the biomedical model, resulted in a faster return to sport (3.4 days versus 51 days) in individuals who did not sustain a vertebral injury. This quick return is likely due to physician comfort in the knowledge that the spine was anatomically ‘normal’ allowing the physician to release the patient earlier to full play while doing therapy at the same time to work on mechanics and functional issues. However, this knowledge comes at a high monetary cost.

Adolescent LBP can be intimidating for clinicians to care for in clinical practice and dogma for pediatricians and trainees has been that most LBP in this population has an identifiable diagnosis. This thinking has been perpetuated because up to 47% of adolescent athletes were reported to have spondylolysis when presenting with extension-based LBP. Moreover, medical trainees are taught that adolescents with LBP lasting longer than two to three weeks should be investigated; prompting radiographs and often times advanced imaging. Both single photon emission computed tomography (SPECT) with computed tomography (CT) and magnetic resonance imaging (MRI) can be utilized to identify spondylolysis, however, advanced imaging comes at a significant cost and is not without risks. There is no one test that fits all situations and is available to answer all questions about the potential etiology of pain in the adolescent spine. MRI is an appealing test due to the improving diagnostic accuracy without ionizing radiation, but many consider SPECT with CT the gold standard in identifying stress reaction or fracture of the posterior elements of the lumbar spine. Campbell et al looked at MRI versus SPECT with CT in a diagnostic validation study and found MRI is an accurate means of demonstrating a normal pars,
acute complete defects, and chronic established defects but was limited in its ability to accurately diagnose stress reaction and incomplete defects; prompting some clinicians to still utilize SPECT in the care of their patients. Further, both MRI and SPECT with CT come at a significant monetary cost.

Recent research has challenged the thought process that there is frequently an identifiable cause for LBP in adolescent athletes. A high quality prospective study of 73 pediatric LBP patients followed for two years found that nearly 80% had no definitive diagnosis. A retrospective study by Miller et al found that a majority of school age children presenting to a tertiary referral center to see a pediatric orthopedic specialist had undiagnosed mechanical LBP. Of 2846 patients followed over an 8-year period, 75.9% were determined to have undiagnosed mechanical LBP. The majority of patients diagnosed with non-specific mechanical LBP had ≤ 2 follow-up visits, indicating that recovery was obtained quickly in these patients. Similar to reports by Miller, Houghton, and Shah, imaging in the current pilot study found an identifiable etiology in three of eight participants (2 spondylolysis and 1 herniated disc). Pursuit of a specific etiology comes at significant monetary cost given that 100% PT First program participants were able to ultimately advance back to full sports participation without advanced imaging.

Based on the results of this pilot study, the authors suggest that LBP in adolescent athletes can be successfully addressed by basing treatment and progression on functional outcomes without utilizing expensive imaging modalities that often times do not reveal a true etiology for the patients’ LBP.

LIMITATIONS

This pilot study is not without limitations, primarily the lack of blinding and randomization to the models of care. Blinding the treating clinicians and patients to the assigned model of care was impractical due to the nature of the planned treatments. The non-randomized design potentially biased the results of this pilot study, particularly with the slightly higher levels of pain and dysfunction at baseline noted in the biomedical model group. The authors plan a future larger randomized study to reduce study bias and assess clinical effectiveness of the PT First program.

CONCLUSION

The proposed physical therapist guided functional progression (PT First) program may be a viable method for treating adolescent athletes with low back pain, particularly when there are financial concerns, concerns for radiation exposure, or the athlete is in their off-season. However, the authors admit that the PT First program produced a much longer duration of therapy and was associated with a longer return to play timeline compared to the biomedical model where imaging was done. A speedy return-to-play should be considered in an in-season or high-level adolescent athlete if it can be done without patient harm. The authors of this study plan to continue to study the physical therapist guided functional progression (PT First) program protocol through a larger randomized controlled trial.

CONFLICTS OF INTEREST

The authors have no conflicts of interest to report.

Submitted: November 18, 2019 CST, Accepted: June 16, 2020 CST
REFERENCES


The prevalence of spondylolysis amongst adolescent athletes presenting with low back pain has been reported as high as 47-55%. Youth athletes participating in sports involving movements combining compression, extension and rotation appear most susceptible. As such, young golfers are a high-risk group, particularly given the high shear and compressive forces associated with the golf swing action. This is compounded by a culture which encourages very high practice volumes, typically poorly monitored. Although non-operative interventions are deemed the gold-standard management for this condition, surgery is indicated for more severe presentations and cases of ‘failed’ conservative management. The case presented herein outlines an inter-disciplinary, non-operative management of a 17-year old elite golfer with a moderate to severe presentation. A 4-stage model of reconditioning is outlined, which may be of use to practitioners given the paucity of rehabilitation guidelines for this condition. The report highlights the benefits of a graded program of exercise-based rehabilitation over the typically prescribed "12 weeks rest" prior to a return to the provocative activity. It also supports existing evidence that passive therapeutic approaches should only be used as an adjunct to exercise, if at all in the management of spondylolysis. Finally, and crucially, it also underlines that to deem non-surgical rehabilitation ‘unsuccessful’ or ‘failed’, clinicians should ensure that (long-term) exercise was included in the conservative approach.

Level of Evidence
4-Case Report

INTRODUCTION/BACKGROUND

Spondylolysis is a defect in the pars interarticularis of a vertebra. The pars interarticularis is a small isthmus of bone between the superior and inferior articular facets of spinal vertebra. The fracture can be unilateral or bilateral and although any spinal level may be affected, 71% to 95% of lesions occur at L5 and 5% to 23% at L4.2,3 The cause is most commonly a fatigue fracture, as a result of higher stress loads with movements combining compression and extension or rotation.4 The injury starts as a stress fracture, and can develop into a full fracture, non-union, and eventually a spondylolisthesis.2,5 Spondylolysis most commonly occurs in sports involving these movements, for example gymnastics, cricket, tennis, golf, football, hockey, athletics, swimming, and basketball.5–8

Spondylolysis has a reported incidence of 6% in the general adult population and 4.4% in the paediatric population as a cause of low back pain.9 In the sporting population incidence of spondylolysis has been reported as high as 47-55% in adolescent athletes presenting with low back pain.5 Early diagnosis is important to prevent non-union which has been associated with an increased incidence of spondylolisthesis.5 Moreover, earlier recognition of acute spondylolysis is associated with improved fracture healing.2

Due to the anatomy of the sacral angle and the inferior facet of L5, a large anterior shear on the L5 pars interarticularis is created. In young athletes, the spine is undergoing growth and re-modelling with full bony maturation of the pars interarticularis not occurring until the age of 25.3 The anterior shear, along with bony immaturity of adolescence are thought to be two of the greatest contributing factors making spondylolysis more common in the adolescent population.2

Corresponding author: Simon Brearley Cranleigh School Annexe, Field view, Upfold Ln Cranleigh, UK GU68PD simonlbrearley@gmail.com
Individuals who stand with an excessive anterior pelvic tilt will increase the anterior shear at the L5 level, therefore increasing the risk for spondylolysis at L5. It has been proposed this may be emphasized in adolescents presenting with lower abdominal weakness; hip flexor, hamstring and thoracolumbar fascial hypertonicity; increased femoral anteversion; genu recurvatum, and increased thoracic kyphosis. Reduced hip-lumbar and thoracolumbar dissociation is also a common trait in adolescent athletes. A higher body mass index is also associated with a higher lumbar lordosis.

Other factors likely to increase the risk for youth golfers specifically are both biomechanical and load related. Given the growing importance of driving distance players may adopt techniques which increase the stress at the lumbar spine in pursuit of greater club head speed (CHS) e.g. seeking a large rotation of the torso relative to the pelvis, commonly referred to in the literature as the ‘X-Factor’. Combining such techniques with high and poorly monitored volumes (often spiked in response to a step up in level i.e. selection for a regional or national squad) is likely to increase the chances of developing spondylolysis. Indeed, it is not uncommon for age-group regional level golfers to perform up to 1000 swings per week with considerable variations in golf volume across the year, seemingly driven by exam periods. The variability of volume is an important point to note given previous research has shown this to be more predictive of injury than volume alone.

The current gold standard for investigating and diagnosing spondylolysis is bone scintigraphy with SPECT (single photon emission computed tomography). This should be complimented with thin sliced reverse-gantry axial computed tomography (CT) if bone scintigraphy is positive. Magnetic resonance imaging (MRI) has many useful advantages including being non-invasive, and an absence of ionising radiation. However, the use of MRI for first-line investigation has shown a significant number of false-negative scans.

Research stipulates that conservative management for these patients is the gold standard for adolescents with lumbar spondylolysis in preference to surgical interventions. In fact, adolescent athletes return to play 92.2% of the time with nonoperative management, compared to 90.5% when treated surgically. Surgical intervention is indicated if there is failure of conservative treatment after 6 months, persistent back pain after 9-12 months, or non-union after 9-12 months. Other relative indicators for surgical management are in athletes with spondylolisthesis of more than 50% in those who have not reached skeletal maturity, neurological deficit with continued lumbar spine pain, and vertebral instability. A mean time for return-to-play following surgical intervention is 7.9 months.

Evidence by Sundell et al highlights that early stage stress reactions of the pars interarticularis will heal with 3 months of rest from physical activity with no restrictions in activities of daily living and without a brace. Early stages were seen to heal quicker than late stages, which highlights the importance of early diagnosis. Having reviewed the literature, both Tawfik et al. and Panteliadis et al. both agreed with a mean return-to-play of 3.7 months following conservative treatment of bracing, rest, and rehabilitation in the form of strength and flexibility. Rehabilitation in 25 ice hockey players with spondylolysis aged between 15-18 years were rehabilitated conservatively using rest from physical activity, core strength, flexibility, and anti-lordotic stabilisation in particular. Return-to-play ranged from 6 to 12 weeks with an average of eight weeks.

Currently, to the authors knowledge there are no case reports outlining the rehabilitation and reconditioning of spondylolysis in adolescents. The purpose of this case report is to outline a structured guideline for rehabilitation during the commonly ordered 12-week rest from the instigating/provocative activity.

CASE DESCRIPTION

The athlete (male, age: 15 years; stature: 1.75m; body mass: 66Kg [initial assessment]) presented to England Golf regional squad training in the autumn of 2015 (provided as a part of the England Golf Union performance support program) reporting ongoing (~12 weeks duration) low back pain of gradual onset which had not improved with acupuncture and manual therapy, received from another provider. He had a golf handicap of three strokes but was unable to play competitively over the previous summer due to back pain. As a result, his parents were seeking a second opinion regarding treatment options and were awaiting referral to orthopedics. In the meantime he rested intermittently from golf which alleviated symptoms but pain consistently returned on return to the activity.

The initial orthopedic consultant to review the case (October 2015) suspected no bony injury and the patient was reassured. However, persistence of symptoms led to referral for MRI in March 2016. The MRI showed pars fractures bilaterally with 1mm and 2mm defects both at acute angles. He was advised to rest for 12 weeks to promote recovery but a follow up CT scan in June 2016 showed little evidence of healing bilaterally. A primary posterior fusion to stabilize the non-united L1 vertebrae was therefore suggested. At this juncture his parents sourced a second orthopedic opinion in July 2016. Review of previous MRI revealed further non-united bilateral pars defects at L5, together with those previously identified at L1. These were larger than the L1 defects, measuring approximately 7mm and 8mm respectively. Concern was also expressed about a slight L5/S1 listhesis. Accordingly, steroid injections were proposed together with a pain diary during an experimental return to play phase, to differentiate which defect was causing the pain. Spinal fusion was discussed as the preferred surgical option, despite the chance of a rotational hypomobility which may prevent further participation in competitive golf.

INITIAL EXAMINATION

SUBJECTIVE

The athlete was assessed by the support team physiotherapist in September 2016, with a view to exploring all non-surgical and surgical options. The steroid injections were already booked at the time of the assessment, as the consultants felt all non-surgical options had been exhausted.
However, an in-depth review of the athlete’s history revealed that no structured exercise-based rehabilitation plan had been adhered to.

**OBJECTIVE ASSESSMENT**

An 11-point numerical pain rating scale (NPRS), where 0 = no pain and 10 = worst pain imaginable, was used to objectively measure the pain the subject was experiencing in different tasks. At rest the athlete was pain-free. During short swims pain increased to 7/10, and took two to three hours to resolve completely.

On assessment, the athlete had minimal pain in standing, yet golf ‘address’ posture caused pain to rapidly increase to 7/10. His lumbar spine range of movement (ROM) was normal in flexion and extension. Right and left side lumbar flexion increased pain, 2/10 bilaterally. There was full ROM bilaterally in hips and knees, and through thoracic spine flexion. Extension was stiff and occurred at the thoracolumbar region together with rib flare but there was no loss in ROM. Seated thoracic spine rotation caused some apprehension but no pain. Right rotation was slightly limited in comparison to the left at end ROM. There was increased muscular development visible in the right lumbar paravertebral.

Further assessment was informed by the movement demands of the sport and previous research highlighting the predisposing biomechanical and postural factors for lumbar spine stress fractures, discussed previously. Accordingly, this centered around assessment of inter-segmental control of thorax on pelvis in anatomical positions relevant to the sport i.e. hip hinge with overhead shoulder movement (particularly flexion/abduction external rotation). Initial observation revealed poor lumbar-extension (shelving), pelvic-thorax (ribcage flaring), and cervical extension (poking chin) control during hinging and this movement produced hypertonicity in the paravertebrals together with a general apprehension, all of which were further pronounced by the addition of increasing shoulder flexion/abduction. Moreover, there was poor dissociation of the pelvis on the torso (and vice versa) with a lateral hip shift and a compensatory lateral flexion with rib flare occurring when trying to rotate the torso independently. Finally, although the subject had full ROM in anterior to posterior pelvic tilt, active control was poor – likely a habituated behavior secondary to pain or threat of pain.21

These findings were triangulated with the golf coach’s more specific (swing) movement analysis which combined basic motion capture techniques using a high-speed camera, review of historical footage and coaching eye. Subsequently, the following assessment points were agreed on relating to technical aspects which may have contributed to the development of the injury:

- Excessive (spinal) extension and scapulae elevation with overly high muscle activity of the neck and paraspinals at address and into takeaway;
- Compensatory lateral (spinal) flexion and lateral hip shift during rotation (backswing);
- Excessive “crunch factor” - lateral spinal flexion through impact;
- Substitution of (or concomitant) lumbar extension for hip extension during the acceleration phase, impact and follow through.

**INTERVENTION PLAN**

Both the athlete and his parents were advised that long-term exercise-based rehabilitation should be given a fair chance before consideration of surgery. Expectations were managed by proposing a 12-month timeline for the plan up-front. Inter-disciplinary input was deemed important and therefore performance support experts were recruited from the disciplines of Coaching/Biomechanics and Strength and Conditioning (S&C) to support Physiotherapy. Given the outcomes of these respective initial assessments, the overarching plan was to both reduce load going through the injured region during the golf swing, while increasing the load the athlete can tolerate to provide further insurance. At this juncture both the athlete and his parents gave informed consent to participate and for the data collected during the intervention to be published. The study was subsequently approved by the University of Essex ethics board.

**PHASE 1: ACUTE**

During the first few weeks of this phase all other physical activity was restricted apart from the rehabilitation program itself. As soon as the subject was pain-free into lumbar extension stationary cycling was introduced to maintain cardio-respiratory fitness and mental wellbeing. Program design at this stage was led by the physiotherapist with the emphasis on reducing biomechanical load subjected to the lumbar spine by improving inter-segmental control and mobility (lower limb flexibility/muscle extensibility, tho-
Table 1: Phase 1: Acute Rehabilitation Program

<table>
<thead>
<tr>
<th>Motor Control</th>
<th>Intended Physical Outcome</th>
<th>Physical Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hip Hinge with Dowel</td>
<td>Motor control</td>
</tr>
<tr>
<td>2a</td>
<td>Modified Dead Bugs - Wall Heel Taps</td>
<td>Segmental stabilization</td>
</tr>
<tr>
<td>2b</td>
<td>Modified Dead Bugs with Wall Heel Tap Arcs</td>
<td>Segmental stabilization</td>
</tr>
<tr>
<td>3a</td>
<td>Hip Hinge with band crab walks</td>
<td>Motor control / lateral hip stability</td>
</tr>
<tr>
<td>3b</td>
<td>Hip Hinge band crab walks in split stance</td>
<td>Motor control / lateral hip stability</td>
</tr>
</tbody>
</table>

*2b & 3b were progressions added upon mastery of 2a/3a

Figure 2: Inter-disciplinary conservative management / rehabilitation plan showing increasing emphasis on load tolerance towards return to play. (S & C refers to strength and conditioning specialist)

To the authors knowledge, there is little evidence regarding specific criteria for graduated return to play in adolescents. Notwithstanding, the support team valued setting visible, achievable milestones throughout the rehabilitation process for motivation purposes. Therefore although experiential in nature (as recommended by the authors), exit-criteria for this phase was as follows:

- Able to walk 18 holes without pain during or after;
- Able to cycle 20 mins rating of perceived exertion (RPE) 6 without pain during or after;
- Pain-free lumbar extension and stork test;
- Reduced movement guarding and apprehension;
- Well dissociated pain-free repeated bodyweight (BW) hinge in kneeling and standing without kinetic chain compensations observed at initial assessment.

PHASE 2: SUB-ACUTE/LOAD INTRODUCTION

It was at this phase that coach collaboration became a pivotal part of the rehabilitation process as the team were keen to re-introduce controlled putting practice. This was monitored via ‘time on green’ and periodically interrupted with ‘movement breaks’ which consisted of progressions and variations of phase-1 motor control drills which now formed a ‘micro-program’. This was essentially a minimalist program which the subject performed daily alongside a newly introduced strength and conditioning (S&C) program which was performed 2-5x per week.

A key factor determining the spinal stability strategy deployed by the central nervous system is the magnitude of imposed load,\(^{21,22}\) with increasing motor unit recruitment of (superficial) muscles with higher contractile potential as...
load-transfer, proximal lower-limb segments can be responsible for failed distal segment. Sequencing resulting in a summation of forces at the final which involve a high-speed proximal-to-distal sequential inv olve a high-speed proximal-to-distal sequential force is crucial to minimise strain of vulnerable tissues in the spine. Indeed, it has been suggested that an even distribution of force is crucial to minimise strain of vulnerable tissues in the spine. This is particularly important to the golf-drive which involve a high-speed proximal-to-distal sequential sequencing resulting in a summation of forces at the final distal segment. Insufficient muscular capacity in the proximal lower-limb segments can be responsible for failed load-transfer, which provides justification for addressing the appendicular skeleton as well as the immediate supporting spinal musculature.

Table 2 outlines how the athlete was subjected to greater control and stability challenges, building on phase-1 segmental stabilisation exercises with spinal dissociation and segmental control work of the identified areas. Full definitions and classifications of these specific spinal abilities are available in Spencer et al.\textsuperscript{29} consensus statement on spinal-exercise prescription in sport. This was followed by a progressive trunk work-capacity program which utilised non-functional, isometric ‘pillar’ exercises to raise the metabolic capacity of the trunk muscles (i.e. increased mitochondria, capillarization, and cross-sectional area etc.), preserving force production and providing greater resistance to fatigue when absorbing, transmitting or dissipating repeated or sustained sub-maximal forces.

Exit-criteria for this phase was as follows:

- No reaction to introduction of putting practice sessions;
- 2 minute holds on all isometric trunk work capacity assessments (side plank left & right, double leg lower, prone trunk);
- Maintenance of phase 1 exit criteria.

### Table 2: Phase 2: Sub-Acute Load Intro Rehabilitation Program

<table>
<thead>
<tr>
<th>Mobility &amp; control</th>
<th>Program of Rehabilitation: Phase 2: Sub-Acute / Load Intro</th>
<th>Intended physical outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a DB split squat (trail leg focus)</td>
<td>Set Rep Rest</td>
<td>Hip strength &amp; mobility</td>
</tr>
<tr>
<td>1b Open the book</td>
<td>3 8</td>
<td>8 30s</td>
</tr>
<tr>
<td>2a Band assisted OHS</td>
<td>3 6-8 30s</td>
<td>Thoracic extension mobility / pelvic-thorax control</td>
</tr>
<tr>
<td>2b MB lunge with rotation</td>
<td>3 6</td>
<td>6 30s</td>
</tr>
<tr>
<td>3a Kneeling hip hinge</td>
<td>3 6-8 30s</td>
<td>Hip-lumbar dissociation / local loading / gluteal strength</td>
</tr>
<tr>
<td>3b Standing hip hinge with shoulder ext. rotation</td>
<td>2 6-8 30s</td>
<td>Hip-lumbar dissociation / local loading / external rotation strength/mobility</td>
</tr>
<tr>
<td>3c Wall angels</td>
<td>2 6</td>
<td>8 30s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>'Pillar' work capacity</th>
<th>Set Rep Rest</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Supine band pullover hold</td>
<td>3 20-90s 30s</td>
<td>↑ metabolic capacity of anterior trunk musculature</td>
</tr>
<tr>
<td>2 Glute bridge series</td>
<td>3 20-90s 30s</td>
<td>↑ metabolic capacity of posterior hip musculature</td>
</tr>
<tr>
<td>3 Palloff series</td>
<td>3 20-90s 30s</td>
<td>↑ metabolic capacity of anterior trunk/motion muscle</td>
</tr>
<tr>
<td>4 Prone extension</td>
<td>3 20-90s 30s</td>
<td>↑ metabolic capacity of posterior trunk musculature</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Control</th>
<th>Set Rep Rest</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Superman series</td>
<td>N/ A N/A N/A</td>
<td>Segmental stabilization / spinal dissociation</td>
</tr>
<tr>
<td>2 Modified dead bugs with wall heel taps</td>
<td>N/ A N/A N/A</td>
<td>Segmental stabilization</td>
</tr>
<tr>
<td>3 Hip Hinge band crab walks in split stance</td>
<td>N/ A N/A N/A</td>
<td>Motor control / lateral hip stability</td>
</tr>
</tbody>
</table>

DB = dumbbell, MB = medicine ball, OHS = overhead squat
**Table 3: Phase 3: Reconditioning Program**

<table>
<thead>
<tr>
<th>Strength-accumulation</th>
<th>Program of Rehabilitation: Phase 3: Reconditioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a DB split squat</td>
<td>Set 3 Rep 8/8 Rest 90s RPE 8 Intended physical outcome</td>
</tr>
<tr>
<td>1b Walking lunge w/ around the world</td>
<td>3 8</td>
</tr>
<tr>
<td>2a Trap-bar deadlift</td>
<td>4 8-10 90s 8 Leg &amp; trunk strength</td>
</tr>
<tr>
<td>2b Suitcase carry</td>
<td>3 6</td>
</tr>
<tr>
<td>3 BB RDL / BB hip thrust</td>
<td>4 8-10 90s 8 Leg &amp; trunk strength</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strength-intensif.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1a RFE split squat</td>
<td>Set 3 Rep 6</td>
</tr>
<tr>
<td>1b MB lateral bound &amp; stick</td>
<td>3 6</td>
</tr>
<tr>
<td>2a Trap-bar deadlift</td>
<td>4 5 90s 8 Leg &amp; trunk strength</td>
</tr>
<tr>
<td>2b Cable chop</td>
<td>3 6</td>
</tr>
<tr>
<td>3 BB RDL / BB hip thrust</td>
<td>4 5 90s 8 Leg &amp; trunk strength</td>
</tr>
</tbody>
</table>

**Trunk (Static) RFD**

| 1 MB rotary wall rebound throw’s | Set 2 Rep 10 Rest 60s N/A Trunk power (dynamic & static RFD) |
| 2 MB seated wall rebound OH throw’s | 3 6 60s N/A Trunk power (dynamic & static RFD) |
| 3 MB hinge wall rebound throw’s | 3 20s 60s N/A Trunk stiffness |
| 4 Partner feed kneeling slams | 2 5 60s N/A Trunk power (dynamic & static RFD) |
| 5 Partner feed ploy russian twist | 2 5 60s N/A Trunk power (dynamic & static RFD) |
| 5 Suitcase carry | 2 20m 60s N/A Trunk stiffness |
| 6 Side hold w/ plate press | 2 20s 60s N/A Trunk stiffness |

**'Pillar' work capacity**

| 1 MB dish sit | Set 2 TUT 60s 60s N/A ↑ metabolic capacity of anterior trunk musculature |
| 2 Banded lateral bear crawl | 2 60s 60s N/A ↑ metabolic capacity of trunk/hip musculature |
| 3 Asymmetric shoulder raise / palloff walkout | 2 60s 60s N/A ↑ metabolic capacity of anterior trunk /rotation muscle |
| 4 Weighted back extensions | 2 60s 60s N/A ↑ metabolic capacity of posterior trunk musculature |

**DB = dumbbell, RFD = rate of force development, w/ = with, BB = barbell, MB = medicine ball, OH = overhead, RPE = rate of perceived exertion, TUT = time under tension**

**PHASE 3: RECONDITIONING**

Reconditioning involved a more aggressive pursuit of the objectives outlined in the previous phase having now established greater load tolerance. This allowed for a natural transition to a performance orientated S&C program addressing the subject’s broader athletic development needs while maintaining an emphasis on the development of trunk function. Specifically, this saw a progression from control and work capacity to strength, power and stiffness development (see Figure 3). Again, for full definitions of these physical qualities the reader is directed to Spencer et al.50

This phase was split broadly into two with an initial ‘accumulation’ and an ‘intensification block’, a training organization concept borrowed from Issurin51 where increased capacity in the former prepares the athlete for the intensity in the latter. The initial accumulation phase progressed linearly from moderate to fairly high volumes of work centred around four focus compound lifts – Split Squat, Romanian Deadlift, Barbell Hip Thrust and Trap-Bar Deadlift. Using high-moderate rep-ranges and low to moderate loads initially allowed the subject to become competent and develop coordination in these exercises while increasing their work capacity and stimulating muscle hypertrophy. Focus exercises were generally paired with a stability challenge or a trunk strength exercises and followed by a medicine ball circuit tailored towards trunk stiffness and maintenance of work capacity (Table 3). Coach collaboration remained of utmost importance during this accumulation phase as the subject was allowed to return to some wedge play (half back-swing length). Both the athlete and the coach were responsible for monitoring his golf volumes which started at 40 and progressed to 100 swings (wedges) per week.
Table 4: Rate of perceived exertion (RPE)

<table>
<thead>
<tr>
<th>RPE</th>
<th>REPS IN RESERVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>ALL OUT, I HAD NOTHING LEFT</td>
</tr>
<tr>
<td>9</td>
<td>1 REP LEFT IN THE TANK</td>
</tr>
<tr>
<td>8</td>
<td>2 REPS LEFT IN THE TANK</td>
</tr>
<tr>
<td>7</td>
<td>3 REPS LEFT IN THE TANK</td>
</tr>
<tr>
<td>6</td>
<td>4 REPS LEFT IN THE TANK</td>
</tr>
<tr>
<td>5</td>
<td>5 REPS LEFT IN THE TANK</td>
</tr>
</tbody>
</table>

Following this extensive (12-week) accumulation period the case began an intensification block consisting of moderate-low volumes (3-5 repetitions) of increasing intensities on the focus exercises to drive greater increases in maximal strength (Table 3). An autoregulatory system was used to intensify training throughout the block. This involved assigning a RPE (e.g. 7/10) to each exercise so that the athlete could select a weight that corresponded with that effort level on the specific time/day of the training session. Some studies have found this to produce better training outcomes than fixed loading parameters based on percentage repetition maximums as it possibly yields a higher rate of progressive overload. Table 4 shows a resource given to the athlete to ensure their understanding of RPE where perceived effort ratings were linked to ‘repetitions in reserve’.

PHASE 4: GRADED RETURN TO GOLF (GRTG) PROTOCOL

Although the athlete had now been subjected to considerable gym training-load, the principle of specificity applies to load tolerance and therefore it was deemed essential to graduate return to pre-injury golf volumes to minimise the chances of relapse/re-entering injury. Moreover, given that the athlete had made a significant swing change, this would have been important regardless of injury history as different movement strategies alter degree of structural loading at specific anatomical sites. The basic principle of the graded return to golf (GRTG) program was to change only one variable at a time. For instance, when increasing intensity (guided by length of backswing or % max club head speed), no changes were made to number of swings per week. Table 5 shows the first four weeks of the return to golf protocol; beginning with a set number of swings per week initially, before increasing the intensity of those swings (weeks two and three) and then accumulating swings in a given week (week four). This general pattern was repeated until the patient returned to ~75% of their pre-injury typical weekly volume. Chipping and putting practice were allowed on any other day throughout the return but prolonged practice was avoided at any time. Movement breaks (every 10-15mins) were encouraged to avoid prolonged hinging.

OUTCOME

12-months into the rehabilitation program (Jan 2018) the subject had increased his training loads from 40Kg (self-selected RPE 8 load for 8 repetitions) to 110Kg (self-selected RPE 8 load for 5 repetitions) in the Barbell Romanian Deadlift, Barbell Hip Thrust and Trap Bar Deadlift, evidencing large increases in strength and gym-based load tolerance. Moreover, time to failure in the isometric ‘pillar’ trunk exercises had increased from between 47s-77s to consistently in excess of 120s across all four quadrants (double leg lower, side plank left and right side, prone extension) demonstrating large increases in work capacity. Basic motion analysis undertaken by the golf coach revealed reduced spinal lateral flexion and extension post impact. On one occasion during the reconditioning (intensification) phase the subject experienced a relapse of symptoms (pain/spasm/guarding response). The athlete was reassured (that this was to be expected) and returned to the beginning of the accumulation block and a maximum of 40 wedge half-swings per week to temporarily reduce intensity. Review 18-months post-intervention showed no signs of further inter-vertebral slippage, and the athlete remained asymptomatic despite return to pre-injury golf volumes. In April 2019 the athlete accepted a golf scholarship at a US college.
## Table 5: Graded Return to Golf (GRTG) Protocol

### Week 1:
- **Monday:** Wedge play (half swing @ 75-85%) - 40 balls
- **Wednesday:** 7/8 iron play (half swing @ 75-85%) - 40 balls
- **Friday:** Wedge play (half swing @ 75-85%) - 40 balls
- **Total:** 120 balls

### Week 2:
- **Monday:** Wedge play (3/4 swing @ 75-85%) - 40 balls
- **Wednesday:** Mid-iron (3/4 swing @ 75-85%) 40 balls
- **Friday:** Par 3 ~10-12 holes
- **Total:** ~120 balls

### Week 3:
- **Monday:** Wedges and/or mid-iron (full swing – 80-95%) - 50 balls
- **Wednesday:** Long Iron / Wood / Driver (full swing – 80-90%) - 20 balls
- **Monday:** Par 3 course ~12-15 holes
- **Total:** ~120 balls

### Week 4:
- **Monday:** Wedge play (full swing – 80-90%) - 40 balls or Par 3 course ~10-12 holes
- **Wednesday:** Long Iron / Wood / Driver (full swing – 80-90%) - 40 balls
- **Friday:** Par 3 course ~18 holes
- **Total:** ~150 balls

% of intensity guided by length of backswing and % of max club head speed  
e.g. half swing @ 75 - 85% swing speed.

### DISCUSSION

Thus far each of the rehabilitation phases and their respective objectives have been described largely in structural terms. Although sound structurally focused mechanistic reasoning is likely to improve the manner in which interventions are designed and delivered, it is important to recognize that an observed physical change (i.e. work capacity, mobility, strength) is not necessarily due to these mechanisms alone. The existing literature supports the findings herein; that exercise-based interventions are more efficacious than many popular physical therapy alternatives (e.g. manual therapy, acupuncture etc). Indeed, in this case ‘therapy’ without the use of exercise proved consistently ineffective whereas when exercise was introduced the athlete improved. However, it is likely that the underpinning mechanisms for this are more general and grounded in neuropsychophysical and a biopsychosocial model. This model would attribute the athlete's observed reductions in symptoms and increased load tolerance herein to reductions in catastrophising and fear avoidance behaviours, and improved self-efficacy. It is thought this ultimately leads to reductions in pain as it delivers greater movement confidence and positively reinforces physical activity. This in turn promotes recovery through a number of proposed mechanisms: 1) reassurance through reduced perceived threat and decreased sensitisation through neuromodulation, 2) mechanotransduction, 3) reduced nociceptor activity, and 4) improved immune response through increases in anti-inflammatory cytokines. Therefore if we consider the phase by phase outcomes of the rehabilitation program mechanistically, the progression of hip hinging may have acted as a form of graded exposure (progressing the ROM, time under tension, net volume or intensity in line with the athlete's pain or apprehension), or the positive response could be attributed to mechanotransduction and associated tissue repair in line with principles of mechanotherapy in response to loading the approximate region.  

Realistically more than one mechanism is likely responsible for the successful outcome, for instance early graded exposure dampened the highly sensitive pain/apprehension response and the graded activity of the reconditioning program provided the subject with the necessary physical capacities to stabilise and support the spine. There has been much debate within the last two decades around the structurally-focused rationale for enhancing trunk muscle function to support spinal stability, recently outlined in the thorough critical review by Wirth and colleagues. In particular the common categorising of the trunk musculature into "deep" and "superficial" has been challenged. Further, the view of increased activity of the "deep" muscles (i.e. transverse abdominis) being critical for spinal stability,
and the notion that these muscles are best or only achieved with low-load tasks, has been debunked. In some ways this challenges the trunk training strategy (Figure 3) deployed herein - prioritising control exercises in phase 1, however when we again consider the biopsychosocial model, starting the rehabilitation program with lower-load exercises would be viewed sensible graded activity. Perhaps in light of this research it could be argued that beyond the acute and sub-acute phases the micro-program was of little added value in structural terms. However, it did likely remain a helpful break and local muscle fatigue management strategy during putting practices.

Another probable key factor allowing the subject to return to pre-injury golf volumes was the technical changes shaped by the golf coach, which ultimately reduced the demand on the spinal stabilisers. Indeed, McCarroll et al. identified degree of lateral spinal flexion as an indicator of lumbar spine stress in the golf swing so a reduction in lateral shear forces is a plausible explanation for the athlete's newfound tolerance to the game. It is also probable that education of the athlete throughout the process, specifically around load management was important in his ability to sustain ongoing participation in the sport.

CONCLUSION

Regardless of underpinning mechanisms, this case report highlights the benefits of a graded program of exercise-based rehabilitation over the typically prescribed "12 weeks rest" prior to a return to the provocative activity. It also supports existing evidence that passive therapeutic approaches should only be used as an adjunct to exercise, if at all, in the management of this condition. Recovery from spondyloysis can be a long and slow process, in this case a program of exercise rehabilitation with clear objectives and milestones had a positive effect on recovery whereas previous periods of rest and passive therapy alone had not facilitated a successful return to golf. It is therefore stressed that to deem a non-surgical rehabilitation 'unsuccessful' or 'failed' in the management of this condition, clinicians should ensure that (long-term) exercise was included in the conservative approach. In this case having the patience and diligence to adhere to such an approach avoided a surgical intervention which aside from being a major life stress, may well have prevented further participation in golf and made his scholarship offer unlikely.

CONFLICTS OF INTEREST

The authors report no conflicts of interest

Submitted: June 10, 2020 CST, Accepted: October 03, 2020 CST

This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY-NC-ND-4.0). View this license's legal deed at https://creativecommons.org/licenses/by-nc-nd/4.0 and legal code at https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode for more information.
REFERENCES


Case Reports

The Utility of Neuromotor Retraining to Augment Manual Therapy and Vestibular Rehabilitation in a Patient with Post-Concussion Syndrome: A Case Report

Andrew Teare-Ketter, PT, DPT¹, Alyssa LaForme Fiss, PT, PhD², Jeffrey Ebert, PT, DPT³

¹ Department of Physical Therapy, Mercer University, Atlanta, GA, USA; Division of Sports Medicine, Department of Physical Therapy and Rehabilitation, Floyd Medical Center, Rome, GA, USA, ² School of Physical Therapy, Texas Women’s University, ³ Department of Physical Therapy, Mercer University, Atlanta, GA, USA

Keywords: vestibular rehabilitation, post-concussion syndrome, movement system, concussion, cervicogenic

Background and Purpose

Less than half of patients discharged from the emergency department post-concussion receive patient education or follow-up care, and 10-20% of individuals will develop symptoms that last longer than six months. Current research on interventions for post-concussion syndrome (PCS) shows inconsistent results, and recommendations for effective physical therapy treatment for patients with chronic PCS are lacking. The purpose of this case report is to highlight a successful, multi-system approach to physical therapy examination and treatment of a patient with chronic PCS.

Case Description

This case describes a 21-year-old male who sustained a concussion 356 days prior to evaluation. He received no follow-up treatment and reported periods of worsening symptoms since the injury. Impairments in cervical range of motion and accessory mobility, vestibular and vestibulo-ocular function, and postural stability were identified. Both cognitive and emotional symptoms were also present. The patient attended eight, sixty-minute sessions over a five-week period in an outpatient setting. Comprehensive physical therapy interventions included manual therapy, vestibular rehabilitation, and neuromotor retraining aimed at restoring proper sensory integration and midline postural orientation.

Outcomes

Outcomes included cervical spine goniometric measurements and accessory mobility assessments. Objective measures of postural stability included the Modified Clinical Test of Sensory Interaction in Balance (m-CTSIB) and the Fukuda Step Test. The Rivermead Post-Concussion Symptoms Questionnaire (RPQ) was used to subjectively assess symptom severity. At discharge, goniometric measurements returned to within normal limits except left cervical rotation active range of motion (ROM), and both the m-CTSIB and Fukuda Step Test were within normal ranges. The RPQ score reduced from 20 to 2 demonstrating symptom resolution in all items but "headache."

Discussion

PCS can affect multiple systems, necessitating a comprehensive approach to examination and intervention. Manual therapy was used to restore cervical spine ROM, vestibular rehabilitation was utilized to improve gaze stability and visual motion sensitivity, and neuromotor retraining was implemented to improve postural stability and sensory integration. Physical therapists have the ability to treat multiple systems impacted with PCS, with the potential to reduce the longevity and severity of impairments for patients.
Level of Evidence

BACKGROUND

Concussions, or mild traumatic brain injuries (TBI), have become an important topic in healthcare. Research has emphasized the need for understanding the etiology of concussions and the long-term effects concussions can have both cognitively and physically. The notion of a disorder associated with post-concussive symptoms was once controversial, but recent research and the increasing prevalence in professional athletes, collegiate and high school athletes, and the general population has led to the acceptance of a Post-Concussion Syndrome (PCS). Concussions and PCS are not exclusive to athletes as all individuals are susceptible to mild brain injuries and the lasting impairments that can be associated with such injuries.

In the United States, there are over two million TBI-related emergency department visits each year, and mild TBIs account for 80-90% of all TBIs. There are between 1.7 and 3 million sport-related concussions annually, and 20-50% of individuals with a mild TBI will have symptoms that last longer than three months. Approximately, 22% of individuals with mild TBIs are functionally impaired after one year; however, any degree of brain trauma can create lasting cognitive, emotional, and/or physical detriments that can impair an individual's functional capabilities. Although protocols have been enacted with athletic evaluations, less than half of all individuals who report to an emergency department after a mild TBI receive any form of education on symptomology and medical management, or are instructed to visit a medical professional for a follow-up appointment within three months. Furthermore, a study by Vargo et al. has shown that referrals to physical therapy post-concussion are not yet common; only 28% of patients were referred to physical therapy from a concussion clinic within an academic medical center, although many patients may benefit from rehabilitation during recovery. This lack of follow-up care may increase the risk of prolonged symptoms after the initial injury.

Risk factors for prolonged recovery may include loss of consciousness at time of injury, dizziness at time of injury, amnesia surrounding time of injury, migraine symptoms acutely after initial injury, severity of acute symptoms, delayed symptom onset, history of previous concussions, or a history of psychological considerations. In 70-90% of concussions, symptoms resolve within two weeks, and the majority of physiologic symptoms resolve within seven to ten days. The standardized definitions of PCS by the International Classification of Diseases (ICD-10) as well as the Diagnostics and Statistics Manual (DSM-IV) demonstrate poor specificity and include symptoms often demonstrated with other neurologic disorders such as migraine and depression. To meet the criteria for PCS as defined by the DSM-IV, the patient must demonstrate symptoms longer than three months. These shortcomings related to diagnosis can further delay the identification of PCS.

The ICD-10 defines PCS as the presence of three or more of the following symptoms within the first month post-injury: headache, dizziness, fatigue, irritability, insomnia, and concentration or memory difficulty. The DSM-IV defines PCS as cognitive deficits in attention or memory and at least three or more symptoms including: headache, dizziness, fatigue, irritability, apathy, personality change, or sleep or affective disturbance. Symptoms of concussions can vary in presentation, intensity, and duration depending on the systems disrupted by the initial injury. Symptoms can have a neurologic, vestibular, or musculoskeletal origin or concurrent dysfunction among these systems.

Neurologically, there is a disruption of cerebral blood flow, ionic homeostasis, and axonal health within the cerebrum at the time of injury, all of which lead to a decrease of consciousness and amnesia. Persistent disruption in neuronal depolarization and metabolism and in cerebrovascular function can manifest as headaches at rest, light and sound sensitivity, irritability, and fatigue. There can also be autonomic disruption that can manifest as abnormal vital sign responses such as hypotension and/or elevated heart rate at rest and with exertion, and low symptom threshold with physical activity.

Authors have suggested that dizziness and disequilibrium experienced in patients with a TBI can be caused by vestibular pathology 40-60% of the time. Decreased gaze stability and postural stability experienced with an acute concussion also can be caused by vestibular involvement. Central vestibular dysfunction predominates the majority of concussions; however, peripheral vestibular dysfunction can also be present. The most common peripheral vestibular pathology post-concussion is Benign Paroxysmal Positional Vertigo (BPPV). A labyrinthine concussion, which is a term used to describe peripheral vestibular dysfunction following head trauma, can also be present. Damage to the labyrinthine system can progress to unilateral vestibular hypofunction (UVH) and eventually to chronic unilateral vestibular hypofunction, if not compensated or addressed. Chronic UVH can produce many of the symptoms of concussions and PCS such as dizziness, disequilibrium, postural instability, motion sensitivity, diplopia, nausea and vomiting, and headaches associated with complex visuospatial environments.

There is also evidence describing the role of the cervical spine in post-concussion symptoms and PCS. Forces similar to those sustained with whiplash-associated injuries are often concurrent with mild TBIs and are frequently overlooked. Damage to the zygapophyseal and intervertebral joints and to the soft tissues of the region, particularly the upper cervical spine, can disrupt the large role the cervical spine has in proprioceptive input to the brain. This dysfunction can create cervicogenic headaches and muscular tension, impair postural stability and spatial orientation, and alter oculomotor control. Authors have suggested that symptoms of PCS persisting beyond three months are often of musculoskeletal origin. These findings stress the importance of identifying and treating impairments associated with the cervical spine and highlight the region's influence on symptomology. Additionally, authors suggest a positive correlation exists between emotional and physi-
cal symptoms, indicating that persistent emotional symptoms, commonly associated with neurological dysfunction, can be increased by persistent vestibular and musculoskeletal dysfunction.

A systematic review by Brolinson on sport-related concussion management concluded that many of the studied treatment strategies are inconsistent and do not yet have enough scientific support for adoption as a standard treatment protocol. The most promising evidence demonstrates that individualized physical therapy consisting of manual therapy and sensorimotor retraining can aid in improving return to sport outcomes in patients with PCS when compared to graded aerobic exercise and rest. However, the literature lacks studies that demonstrate successful interventions in patients with multiple system involvement, or the utility of physical therapy as a primary intervention. Therefore, the purpose of this case report is to highlight a successful, multi-system approach to physical therapy examination and treatment of a patient with chronic PCS.

CASE DESCRIPTION: SUBJECT HISTORY AND SYSTEMS REVIEW

The subject described in this case report is a 21-year-old male who suffered a concussion 356 days prior to the physical therapy evaluation. The injury occurred during a fall out of a moving golf cart onto his left shoulder/neck region. The subject reported loss of consciousness and post-traumatic amnesia following the injury. The subject was taken to a local emergency department and CT scan results appeared negative for cerebral bleeding but identified a left temporal bone fracture not requiring medical intervention. The subject received no education on symptomology or symptom duration, and no referral or follow-up was scheduled at the time of discharge. The subject reported a history of four previous concussions, three of which were sport-related, but otherwise had no co-morbidities or significant past medical history. Only minor residual symptoms from his previous concussions were reported that all gradually resolved. The subject had constant, persistent symptoms since the injury that impaired his abilities in school as well as his social life and had restricted athletic or recreational activities, reducing his overall quality of life. The subject visited his primary physician a few weeks prior to evaluation; his cervical spine was cleared via radiographs, and he was referred to a metropolitan outpatient physical therapy clinic.

The subject was given the Rivermead Post-Concussion Questionnaire (RPQ) to assess symptomology. The RPQ is a subjective, self-report measure that encompasses 16 items, each of which is scored from 0-4 in increasing severity, assessing separate cognitive, emotional, and somatic physical factors. The RPQ demonstrates high test-retest and inter-rater reliability for both total score and individual items via spearman rank correlation coefficients \((r = 0.91, r = 0.87)\) respectively. The subject’s chief reported symptoms during the initial evaluation were neck pain and stiffness, bilateral radicular symptoms that were worse in the left shoulder and upper extremity, lightheadedness, nausea, dizziness, blurred vision and diplopia, sensitivity to light, impaired balance, slurred speech, trouble sleeping, fatigue, slower thinking, and frustration. The subject’s primary complaint was his headache symptoms, which the subject reported were brought on by reading, scanning, driving, or cervical movements. The subject also reported a period of gradual worsening during the weeks and months following his injury. The subject’s goals for physical therapy were to reduce the severity of symptoms experienced since the injury, primarily concerning his headache, fatigue, and neck pain symptomology, as he reported these symptoms have impacted his abilities as a college student and decreased his participation in his social life.

The subject described in this case report provided informed consent for the study and was informed that the data collected would be used for publication. This study has been approved by the Mercer University Institutional Review Board and Office of Research Compliance. The primary author providing patient care and clinical decision making was a student physical therapist at the time of subject interaction and was supervised by a licensed physical therapist.

CLINICAL IMPRESSION #1

The subject’s mechanism of injury, with loss of consciousness and amnesia, but lack of intracranial bleeding, suggests that the subject sustained a mild traumatic brain injury or concussion. This along with other neurologic, vestibular, and musculoskeletal symptoms, and his past medical history of multiple concussions, indicated a high probability for PCS. The mechanism of injury of a fall onto the neck/shoulder region increases the likelihood of trauma to the cervical spine and/or peripheral vestibular system. The subject’s headache symptoms likely indicate a vestibular or cervicogenic origin as his symptoms worsened with periods of reading, scanning, or cervical movements rather than with exercise or at rest. It was hypothesized that the subject would have impairments in cervical spine accessory and soft tissue mobility, range of motion (ROM), vestibular function including vestibular-ocular reflex and gaze stability, balance and somatosensory input, and posture. Due to the chronicity of the subject’s condition and multi-system involvement, physical therapy examination and intervention targeting multiple systems was warranted.

EXAMINATION

A cardiovascular systems review indicated normal vital signs. Assessment of the subject’s static posture (Figure 1) demonstrated a right lateral side bend of his cervical spine of 7 degrees, with an associated shift of the trunk to the left. As a result, there was significant asymmetry of cervical and thoracic soft tissue. Bilateral upper trapezius and sternocleidomastoid musculature were hypertrophied, with the left upper trapezius, left sternocleidomastoid, and left levator scapulae being more prominent. His right shoulder demonstrated abnormal elevation, and his right upper extremity and scapula had increased relative abduction that was also present with functional movements. He demonstrated forward head posture and left scapular protraction with slight trunk rotation to the right.
Table 1: Cervical goniometric range of motion assessment at both initial evaluation and discharge, reported in degrees. Measurement reflects both active and passive range of motion as identical measurements were obtained.

<table>
<thead>
<tr>
<th>Motion</th>
<th>Normal</th>
<th>Initial Evaluation</th>
<th>Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td>45</td>
<td>56</td>
<td>70</td>
</tr>
<tr>
<td>Extension</td>
<td>45</td>
<td>40</td>
<td>52</td>
</tr>
<tr>
<td>Right Rotation</td>
<td>70</td>
<td>44</td>
<td>73</td>
</tr>
<tr>
<td>Left Rotation</td>
<td>70</td>
<td>56</td>
<td>63</td>
</tr>
<tr>
<td>Right Sidebend</td>
<td>45</td>
<td>39</td>
<td>55</td>
</tr>
<tr>
<td>Left Sidebend</td>
<td>45</td>
<td>40</td>
<td>52</td>
</tr>
</tbody>
</table>

Table 2: Joint accessory mobility assessments at initial evaluation and discharge.

<table>
<thead>
<tr>
<th>Location</th>
<th>Initial Evaluation</th>
<th>Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CPA</td>
<td>UPA</td>
</tr>
<tr>
<td>C1-C2</td>
<td>Early capsular end feel</td>
<td>Early capsular end feel, pain (L&gt;R)</td>
</tr>
<tr>
<td>C2-C3</td>
<td>Early capsular end feel, pain</td>
<td>Early capsular end feel, pain (L&gt;R)</td>
</tr>
<tr>
<td>C3-C4</td>
<td>Early capsular end feel, pain</td>
<td>Early capsular end feel, pain (L&gt;R)</td>
</tr>
<tr>
<td>C4-C5</td>
<td>Early capsular end feel, pain</td>
<td>Early capsular end feel, pain (L&gt;R)</td>
</tr>
<tr>
<td>C5-C6</td>
<td>Early capsular end feel, pain</td>
<td>Early capsular end feel, pain (L&gt;R)</td>
</tr>
<tr>
<td>C6-C7</td>
<td>Early capsular end feel, pain</td>
<td>Early capsular end feel, pain (L&gt;R)</td>
</tr>
</tbody>
</table>

CPA: Central posterior-anterior mobilization; UPA: Unilateral posterior-anterior mobilization

Upon palpation, tenderness, hypertrophy, and myofascial trigger points were discovered throughout his cervical and thoracic musculature with greater dysfunction on the left than the right. Both active and passive cervical ROM were assessed, and identical measurements were obtained. (Table 1). The subject reported pain and tightness with all cervical active and passive motions, with an increase in headache pain with repeated cervical movements into extension. All ROM measurements, except flexion, were below normal. Repeated cervical motions recreated numbness and tingling in his left upper extremity extending down to the second and third digits, as well as decreased sensation. Spurling’s tests and cervical compression test were negative. Bilateral shoulder AROM tested within normal limits.

Unilateral posterior-anterior mobilizations (UPAs) of the cervical spine revealed decreased available range of movement with an early capsular end feel throughout all levels, with more restriction assessed in segments C1–C3. Increased restriction and pain was identified on the left compared to the right. Central posterior-anterior mobilizations (CPAs) of the cervical intervertebral joints also revealed decreased available range of movement with an early capsular end feel and pain throughout all levels. (Table 2). Assessment of central posterior-anterior mobilizations of the upper and middle thoracic intervertebral joints in prone identified decreased available range as well. Increased available range and pain were assessed at T6, with hypermobility identified. This segment also demonstrated increased motion with thoracic active extension. Reduced available range and pain with first rib depression also assessed on the left. The subject’s dizziness was not position-dependent and could last several minutes to hours in duration. Due to these subjective reports and time since onset, BPPV was not suspected; rather, UVH was hypothesized and a positional assessment was deferred. Tests of vestibulo-ocular reflex (VOR) gain reproduced the subject’s symptoms of nausea, dizziness, and disequilibrium, and no nystagmus or saccadic intrusions were observed with ocular movements. A formal vestibulo-ocular motor screening (VOMS) or test of Dynamic Visual Acuity (DVA) were not performed which are considered limitations of this report. A VOMS incor-
Table 3: Outcome measures at initial evaluation and discharge. Outcome measures include the Fukuda Step Test, Modified Clinical Test of Sensory Interaction in Balance, and the Rivermead Post Concussion Questionnaire.

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Initial Evaluation</th>
<th>Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>70° Rotation to Left</td>
<td>20° to Left</td>
</tr>
<tr>
<td><strong>Fukuda Step Test</strong>&lt;sup&gt;*&lt;/sup&gt;</td>
<td>EO: 3</td>
<td>EO: 3</td>
</tr>
<tr>
<td>M-CTSIB</td>
<td>EC: 2</td>
<td>EC: 3</td>
</tr>
<tr>
<td></td>
<td>EOF: 3</td>
<td>EOF: 3</td>
</tr>
<tr>
<td></td>
<td>ECF: 2</td>
<td>ECF: 3</td>
</tr>
<tr>
<td><strong>RPQ†</strong></td>
<td>20/64</td>
<td>2/64</td>
</tr>
</tbody>
</table>

<sup>*</sup> <45° normal result for Fukuda Step Test
<sup>†</sup> ≥16 on RPQ indicative of post-concussion syndrome

EO: Eyes open; EC: Eyes closed; EOF: Eyes open firm surface; ECF: Eyes closed firm surface;
M-CTSIB: Modified Clinical Test of Sensory Integration in Balance; RPQ: Rivermead Post-Concussion Questionnaire

porates testing of smooth pursuit, saccades, convergence, VOR, and visual motion sensitivity and has demonstrated internal consistency and sensitivity in identifying concussions. DVA would have aided in quantifying and measuring impairment in gaze stability and should be included in the evaluation of similar patients.

The subject’s postural stability and sensory organization were assessed using the Fukuda Step Test and the Modified Clinical Test of Sensory Integration in Balance (m-CTSIB). The Fukuda Step Test has not been shown to identify the side of a potential vestibular lesion, and the test-retest reliability should be interpreted with caution; therefore, more than one balance assessment was selected. However, this test is commonly used to screen for postural instability and vestibular dysfunction, as it is easily accessible and reproducible within a clinical setting. The subject demonstrated a 70-degree turn to the left, an abnormal response is a turn in either direction greater than 45 degrees.

The m-CTSIB is a shorted version of the original six-item CTSIB and is utilized to assess balance deficits and sensory organization. The original CTSIB has demonstrated good test-retest reliability and has demonstrated moderate correlation with the Sensory Organization Test (SOT) to determine sensory-related postural instability. The m-CTSIB is a 30-second test of independent standing scored on an ordinal scale based time and sway for four progressively difficult balance conditions: EO (eyes open, firm surface), EC (eyes closed, firm surface), EOF (eyes open, foam surface), ECF (eyes closed, foam surface). The scale ranges from 0–3 (0=unable, 1=fall <30s, 2=unstable, 3=stable for 30s). The differing sensory conditions investigate postural stability with varying visual and/or somatosensory input. The subject was able to maintain balance with EO for 30 seconds, but could not maintain postural stability with EC and ECF. This indicates the subject relied more heavily on somatosensory and visual feedback to maintain postural stability. The results are listed in Table 3.

Upon item analysis of the Rivermead Post-Concussion Questionnaire, the subject’s condition could be categorized as encompassing both vestibulo-ocular and cervicogenic involvement. A recent study determined a cutoff score with patients experiencing prolonged symptoms (at least six months post-mild TBI) that demonstrated high diagnostic accuracy of PCS as 16 or above. The subject scored a 20 during the initial evaluation, indicating a strong likelihood of PCS as the source of his symptoms.

**CLINICAL IMPRESSION #2**

The subject examination revealed impairments that coincide with vestibular and musculoskeletal driven PCS. Limitations in cervical ROM, accessory mobility, and soft tissue extensibility were discovered. Asymmetric soft tissue hypertrophy and a myofascial trigger points on the subject’s left indicated potential soft tissue dysfunction. It is possible this originated from decreased somatosensory input from the cervical spine, from vestibular dysfunction, or both. The results of the subject’s vestibular exam indicated more peripheral vestibular involvement as impaired VOR gain was assessed and symptomatic, but no nystagmus or saccadic intrusions were identified with ocular movements. The subject’s cervical sidebend at rest could have developed from these impairments or as a result of the initial injury, as either a compensatory offload of an injury to the cervical spine or an asymmetrical neural discharge from the peripheral vestibular system. It is hypothesized that these impairments led to further postural and movement system abnormalities. The subject’s headache symptoms were likely a result of a combination of dysfunctional vestibulo-ocular reflex and cervical muscle tension. The subject’s self-reported tolerance to exercise, lack of headaches at rest, and normal vitals reduced the likelihood of extensive autonomic involvement.

The multi-system involvement supported the need for a comprehensive approach to physical therapy intervention including manual therapy to aid in musculoskeletal tissue health, vestibular rehabilitation, and neuromotor retraining to improve sensory organization and balance and to reinforce optimal system integration. Decreases in pain, headache severity, fatigue, and other subjectively reported symptoms during the subject’s activities of daily living were expected throughout the plan of care. It was also hypoth-
esized that as the subject’s physical symptoms subsided, emotional symptomology would decrease as well due to the positive correlation between the two symptom subgroups. Objective improvements in cervical spine ROM and accessory mobility, a decrease in lightheadedness experienced with gaze stabilization exercises, and improvements in balance assessments were expected with intervention.

**INTERVENTION**

The subject attended an initial evaluation followed by seven 60-minute treatment visits over a five-week period in an outpatient physical therapy clinic. Sessions are outlined in Table 4. The primary approach to treatment was restoring cervical spine ROM and vestibulo-ocular input, all while restoring optimal posture and sensory integration via neuromotor retraining. It was known at the time of the initial evaluation that the subject needed to be discharged from therapy after five weeks in order to return to school full-time. The subject also reported that he would be unable to attend therapy during the second week of the plan of care, prioritizing the need for early reduction of inflammation and irritability, as well as offloading of neural structures, during the initial treatment session. The subject was prescribed a daily home exercise program that included self-stretching of cervical musculature and self-mobilization of the cervical spine. Additionally, gaze stabilization exercises, to be performed multiple times per day, were prescribed.

Each treatment session began with manual therapy targeting asymmetries in cervicothoracic joints and musculature. Techniques included manual traction, central and unilateral posterior-anterior cervical and thoracic joint mobilizations, soft tissue mobilizations, and active and passive stretches with emphasis placed on the hypertrophied regions. Low-velocity mobilizations were performed at all levels and gradually increased by grade and from mid to end range to reduce pain and increase overall available range of movement. Mobilizations were performed in sets of 30 repetitions. Neural glides in the median nerve pattern were also performed with alternating elbow and wrist flexion/extension in sets of 10 until reduction in neural symptoms. Soft tissue stretches were held for 30 seconds for two repetitions.

For therapeutic exercise, the subject was educated on and placed in proper posture in midline orientation with tactile cues. All exercises were performed in front of a mirror.

---

Table 4: Interventions by session including manual therapy, soft tissue mobility, therapeutic exercise, vestibular rehabilitation, and neuromotor retraining.

<table>
<thead>
<tr>
<th>Session</th>
<th>Manual Therapy*</th>
<th>Soft Tissue Stretches†</th>
<th>Therapeutic Exercise‡ Vestibular Rehabilitation§ Neuromotor Retraining**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Evaluation</td>
<td>STM#, cervical and thoracic spine CPAs, cervical spine UPAs, manual traction, median nerve glides</td>
<td>Passive: UT, LS, SCM, scalenes, suboccipitals, pectoralis minor</td>
<td>Scapular retraction, deep cervical flexion</td>
</tr>
<tr>
<td>2</td>
<td>Same as session one; added first rib depression mobilizations</td>
<td>Passive: UT, LS, SCM, scalenes, suboccipitals Self: pectoralis minor, paraspinals</td>
<td>Scapular retraction, deep cervical flexion, cable rows, seated balance on Swiss ball, VORx1, saccades</td>
</tr>
<tr>
<td>3</td>
<td>Same as session 2</td>
<td>Same as session 2</td>
<td>Same as session 2</td>
</tr>
<tr>
<td>4</td>
<td>Same as session 2</td>
<td>Self: UT, LS, SCM, scalenes, suboccipitals, pectoralis minor paraspinals</td>
<td>Scapular retraction, deep cervical flexion, cable rows, cable pull downs, VORx1 and saccades w/laser Harness**</td>
</tr>
<tr>
<td>5-8</td>
<td>STM, cervical and thoracic CPAs, cervical UPAs, manual traction, first rib mobilizations</td>
<td>Same as session 4</td>
<td>Same as session 4</td>
</tr>
<tr>
<td>Home Exercise Program</td>
<td>Self-UPAs with towel throughout cervical spine, 3x30 in sitting</td>
<td>Same as session 4</td>
<td>VORx1 to onset of symptoms, 5x/day</td>
</tr>
</tbody>
</table>

*Mobilizations progressed from grades I-III to grades III-IV, performed on all hypomobile cervical and thoracic segments for three sets of 30 repetitions; neural glides performed in three sets of 10 or to reduction of symptoms after mobilizations
†Soft tissue stretches performed in two sets with 30 second hold
‡Therapeutic exercises performed for three sets of 10, 15, or 20 repetitions depending on rate of fatigue
§Vestibular exercises included VORx1 and saccades with head movements and performed in sets of three to onset of dizziness or headache
**Neuromotor retraining included performance of VORx1 and saccades with head movements while wearing laser harness, in sitting, for three sets of one minute or until onset of dizziness or headache; harness placed above ears and around trunk for sagittal plane alignment, mirror placed in front for self-correction
#Soft tissue mobilization to cervical and thoracic musculature included multidirectional petrissage or trigger point release to bilateral UT, LS, SCM, suboccipitals, and longus colli depending on pain and tissue extensibility

STM: Soft tissue mobilization; CPA: Central posterior-anterior mobilization; UPA: Unilateral posterior anterior mobilization; UT: Upper trapezius; LS: Levator scapulae; SCM: Sternocleidomastoid; VOR: Vestibulo-ocular reflex
ror for increased positional awareness and to aid in restoring the afferent ability of the cervical and thoracic spine. Several exercises incorporated a two-sided cable system for further neuromotor input to aid in symmetrical movement patterns and postural stability. Each exercise was performed in sets of 10, 15, or 20 repetitions on the subject’s rate of fatigue, in order to improve postural endurance but promote proper orientation. VOR exercises, saccadic exercises in conjunction with head movements, and habituation exercises were performed as it has been shown that vestibular substitution, adaptation, and habituation significantly reduce symptomology and improve function in patients with uncompensated UVH.12

Beginning with session 4 and performed for the remainder of the POC, the subject participated in neuromotor retraining exercises while wearing a laser system (Figure 2) to integrate improved vestibular and somatosensory function. The four-laser harness system symmetrically placed lasers above each ear and around the thorax at the level of the 12th ribs. The system gave the subject feedback regarding sagittal plane alignment for both the trunk and head, with a mirror placed in front of the subject for self-correction. By actively aligning the lasers horizontally, the subject was able to re-associate afferent input from cervical and thoracic regions and vestibular system with symmetrical alignment, emphasizing system interaction in optimal positioning.

The subject performed VORx1, with eyes on fixed target and head rotating side to side, for vestibular adaptation of the vestibular-ocular reflex. The subject would then perform saccadic exercises in conjunction with head movements for substitution and compensation of the central nervous system for the disruption in VOR gain. The subject would do this by moving eyes from one target to another with head fixed then moving head to follow with eyes fixed. This also encouraged utilization of improved cervical ROM while restoring the cervical spine’s role on the ocular and somatosensory systems. All exercises were performed for at least three sets and to onset of dizziness to aid in habituation of visual motion sensitivity, but not performed past onset of dizziness to aid in pacing and prevention of prolonged symptom exacerbation; however, the APTA CPG recommends at least 20 minutes a day of gaze stabilization exercises for chronic UVH.12

Each session concluded with 15 minutes of heat and interferential current (IFC) electrical stimulation applied predominantly on the hypomobile and hypertrophied side of the cervical spine for pain reduction.

OUTCOMES

At the beginning of each session, the subject was reassessed subjectively regarding symptom resolution and objectively via cervical AROM, joint mobility of all cervical levels, median nerve tension, and VOR sensitivity. There was a steady improvement in his condition throughout the plan of care. By session 4, the subject’s radicular symptoms and neck pain had resolved. His lightheadedness, dizziness, visual disturbances, and headaches were reported to have decreased in frequency but were dependent on prolonged activity. At the time of discharge, all of the subject’s symptoms had completely resolved except for his headaches, which were reported as “mild” and “infrequent.” The subject had also discontinued use of his prescription glasses, as he reported no continued diplopia.

The subject demonstrated postural improvements in all planes (Figure 3). His cervical musculature appeared to have more symmetrical definition and his forward head posture was reduced. His resting cervical lateral flexion had decreased from 7 degrees to 2 degrees and there was a significant reduction in hypertrophy of the paraspinals throughout the cervical and thoracic spine. The subject demonstrated improved scapular position and improved scapular upward rotation with overhead movements. The upper extremities also rested in a more natural position. Despite these notable postural improvements, he continued to demonstrate some postural asymmetries at discharge, most notably slight left shoulder elevation and right pelvic elevation. Ideally, his postural progression would have continued during a longer plan of care; however, the subject’s symptom reduction was the primary goal and was achieved after eight sessions.

The subject’s cervical ROM increased in each plane and returned to normal ranges except for left rotation, and all

Figure 2: Performance of neuromotor training using laser harness.

Figure 3

A: At discharge, anterior postural assessment.
B: At discharge, posterior postural assessment.
C: At discharge, lateral postural assessment.
motions were no longer painful at end-range with no onset of symptoms with repeated motions (Table 1). The subject’s cervical spine accessory mobility normalized bilaterally, with tenderness to palpation only experienced with CPAs at C5–C6 (Table 2). Left first rib mobility also normalized with no tenderness assessed. Increased overall available motion remained with CPAs at T6 but no pain reproduction. Cervical and thoracic myofascial restriction had reduced bilaterally with no tenderness to palpation upon assessment.

The subject’s symptoms of dizziness, nausea, or diplopia could not be recreated with VOR exercises during treatment or at home, and both the Fukuda Step Test and m-CTSIB tested within normal ranges (Table 3). The subject displayed improved balance and postural stability with no recurrence of dizziness, lightheadedness, diplopia, or nausea while performing the Fukuda Step Test or the m-CTSIB. All but one item on the RPQ were reported as resolved, with "headaches" categorized as "mild." The subject chose to continue his home exercise program upon returning to school without physical therapy after discharge.

DISCUSSION

This case report describes the comprehensive physical therapy management of a patient with PCS that had not received any medical follow-up prior to referral for initial evaluation. The subject was almost 12-months post-injury had since experienced symptoms including neck pain, upper extremity radicular symptoms, lightheadedness, dizziness, nausea, diplopia, light sensitivity, impaired balance, slurred speech, trouble thinking, fatigue, and slower thinking.

It was hypothesized that the majority of the subject’s symptoms were the result of damage sustained to the labyrinthine vestibular system and cervical spine that, with lack of medical follow-up, were never identified or addressed. Chronic unilateral hypofunction produces many of the symptoms experienced by the subject such as nausea, dizziness, decreased postural stability and spatial orientation, motion sensitivity, diplopia, and headaches produced by complex visuospatial environments. Upon reflection, it is likely that partially compensated central vestibular dysfunction could also have been present considering the pathophysiology of concussion. Impairments experienced by this subject including nausea and dizziness, impaired postural stability, disrupted VOR, and motion and visual motion sensitivity could have been a result of both central and peripheral pathology. Moving forward, it is important to recognize that treatment for patients with dizziness following head trauma must be planned knowing that the central and peripheral vestibular systems, and the cervical spine can be involved.

Impairments in cervical accessory and soft tissue mobility have been shown to create muscular tension and cervicogenic headaches, as well as decreased somatosensory and positional input to the brain leading to decreased spatial orientation and postural stability. It is suspected that the abnormalities in joint mobility, muscular tension, proprioceptive input, and spatial orientation created the postural deviations and impaired movement patterns displayed by the subject, which had become chronic, and likely drove further dysfunction.

The primary focus of intervention was to restore cervical spine ROM and improve vestibular function. Manual therapy and stretches aided in restoring symmetrical accessory mobility, ROM, and muscular tension. This reduced the subject’s pain, normalized impairments, and reduced the hypermobility assessed in the thoracic spine. Therapeutic exercises strengthened dysfunctional postural musculature and incorporated neuromotor retraining to aid in restoring proper afferent input and functional movement patterns. The success of these interventions reinforces the benefit of individualized spinal manual therapy and sensorimotor input in treating post-concussion syndrome recognized by Brolinson; however, the subject in this case report presented with disruption in both the vestibular and musculoskeletal systems.

Vestibular rehabilitation included adaptation and substitution of the vestibular-ocular reflex, as well as habituation exercises for motion and visual motion sensitivity. VORx1 targeted adaptation and recovery of disrupted VOR gain. Horizontal and vertical saccades in conjunction with head movements was performed to allow an intact central vestibular function to substitute for disrupted VOR gain and increase gaze stability. These vestibulo-ocular exercises and cervical movements were performed to onset of dizziness to aid in the habituation of motion and visual motion sensitivity. As decreased gaze stability and motion and visual sensitivity can be a result of both central and peripheral vestibular pathology, the interventions would have been appropriate for central dysfunction although a peripheral abnormality was hypothesized.

The laser harness system gave the subject increased postural awareness in an attempt to increase somatosensory and proprioceptive input. The visual feedback provided by the lasers improved the vestibular system’s ability to detect, regulate, and maintain position sense. This reduced the subject’s disequilibrium while also restoring the proprioceptive role of the cervical spine. This intervention was selected primarily because the subject displayed both vestibular and musculoskeletal involvement. The exercise allowed rehabilitation of the two systems simultaneously and emphasized neuromotor retraining as the subject was also able to self-correct abnormal movement patterns and regulate proper posture during functional movements.

The reduction in vestibulo-ocular related symptoms and in headaches reported supports the findings stated by the APTA’s clinical practice guideline on unilateral vestibular hypofunction that vestibular adaptation, substitution, and habituation are effective. As the subject’s vestibular and musculoskeletal symptoms reduced throughout the plan of care, so too did the subject’s reported symptoms of trouble sleeping, fatigue, frustration, difficulty concentrating, and slowed thinking, echoing data suggesting that emotional and cognitive symptoms can also be driven by prolonged physical symptoms.

The results of the interventions above demonstrate the importance of a comprehensive approach to evaluation and treatment of a patient with chronic post-concussion syndrome, as well as the efficacy of physical therapy as a referral destination. As discussed, PCS can present with multiple etiologies that can become muddled with chronicity; how-
ever, the subject was successfully evaluated and treated. A plan of care was established with comprehensive interventions targeting multiple systems that, except for infrequent and mild headaches, led to complete resolution of the subject’s symptoms. The subject was almost 12-months post-injury and received no follow-up care after discharge from an ER, highlighting the importance of medical follow-up after concussion. The success of this case also demonstrates that physical therapy can serve as a routine referral destination after more significant brain injury has been ruled out.

Limitations to this study include lack of more sensitive and objective vestibulo-ocular testing, including the VOMS or DVA, to quantify central and peripheral dysfunction and gaze stability. Subjective symptom-specific outcome measures such as the Headache Disability Index, Dizziness Handicap Inventory, or Visual Vestibular Analog Scale could also have been utilized. The use of a graded treadmill test upon initial examination would have aided in assessing the role, or lack thereof, of autonomic involvement in the subject’s condition. Due to the multi-system involvement of PCS, it is difficult to identify an intervention that was most beneficial in this case, which can be considered a limitation; however, the purpose of this case report is to demonstrate a comprehensive, multi-system approach to evaluation and treatment of PCS. Further research is warranted on the use of neuromotor retraining in conjunction with comprehensive interventions in athletes and other types of patients with PCS. Research should also investigate patient outcomes of physical therapy as the primary referral post-injury.

CONCLUSION

The results described in this case report detail a successful comprehensive approach to treating a patient with chronic post-concussion syndrome who reported multiple symptoms and several risk factors for prolonged dysfunction. The subject’s condition demonstrated involvement of multiple systems which necessitated a comprehensive examination and plan of care. Using neuromotor retraining along with manual therapy and vestibular rehabilitation targeted both the musculoskeletal and vestibular systems and aided in restoration of proper function of both systems simultaneously, impacting the overall movement system. Improving posture and correcting movement incoordination as a result of prolonged dysfunction was an important component. This episode of care was beneficial for this subject, even though the subject was almost a year removed from injury, and suggests that physical therapy may be impactful in prolonged recovery from post-concussion syndrome.

CONFLICTS OF INTEREST

All authors disclose no conflicts of interest.

Submitted: December 29, 2019 CST, Accepted: July 24, 2020 CST

This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY-NC-ND-4.0). View this license’s legal deed at https://creativecommons.org/licenses/by-nc-nd/4.0 and legal code at https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode for more information.


The Latarjet procedure with transfer of the coracoid process and its attached conjoint tendon is a well-established surgical technique for the treatment of anterior glenohumeral instability in patients with anteroinferior bone loss and/or high risk for recurrence. Biomechanical and clinical studies have shown excellent results and high rates of return to sports. However, there is an absence of standardized, objective criteria to accurately assess an athlete’s ability to progress through each phase of rehabilitation. Return to sports rehabilitation, progressed by quantitatively measured functional goals, may improve the athlete’s integration back to sports participation. Therefore, the purpose of this clinical commentary is to provide a rehabilitation protocol for the Latarjet procedure, progressing through clearly defined phases, with guidance for safe and effective return to sport. Recommended criteria are highlighted which allows the clinician to progress the patient through each phase appropriately rather than purely following timeframes from surgery. This progression ensures the patient has completed a thorough rehabilitation program that addresses ROM, strength, power, neuromuscular control and a graded return to play.

Level of Evidence: 5

INTRODUCTION AND BACKGROUND

The glenohumeral joint (GHJ) is the most commonly dislocated joint in the body, with over 90% of dislocations occurring anteriorly. GHJ dislocation is especially common in young male athletes, with a high prevalence of 3% per year in this population. The greatest rates occur in contact sports, such as football, ice-hockey, and wrestling, or sports that may involve falls such as skiing, volleyball and gymnastics. In cases of anterior glenoid bone loss of 13.5% or greater, poor clinical outcomes have been reported after soft tissue repair thus indicating a bone augmentation procedure may be necessary in these circumstances. The Latarjet procedure is a possible surgical procedure to treat patients with anterior shoulder instability and accompanied bone loss. It involves transferring the coracoid process and its attached conjoint tendon to the anterior glenoid rim.

Many authors describe excellent clinical outcomes, return to sport rates, and low rates of recurrence after Latarjet. Nonetheless, the Latarjet procedure results in significant distortion in normal anatomy and may be associated with a significant restriction in postoperative range of motion, a result that has been linked with high rates of osteoarthritis. It has been suggested that with early skilled physical therapy these restrictions could be avoided. The purpose of this clinical commentary is to provide a rehabilitation protocol for the Latarjet procedure, progressing through clearly defined phases, with guidance for safe and effective return to sport.

ANATOMY

Unlike the hip joint where the femoral head sits completely in the acetabulum, the humeral head sits on a shallow gle-
noid fossa, with only 30% in contact with the glenoid in various shoulder positions.\textsuperscript{19–21} The GHJ has the highest range of motion of any joint in the human body and relies mainly on soft-tissue stability in the absence of adequate bony coverage. Its biomechanical stability depends on the interaction between static stabilizers and dynamic stabilizers.\textsuperscript{19} Static stabilizers include the articular geometry and congruence of the joint, the glenoid labrum, and the capsuloligamentous complex, which consists of the coraco-humeral ligament, and the superior, middle, and inferior glenohumeral ligaments. Dynamic stabilizers of the GHJ include the scapulothoracic musculature, which include the trapezius, serratus anterior, levator scapulae, rhomboid major, and pectoralis minor, and the rotator cuff muscles, which include the supraspinatus, infraspinatus, teres minor, and subscapularis. The rotator cuff muscles, along with the long head of the biceps increase stability by a process called concavity compression, where muscle contraction forces the articular surfaces of the humerus and glenoid together. The periscapular muscles maintain stability by controlling the position of the scapula during motion of the humerus. Disruption of any of these stabilizers can affect the inherent force couples and compromise stability.\textsuperscript{22} There is an intricate balance between static and dynamic stabilizers in order to provide glenohumeral stability. Rehabilitation principles should focus on maintaining this balance between static and dynamic stabilizers with overall goals of preserving motion and maintaining function and stability.

**BIOMECHANICS**

In 1954, Latarjet first proposed the transfer of the coracoid tip by suggesting that the horizontal limb of the coracoid process be fixed to the anteroinferior margin of the glenoid with a screw.\textsuperscript{23} The success of the intervention can be explained by a combination of effects: Firstly, the conjoint tendon acts as a sling to the inferior subscapularis and anteroinferior capsule when the arm is abducted and externally rotated.\textsuperscript{24} Second, the addition of bone to the glenoid rim increases the anteroposterior (AP) osseous diameter.\textsuperscript{25} Third, the inferior capsule is reinforced with a portion of the coracoacromial ligament.\textsuperscript{24} Cadaveric biomechanical studies have concluded that it is the combination of the bone block, sling, and capsule effect that are helpful in preventing abnormal translation and enhancing stability. Payne et al showed that the combination of the conjoint tendon and coracoid transfer was significantly superior in increasing stability compared to conjoint tendon transfer alone.\textsuperscript{26} Wellman et al. attributed a significant decrease in translation at 60° of abduction to the sling effect or capsular repair as opposed to just the bone block.\textsuperscript{27} Yamamoto et al. evaluated the contribution to stability of the bone block, sling, and capsule repair and concluded that the sling effect provided 76–77% and capsule 25–24% of the stability at the end-range arm position and the sling contributed 51–62% and the bone block 38–49% at the mid-range position.\textsuperscript{28} This is known as the triple blocking effect of the Latarjet procedure, and it should be noted that each portion of the procedure contributes to the overall stability of the GHJ.

**SURGICAL TECHNIQUE**

A standard deltopectoral approach is used to expose the glenohumeral joint and the coracoid process medially. Next, the pectoralis minor is incised off the medial aspect of the coracoid and the coracoacromial ligament is excised off the lateral aspect. Once the coracoid is freed from circumferentially attached soft tissue with preserved conjoint tendon anteriorly, an oscillating saw is utilized to osteotomize the coracoid in a superior to inferior and medial to lateral trajectory. The graft length is on average 25 mm in length. Subsequently, the undersurface of the coracoid is decorticated with a saw, and two drill holes are placed through the coracoid graft.

Next, a subscapularis tendon and capsule split at the junction of the inferior and middle third of the tendon in line with the fibers is performed. Then, a decortication of the anterior aspect of the glenoid neck down to a bleeding bone surface to enhance bone-to-bone healing is done. Two drill holes are established in anterior to posterior direction for later fixation of the coracoid graft to the glenoid. Two 3.5mm screws are used to reduce the coracoid block and construct stability will be confirmed (Figure 1).

**POSTOPERATIVE REHABILITATION**

A successful outcome following Latarjet surgery is a pain-free, stable shoulder that has enough mobility, stability and
strength for a patient's desired level of activity. Additionally, improving function and reducing long-term sequelae is essential.

Literature to support the efficacy of a specific rehabilitation protocol for Latarjet reconstruction is limited. Gaunt et al. developed a consensus rehabilitation guideline following arthroscopic anterior capsulolabral repair and reported initial rehabilitation should aim to restore motion, strength and basic function, while protecting the surgical procedure.\(^{18}\) The available evidence and guidelines are less clear for the later stages of rehabilitation and determination regarding return to sports.

It is the intention of this clinical commentary to describe a post-operative rehabilitation protocol following a Latarjet procedure and introduce a criterion-driven algorithm for progression through return to sport rehabilitation.

**PHASE I: PROTECTION PHASE**

The goals of this phase of rehabilitation are to protect the surgical reconstruction, optimize the environment for tissue healing, control edema and swelling, and achieve protected range of motion (ROM). These goals must be addressed without causing inappropriate stress to the healing structures.

Patient education to convey the rationale of the outlined plan of care and the importance of protecting the healing tissues from excessive stress is critical to ensure compliance. In order to protect the reconstruction, the arm is immobilized for four weeks in an abduction sling. Early passive ROM (PROM) exercises are beneficial in preventing postoperative stiffness. Due to the violation of the subscapularis tendon and repair of the capsule, external rotation (ER) should be limited to <30° for the first three weeks.\(^{29}\) No limitations on other ranges are needed and progression to full PROM is recommended early. In addition to PROM, manual therapy during this phase should consist of soft tissue techniques such as myofascial techniques for the shoulder musculature, specifically the pectorals, as well as scar mobilization. Cryotherapy and other modalities to decrease swelling and muscle spasm and aid in pain relief and sleep are also advocated as needed.

Supplemental activities include active scapular exercises (protraction, retraction, elevation and depression), such as the scapular clock exercise, to facilitate early neuromuscular control. Active ROM of uninvolved joints (hand, wrist, elbow and neck) to minimize stiffness in surrounding joints and encourage blood flow. To protect the healing structures from shear or compressive forces, no isometric exercises should be performed during weeks 0-2 following Latarjet procedure. Especially important is refraining from loading during elbow flexion and supination, to avoid pulling off the coracoid bone block from the glenoid.

After two weeks, isometric exercises of the muscles surrounding the shoulder girdle can be initiated. Submaximal, non-painful, isometrics in neutral rotation can be performed.\(^{30}\) Rhythmic stabilization (RS), involving gentle manual resistance to the proximal forearm using oscillating perturbation in a neutral shoulder position, while the patient is instructed to keep their arm still, are appropriate to facilitate low contraction of the scapular and rotator cuff musculature and can also be beneficial for early neuromuscular re-education and improving dynamic stability.

The criterion to progress to the next phase of rehabilitation is shown in Appendix 1.

**PHASE II: ENDURANCE PHASE**

The goals of this phase of rehabilitation are to advance active shoulder motion and improve muscular endurance and neuromuscular control of the shoulder complex. This should start with active-assisted ROM (AAROM) then progress to active ROM (AROM). AROM can be started in supine, side-lying or prone positions to reduce the effects of gravity, progressing to standing as endurance improves. It is recommended that isotonic exercises should focus on high volume training with 15-25 repetitions, 2-3 sets, with low resistance at less than 65% of the patients one repetition maximum (1RM) in order to create a fatigue response and target the development of local muscular endurance.\(^{31,32}\) Rest times between sets should be no more than 30 seconds.\(^{31}\) ER will often be slow to progress, but it is important to attain full ER ROM, as any deficit in ROM can have long term implications on joint health and development of osteoarthritis.\(^{15,33}\)

The dynamic stabilizers of the shoulder provide stability through an active mechanism referred to as neuromuscular control. The development of neuromuscular control and proprioception should be a priority and begin as active ROM allows. Meyers and Lephart define neuromuscular control as the efferent output in response to afferent sensory ( proprioceptive) stimulation.\(^{34}\) It can be assessed and enhanced through joint position sense (JPS) where the patient works on recognizing where one's joint is oriented in space. This can be limited in individuals with glenohumeral instability and not fully restored until 12 months after surgery for instability.\(^{35}\) An example of an exercise to address this deficit includes the patient closing his or her eyes, and moving the uninjured upper extremity to a selected position and then actively moving their involved limb to the same position (Figure 2). The joint angular replication test (JART) can be used as an exercise as well as an assessment tool for JPS.\(^{36}\) This involves the rehabilitation specialist passively moving the involved limb to a position, the individual holds the position for spatial orientation then it is passively moved back to neutral. The patient actively moves the arm to as close to that position and this angle is measured with a goniometer or inclinometer. Normative data for healthy individuals resulted in an average error of 2.7 degrees.\(^{37}\) Movements can be practiced and tested in the sagittal, frontal and transverse planes.

Propiopceptive neuromuscular facilitation (PNF) exercises, such as D2 flexion/extension, should be started to help gain stability and control into functional patterns. Advancing RS exercises towards end ROM and specifically for internal and external rotators will help facilitate co-contraction of the anterior and posterior rotator cuff musculature.\(^{38}\)

Scapular control should be advanced in this phase as it will help athletes optimize functional performance via improved kinetic chain integration. When the trapezius and the serratus anterior (SA) activate in unison and achieve their optimal force coupling pattern, they significantly con-
ttribute to scapular stability. Particular exercises which have been shown to accentuate peri-scapular control are prone horizontal abduction at 90° with ER, prone extension exercise and prone overhead arm raise at 125°. Dynamic hugs and wall slides (Figure 3) have been shown to produce good SA activation.

Supplemental techniques during this phase include soft tissue mobility and long duration stretching to address any persistent limitations in ROM. Gentle glenohumeral joint mobilizations can be initiated at five to six weeks post-operatively if mobility is slow to return.

The suggested criterion to progress to Phase III of rehabilitation is shown in Appendix 1. It is important that the patient has good neuromuscular control and muscular endurance to progress into the strengthening phase. The JART below 90°, the scapular dyskinesis test as described by McClure and colleagues, and the AROM fatigue protocol test are used to assess this. It is important to not have compensatory movement patterns with these tests.

Utilizing the lower extremity (LE) Y-Balance™ (Y-BAL™) assessment or similar test to identify any LE asymmetries or deficits should be performed at this time.

**PHASE III: STRENGTH PHASE**

The primary goals of Phase III are to increase muscular strength and challenge neuromuscular control. Individuals should not start this phase until Phase II goals are met and at least six weeks post-operative in order to ensure adequate tissue healing. All parameters of progression should also be communicated with all members of the treatment team. At this time, a thorough review of the athlete’s sport requirements is beneficial. If the individual is an overhead athlete, progressing strength into the necessary ranges is important, as well as starting to replicate functional activities involved with their sport.

The strengthening parameters in this phase should start with loads which correspond to a repetition range of an 8-12 repetition maximum (RM) for 3-6 sets. These guidelines allow for a safe increase in load of the shoulder joint and are sufficient to create muscular adaptations. External load can be added to therapeutic exercises in the form of manual resistance from the rehabilitation specialist, dumbbells, medicine balls, kettle bells, sports cords and TheraBand™. Most exercises early on in this phase will focus on strengthening specific muscle groups, such as shoulder external rotators or shoulder internal rotators. Once baseline strength has been established in each muscle group, functional movements with the involved upper extremity will start to replicate movement patterns involved in day to day activity as well as sports performance. De Mey and colleagues have demonstrated maximal scapular muscle activation when muscles are activated in functional patterns and when muscles are activated in specific diagonal patterns using kinetic chain sequences. Examples include resisted PNF exercises (Figure 4) and Crossover Symmetry exercises.

Dynamic stability can be enhanced through progression of neuromuscular control techniques, including reactive neuromuscular control drills and closed kinetic chain (CKC) exercises. RS exercises at this phase can be incorporated during performance of any exercise throughout the ROM. Placing an unstable base under the upper limb such as a stability ball enhances neuromuscular control. Adding perturbation to the exercise challenges proprioception and improves joint position. CKC exercises stress the joint in a weight-bearing position, resulting in joint approximation. Advancing from wall to tabletop or to quadruped position creates a gradual increase in loading and is excellent for scapular control. Additionally, performing exercises that introduce chaos can be beneficial for increasing core stability and rotator cuff recruitment. An example would be chaos band training, such as performing an overhead press with added weight suspended to the barbell, using looped bands. This would add instability and unpredictability to the exercise.

It is critical to build the right balance when it comes to scapular foundation muscles, rotator cuff control, and transfer of energy from the legs, core and shoulder to the arm. The kinetic chain model refers to the ability to transfer large forces through segmental links in the body with the theory of gaining proximal stability for distal mobility, power and precision, all attributes that are required in sporting
Since force production was the biggest focus of Phase III, power development. Power equals force times velocity. The main goal of this phase of rehabilitation is to maximize POWER: PHASE IV.

The criteria to progress from Phase III requires the athlete to have a strength limb symmetry index (LSI) of 80% or greater at external rotation at 0° abduction (ER0), internal rotation at 0° abduction (IR0), abduction and scaption at 90° and belly press. It is important to assess belly press as this isolates the subscapularis muscle and provides a good indication of recovery following the violation of the muscle during surgery. In addition, assessing periscapular muscular strength should be performed if the scapular dyskinesis test is abnormal. This can easily be assessed with the use of a handheld dynamometer (HHD) which offers an accurate, reliable means of measuring isometric muscular strength in multiple positions.

It is important to consider the athletes psychological readiness to return to sport. Evaluating if the athlete is mentally prepared for higher level activity and eventual return to sport should be considered. Outcome measures such as the Athlete Fear Avoidance Questionnaire (AFAQ) specifically targets athletes on their thoughts about their injuries and returning to play. It could be used to identify potential psychological barriers to rehabilitation. If an athlete is struggling with this, it is important to refer to a sports psychologist, as this could be the biggest issue holding back an athlete and if not addressed now, the athlete may be delayed with their return to full participation once they have completed the final Phase of rehabilitation.

If the individual is involved in a sport that does not require power movements, involve contact, or overhead sport demands, once Phase III criteria have been achieved, they can be discharged from therapy with a maintenance program. If their sport does require these demands, they will advance to Phase IV of the rehabilitation program once their strength values are >90% of their contralateral limb. Strength must also be tested at external rotation at 90° abduction (ER90) and internal rotation at 90° abduction (IR90) so the ER/IR ratio can be formulated. The balance between external and internal rotation strength is important to normal glenohumeral function. An adequate external-internal rotator muscle strength ratio at 90° abduction has been emphasized in the literature with a minimum of 65% but optimal between 66% and 75%.

PHASE IV: POWER PHASE

The main goal of this phase of rehabilitation is to maximize power development. Power equals force times velocity. Since force production was the biggest focus of Phase III, the incorporation of velocity into Phase IV will maximize power generation. Based on available evidence, the following guidelines for dosage are recommended when designing a power program for the shoulder. The athlete should work at 80-100% of their 1RM for 3-6 repetitions for 3-6 sets. Functional trainers are cable machines which allow unrestricted multiple planes of motion. They can be a good tool to accomplish power production, with the ability to perform basic exercises like the 90/90 ER for power or progressing to a push-pull arm cable exercise which incorporates the entire kinetic chain (Figure 6).

Plyometrics are also an excellent method to assist in the development of power, recruit fast twitch muscle fibers and enhance neuromuscular control. Plyometric training utilizes the stretch-shortening cycle (SSC) by using a shortening movement (eccentric) which is quickly followed by a shortening movement (concentric) to produce an explosive
UE plyometric exercises can be performed in both an open kinetic chain (OKC) and CKC position. Progression of UE plyometrics performed in an OKC position begins with two-handed drills such as chest pass, side-to-side throws and overhead soccer throws. Once they are performed successfully, the athlete can progress to one-handed drills such as, standing one-handed arm throws, one-handed side arm throw, 90/90 wall dribbles (Figure 7), and prone ball drops.56,57 CKC UE plyometrics can be initiated in a partial weight bearing position by performing wall plyometric push- ups or reformer plyometric UE jumps (Figure 8), progressing to full weight bearing plyometric push- ups, depth drop plyometric push- ups, and clap push- ups.54

Criterion to progress from Phase IV is dependent upon the sport the athlete intends to return to. For simplicity this is classified as either overhead athlete or non-overhead athlete (see Appendix 1). Functional testing options for individuals returning to sport following shoulder injury and surgery is significantly limited, compared to lower extremity functional tests. There are few high-level evidence studies and few tests with good psychometric properties, with no gold standard test proposed. The presented criterion-based functional testing is based on clinical experience and expertise. The tests can be divided into UE power and closed chain tests and additional tests for the overhead athlete. Bilateral UE tests are compared to normative values while the goal for unilateral tests is a LSI of >90%. The UE CKC tests described in the literature include the UE YBAL™ test and closed kinetic chain upper extremity stability test (CK-CUEST). The UE YBAL™ test, the CK-CUEST and modified push up test all assess shoulder stability and endurance and would be beneficial for assessment of return to sport ability in both overhead and non-overhead athletes. It is dependent on the rehabilitation specialist to decide which one is most relevant for the individual athlete. Tests that have normative values to compare the athlete with are more desirable than comparing to the uninvolved UE because decreased function and performance of the uninvolved limb over time or non-dominant limb may produce inflated LSI and misrepresent the functional ability of the rehabilitated UE. The single arm seated shot-put test, which assesses isolated power, can also be utilized if the rehabilitative specialist feels it is relevant to the athlete.

Testing for overhead athletes should also include UE OKC and dynamic stabilization tests such as the 90/90 wall dribble test (WDT) and prone ball drop test, which are beneficial in identifying both scapular and cuff weaknesses and poor endurance.54,57,58 The WDT involves using a 2lb medicine ball and the athlete standing in an athletic stance at the corner of a wall, with their shoulder abducted and externally rotated to 90°. The athlete must perform quick dribbles at 165 bpm (use a metronome) for 60 seconds, maintaining proper position and scapular control, in order to pass. The prone ball drop test involves lying prone on a plinth with the arm in horizontal abduction. The number of releases and catches of a 2lb medicine ball in 30 seconds is recorded. Comparison between dominant and non-dominant arm is used for passing criteria.59

Negrete et al reported that the modified pull up and push up tests may be beneficial assessment tools for throwing athletes given their predictive validity related to throwing distance as compared to other functional tests.60 Analysis revealed that the modified pull-up test was the best predictor of a softball throw for distance as it had the highest correlation with the distance thrown (r = 0.70), followed closely by the push up test (r = 0.63).60,61 Normative values are based on testing of recreational athletes so these goals would be the bare minimum an athlete should aim to achieve. Reassessment of LE YBAL™ and FMS™ at this time frame would also be appropriate in order to see improvements and to be aware of continuing deficits that remain. The goal for LE YBAL™ is <4cm difference between limbs while the FMS™ goal is a score of 14 or more.
The phases of rehabilitation which have been discussed in this clinical commentary represent a progression in which exercises become more demanding and the stresses applied to the shoulder joint gradually intensify. After completion of Phase IV, the athlete has demonstrated enough ROM, neuromuscular control, strength and power to start a return to play progression. This Phase will be dependent on the sport or activity that the athlete is returning to and due to the enormous variety, this section will briefly highlight the necessary components to this challenging process.

Regardless of what sport the athlete is returning to, it is essential to know the demands of the specific sport and the demands of the position the athlete plays. For overhead athletes an interval throwing program (ITP) can be introduced during this phase. The ITP gradually introduces quantity, distance, intensity, and types of throws needed to facilitate the restoration of normal throwing motions for the specific throwing sport. At least six weeks of plyometric training should have been completed prior to starting an ITP. This allows for soft tissue adaptations to occur and prepares the athlete for the stress of throwing.

A graded return to full participation should include practicing the skills needed for the sport, initiating drills without contact, progressing to contact drills, increasing frequency and intensity of training situations to eventually meet the game requirements, with collaboration of the coaches in order to find appropriate progressions. Once the athlete is completing full training sessions which mimic the frequency and intensity of the sport and/or have successfully completed an ITP without pain, while also exhibiting proper throwing mechanics, introducing them to competition situations would be the final step. For overhead athletes an additional outcome measure, the Kerlan-Jobe Orthopaedic Clinic (KJOC) shoulder and elbow score, should also be completed and can be used to gauge readiness to return to full participation with a score of 90% or higher being needed, prior to returning to competition.

CONCLUSION

This clinical commentary describes a criterion-based rehabilitation protocol following Latarjet procedure in an athletic population. It describes progression through clearly defined phases and recommended criteria to achieve prior to progression into the next phase. Phase I focuses on protection and initiation of PROM with supplemental exercises to address ROM of surrounding joints and active scapular mobility. Phase II focuses on initiating AAROM and AROM, neuromuscular reaction drills, such as RS and JPS, and progression of scapular control. Phase III focuses on advancing ROM, strength including functional and in CKC positions and advancing neuromuscular drills such as RS at end range and PNF. Phase IV introduces power specific exercises and plyometrics starting with two-handed exercises to one-handed. A final reassessment of the full kinetic chain with FMS™ or LE YBAL™ is helpful during this Phase. Additional testing at the end of Phase IV is chosen and utilized to see if the athlete is ready for return to play progressions (dependent upon the sport to which they are returning). Functional CKC and OKC tests are recommended and an additional pathway for over-head athletes is used. Phase V focuses on return to full participation with a graded progression, which is dependent on the demands of the specific sport. By methodically following the recommended criterion-driven rehabilitation algorithm and achieving the set criteria, it is anticipated that the athlete will have completed a very thorough rehabilitation program that addresses ROM, neuromuscular control, strength, power and a graded return to play.
REFERENCES


International Journal of Sports Physical Therapy


SUPPLEMENTARY MATERIALS

Appendix 1
Clinical Commentary/Current Concept Review

Hip and Groin Injury Prevention in Elite Athletes and Team Sport – Current Challenges and Opportunities

Steven M. Short, DPT, SCS, FAAOMPT, CSCS, Cameron W. MacDonald, DPT, GCS, OCS, FAAOMPT, Donald Strack, DPT, ATC, OCS, FAAOMPT

1 Physical Therapy and High Performance, Denver Nuggets Basketball Club, 2 School of Physical Therapy, Regis University, 3 Oklahoma City Thunder Physical Therapy, Oklahoma City Thunder Basketball Club

Keywords: risk reduction, injury prevention, hip, groin, adductor

International Journal of Sports Physical Therapy
Vol. 16, Issue 1, 2021

Hip and groin injury (HAGI) has been reported as a source of significant time loss in elite sport. Field and court-based sports such as basketball, football, hockey, soccer, among others, require explosive multiplanar movement in single stance and high-speed change of direction. Often situations arise where sub-optimal pre-season training has occurred or congested in-season competition minimizes physiologic recovery periods between bouts of physical activity, both of which could magnify concomitant existing risk factors and increase injury risk. Identification and management of HAGI can be challenging as numerous structures within the region can be drivers of pain and injury, especially when considering the likelihood of concurrent pathology and injury reoccurrence. Focused prevention strategies have been suggested, but their practical clinical implementation has not been heavily investigated across the sporting spectrum. The purpose of this commentary is to review the historical and current state of HAGI, while focusing on applying evidence and clinical experience towards the development of future risk reduction strategies.

Level of evidence: 5

IS IT INJURY OR MANAGEMENT THAT IS ON THE RISE?

Clinical practice related to hip and groin injury (HAGI) has progressed from broad terminology (i.e. chronic athletic groin pain, Gilmore’s groin, athletic pubalgia, etc) regarding diagnosis and management to highly specific subgrouping of regional diagnoses related to pathoanatomics. Recent consensus statements have attempted to define current best practice in the diagnosis and management of HAGI.1,2 While beyond the scope of this paper to explore all sources of HAGI, it is important to note some common structures and associated athletic-related pathologies. These include, but are not limited to, bony structures (femur, femoral head and neck, acetabulum, pubis) extra-articular, (adductor musculature, iliopsoas, rectus femoris), intra-articular, (acetabular labrum, acetabular cartilage, pubic symphysis), and neural structures. (Figure 1) The noted anatomy may be accordingly impacted by strain, pain, tendinopathy, bony and/or joint stress, osteoarthritis, or a combination of pathology such as osteoarthritis and labral degeneration. Many strategies have been implemented to properly diagnose injury as demonstrated by the Doha agreement1 and have been expanded upon in follow-up clinical commentaries.3 These guidelines have recommended HAGI to be defined specifically as adductor, pubic, inguinal, iliopsoas, or hip-related groin pain.1

Improved diagnostic capabilities and clinical awareness of HAGI has likely resulted in an increased incidence and prevalence of related diagnosis, which has coincided with expanded coverage within the literature. This combination of factors suggests the presence of historical underdiagnosis,4,5 the possibility of modern day overdiagnosis,2,6 and creates the potential for bias in management strategies and reported outcomes. The heterogeneity related to the comprehensive research and management of HAGI has made best practice elusive, especially when targeting isolated structures.7,8 Syndrome-based recommendations2,9 have been endorsed to better appreciate the complex, regionally interdependent and often concomitantly pathologic10–11 nature about the hip, pubis, and lumbopelvis. Regional impairments such as mobility loss, strength deficits, and altered force distribution and motor control have been associated with these defined syndromes, ultimately affecting the athletic movement system. Thus, despite the diversity of specific pathoanatomy, shared clinical characteristics such

---

a Corresponding author: Steven Short Physical Therapy and High Performance – Denver Nuggets Basketball Club, Denver, CO Email: steveshortdpt@gmail.com Phone: 906-282-4747
as pain referral region and aforementioned residual impairment constructs (mobility, strength, motor control, deconditioning, etc) often present irrespective of sensitized or injured structure.12–14 (Figure 2)

Considering the persistent historical challenges associated with management of HAGI, warranted attention has been growing towards mitigating its impact before an athlete becomes medicalized. Risk reduction for HAGI is a hot topic with limited reported success,15 and the available literature-base to support practical, evidence-based practices across various elite sports is often limited and biased.16,17 Current prevention strategies are generally based upon soft-tissue injury while still broadly being grouped in the HAGI spectrum.18,19 Select populations (professional and semiprofessional soccer, rugby union, ice hockey) dominate the literature upon which current evidence-based practice relies.17 Professionals practicing in sports outside of those populations and specifically within sports such as basketball, American football, or elsewhere may be presented with athletes who are currently underrepresented in the literature. Considerations that raise questions regarding the carryover of current risk identification and treatment strategies to a wide range of athletes include, but are not limited to, anthropometric and biomechanical profiles, sport spe-
cific demands (i.e. volume of short space cutting and jumping volume vs time at defined high speed running, etc) and differing historical practices of sports medicine and science in a team-based setting across sports and countries.

REVIEWING THE CLINICAL QUESTION

The New Oxford American Dictionary defines risk as the chance of unfortunate consequences by engaging in an action. In the case of athletics and exercise, the primary adverse event is musculoskeletal injury. The consequences of sporting injury are multifactorial, and can result in the worsening of mental and physical wellbeing as well as increasing the risk of future injury and disability. In elite sport, the consequence moves beyond individual harm, as competitive success and monetary investment are at stake. As sports medicine professionals, we have the potential to impact risk on microscopic and macroscopic scales. Our responsibility is to investigate methods to reduce the risk of the injury burden to our athletes, medical systems, and institutions. Despite what seems like overwhelming, yet diversely varying, consensuses on how to accomplish this goal, a critical investigation on injury prevention is necessary when trying to implement best practice in action for the field of play.

Caring for athletes involves navigating complex interacting systems which makes prediction and prevention quite challenging. Each sport exposes athletes to different risks and dynamic challenges and thus the initial steps in risk reduction are to identify common athletic demands and clinical problems. For example, in professional basketball, much effort has been put into the prevention of ankle and knee injury, as they have been identified as the most common and result in greatest time loss due to injury. Substantial attention has also been paid to catastrophic injuries, that often result in surgery, such as anterior cruciate ligament (ACL) rupture. As a result, research and clinical practice has focused on identification of related risk factor and prevention methods for such high-profile injuries. However, for example, in the National Basketball Association, all knee sprains, not just ACL tears, accounted for just 3.1% of all injuries over 17 seasons. Meanwhile, clinical cases of less investigated injuries, such as hip and groin injury (HAGI), have been identified as just as common, and are potentially increasing in occurrence.

While HAGI has been reported as 5-10% of injuries across multiple sports, in previously identified high risk sports HAGI has been reported to be a greater source of time loss, accounting for approximately 10-25% of all injury. Numerous structures within the region can be drivers of pain and injury. Additional consideration is warranted for the likelihood of concurrent pathology, injury reoccurrence, the chronicity of varying regional pathologies, and suboptimal athletic and health care outcomes. As the diagnosis and management of HAGI remains challenging, efforts should be made to investigate and improve specific injury risk reduction strategies to avert these historical challenges before they arise.

IDENTIFIED RISK FACTORS

Highlighted non-modifiable risk factors identified in the literature include past injury history, age, time in season, and anatomy and morphology. While injury history and age have consistent backing in the evidence base, utilizing diagnostic imaging for identifying a priori pathoanatomic risk factors may be challenging. 'Abnormal' and 'pathological' findings about the hip and pubis, such as cam morphology or tendinous changes at the rectus abdominis and adductor longus origins, are commonly observed in asymptomatic athletes and may be sport specific adaptations. Of clinical interest are modifiable risk factors specific to the hip and groin including range of motion, hip and trunk strength, special testing, movement pattern assessment, and training variables. The evidence behind these identified risk factors and the observed difficulties in their application will be highlighted.

ANALYSIS OF ‘MODIFIABLE’ RISK FACTORS

RANGE OF MOTION

Limited hip internal and external rotation in various positions, including seated, prone, bent knee fall out (flexion abduction external rotation), and the flexion adduction internal rotation (FADIR) test have all been related to HAGI. A measure of total hip rotation less than 85 degrees has also been identified as a risk factor. As with the consideration of total arc of motion compared to a single direction measure (such as the bent knee fall out), relative limb to limb range of motion and range of motion in sport specific positions may warrant deeper consideration as position specific findings may be related to injury. Clinical experience, unpublished data, and homogenous population data indicates that if clinicians are flagging ranges of motion (i.e 85 degrees total arc, bent knee fall out) as a risk factor cut-off point, nearly every athlete within select sports populations could be at risk due to limited hip mobility. In other words, if following the findings of systematic reviews, entire sporting populations would be defined as at risk of groin pain, limiting its effectiveness as a risk factor measure.

There is also a reliance on standardized ROM assessment of the hip which supports validity within studies, but may overlook the natural variance in pelvic morphology between individuals, especially when assessing hip internal rotation (IR). The natural arc of hip motion may vary between individuals due the variations in femoral version and acetabular alignment, such that an individual may demonstrate reduced hip IR in standard testing with excessive ER, but not when the individual’s natural plane of hip motion (which could be defined as hiption, similar to the concept of scapion in the glenohumeral joint) is assessed. Further, this measure may be impacted by the timing of data collection, as rotation has been shown to change following competition and may continue to be dynamic over the course of a season and career.

Considering the prevalence of variations in athlete morphology and its complex relationship with mobility, how modifiable hip range of motion is warrants a more thorough
investigation, as evidence for preventative interventions to address mobility deficits is limited and rarely included in reviews. Transient in-session range of motion increases made by modalities, manual therapy, and therapeutic exercise may be clinically important, potentially redistributing force or changing pain pressure thresholds. However, lasting tissue change has not been documented nor have mobility-based intervention programs been identified as protective.

STRENGTH

Strength measures about the hip and trunk have been related to hip and groin pain. Of consistent interest is absolute and relative adductor strength. Common assessment methods include squeeze testing, during which a sphygmomanometer is used to measure the maximal isometric ability of the adductors in various supine positions. Other primary strength measures include handheld and isokinetic dynamometry. Low strength ratios of hip adduction to abduction, and high hip flexion to extension ratios and trunk flexion to extension ratios have all been identified as risk factors. The timing of muscle activation may be meaningful, but it has not been determined as a cause or a result of HAGI and it is currently nearly impossible to identify functional motor recruitment in sport-specific context. Furthermore, documented standardized strength assessment may not accurately measure strength variables as they relate to sport-specific tasks and associated mechanisms of injury such as defensive shuffling, kicking, single leg jumping, or how an ongoing strength profile improves any tissue's capacity to handle such tasks. Simple strength metrics have been shown to vary according to population, and many other factors indicating a need for clinical reasoning for interpretation and application.

Similar to hip range of motion, a clinical challenge of applying strength data is that current reference data is likely population and context specific. Most documented strength assessments are performed prior to competitive seasons and not intra-season. The differing sporting and training demands, as well as differences in athlete's biomechanical profile (i.e., mechanical advantage according to leg length when performing long lever squeeze assessment) likely limits clinicians ability to interpret and apply normative data across sports, as empirical analysis of subgroup scores are quite different from current published values. If strength is assessed in-season or following competition, whether immediately or next day, there are minimal recommendations on the best ways to interpret or act on such information, particularly when considering congested competition schedules during which optimal recovery from intense activity is impaired.

SPECIAL TESTING

Special testing often combines elements of range of motion and strength for symptom provocation and the tissue and/or system impairments as they relate may indicate a level of risk for example squeeze testing and the FADIR test. Consistent monitoring of special tests may identify significant variance in prior findings and could be related to training volume or pain. These tests provide value for daily clinical reasoning in a dynamic test-retest model, but since these tests generally identify sensitized actions, structures, and/or movements, they are currently more valuable once the athlete is already nursing an injury as opposed to providing prognostic value.

MOVEMENT ASSESSMENT

Clinical movement assessments have been found to have minimal utility in identifying those at risk for hip and groin injury, despite potential construct validity. It has been shown that those with HAGI demonstrate different movement patterns in tasks of varying intensities compared to controls. Differences have been identified in star excursion balance test of posterolateral reach and altered intersegmental biomechanics in various cutting tasks in those with HAGI. Variable movement patterns during a cutting task have not been established as predictive of HAGI, however changes in these patterns, in addition to improved adductor strength, have been shown to occur with intersegmental-focused training when returning from a prior HAGI. It is unclear whether this assists in the cause of the resolution of injury or is changed due to the absence of pain and natural history. While training movement patterns is often a focus in physiotherapist practice, it warrants questioning whether changes in multi-segmental control and/or movement patterns transfers to sport specific and reactive variations of movements, or if changing asymptomatic movement patterns may provide a protective stimulus, and even potentially provide a false level of comfort to the clinician and athlete. With or without symptoms, it has been shown that efficient force distribution about the pelvis is recommended (i.e avoiding excessive trunk lean displacement, excessive displacement beyond the center of mass) and may have implications with HAGI.

MONITORING LOAD AND OBJECTIVE OUTCOME MEASURES

Monitored training variables and resultant outcomes of sport training such as body composition, aerobic fitness, and sport-specific training load volume has been reported as related to injury risk. Load monitoring strategies vary greatly and include internal (physiologic) or external (mechanical) variables. For other highly studied injuries, such as hamstring strain, variables such as distance covered and high-speed running metrics have been documented as injury risk factors. It has been proposed that these factors should be applied across sports and injuries, without consideration of the differing demands of various sports. Court athletes may never achieve similar high speeds or distances as field athletes, while being stressed by different mechanical forces and associated physiologic consequences associated with tasks such as high volume jumping or limited-space, high intensity cutting maneuvers. Sport specific preparation has been identified as a common risk factor, thus, an importance must be placed on defining and training these identified variables, yet are not commonly detailed in the literature, training or in sporting practice.
order for sport-specific training to be provided, these qualifiers must be defined, tested, and trained to evaluate their potential protective capacity. Practical challenges are numerous when attempting to consistently collect and utilize objective outcome measures, especially when considering clinical time demands, the substantial size of data sets, the impact of internal and external factors in elite sport, and the numerous athlete health and performance demands aside from HAGI that present in daily practice.

PRACTICAL GAPS IN SCREENING

Despite significant investigation, much debate continues to take place regarding the value of screening for athletic injury risk factors and its effectiveness has been extensively questioned. Current evidence pertaining to heterogeneous HAGI risk factors is often disproportionately represented from select homogeneous populations. Derivation of risk factors frequently relies on retrospective study design as opposed to more rigid prospectively designed trials. The lack of prospective studies is not shocking, as data collection and application in elite sport presents numerous practical challenges, including appropriate design, collection, sharing, and publication of relevant data. The culture and history of each individual sport presents numerous practical challenges, including appropriate design, collection, sharing, and publication of relevant data. These limitations leave questions as to whether or not sample sizes are robust enough to hold clinical value, if specific qualities are the result of, or potential cause of injury, if these factors are able to be shared across various sports and genders, or if risk reduction research and development can even take place in environments of interest.

INTERVENTION OVER IDENTIFICATION

As opposed to a narrow focus on isolated risk factors, reducing the occurrence of hip and groin injury or otherwise may be best served by focusing on global neuromuscular training combined with individualized and context-specific ‘prevention’ programs that avoid training load error. With shared regional factors (mobility, strength, motor control, altered force distribution, tissue tolerance, etc) about HAGI, global principals are appropriate to apply to mitigation programs. Ultimately, achieving less injury may rely on an adequate volume and adherence of training in these risk reduction strategies, most specifically, appropriately dosed and performed exercise. Despite this working hypothesis, a general well planned, balanced, and executed multi-component exercise training program may be protective regardless of the targeted constructs listed above. Developing numerous qualities within the variables of strength and aerobic capacity may be key modifiers in decreasing an athlete’s risk for HAGI regardless of underlying proposed risk factors defined earlier in this paper. Objective data obtained historically via traditional screening methods may not be predictive in a classical prevention ideology, but may continue to hold secondary value in establishing baselines profiles, and be used to monitor progress and changes in the athletes dynamic system to inform clinical reasoning and athlete care. Monitoring profiles of strength and exercise load metrics are emerging as recommended evidence-based practice for secondary risk reduction allowing for clinicians to make real-time programming decisions to reduce risk. The nature of dosing requires further investigation, as an adequate baseline and minimal effective dose of exercise may serve as protective. Timing the dose as it relates to match day and in relation to activity timing may provide improved adherence and effectiveness.

Again, despite the heterogeneity of the pathology of HAGI, it is valuable to note the homogeneity of physiotherapist intervention. Education, assessment, exercise, movement training, appropriate mobility intervention, optimal dosing of intervention, and continued monitoring have all been commonly recommended in the comprehensive management of various hip joint, osseous and soft-tissue related injuries. Similarly, mobility, hip strength, and motor control are constructs that can be defined respectively as risk factors, injury impairments and rehabilitation goals. The authors recommend that these same constructs be appropriately implemented into future focused risk reduction programs. As these trainable constructs have been consistently identified across the HAGI spectrum, targeting them appropriately could have a mediating effect on past and/or future injury. By focusing on these factors and treating each individual with respect to their sporting demands and body’s specific natural adaptations, it may be possible to develop clinical guidelines for HAGI reduction similar to what has been done regarding ACL prevention. As evidence-informed recommendations have been globally applied to comprehensive knee injury reduction, with further development, the same could be done for HAGI. The nature of global training principles may result in significant similarities between these programs, which is to the benefit of their application.

Of course, the remedy is not as simple or as straightforward as it may seem. Similar to the discussion of highlighted risk factors above, the efficacy and effectiveness of these programs remains limited to the sports in which they have been trialed via the scientific process, integrated, individualized, and accepted as common practice. For example, detailed general programs have been trialed in sports such as European football but few other team based sports. This has been most recently identified in a systematic review detailing the challenges of finding level 1 evidence in elite sport and then applying strategies of lower levels of evidence with high levels of bias. Transference troubles have been seen clinically in recognized pathology-based prevention programs such as neuromuscular training to reduce knee injuries. Many such programs have been established related to a specific gender and age population (adolescent females) and mechanism of injury may be dissimilar when comparing across sports, gender, and sporting maneuvers (i.e dynamic valgus produced by jump landing vs change of direction task).

CONCLUSIONS

Identification of injuries with high incidence and preva-
In the case of HAGI, practitioners continue to rely on generalized risk factors and select populations to provide current best practice despite the growing number of identified HAGI cases. Athletes across sports possess inherent characteristics that predispose them to specific sporting success, and may require a diverse set of risk modifying interventions to increase the odds of prolonged health and sports participation. In order to further improve these programs, the authors extend a call to action to refine important clinical questions and extensively test them in order to advance the practical evidence-base which may improve athlete health. This requires creating integrated institutions and avenues within all levels (youth, collegiate, semi-professional, professional) and geographical locations (including the United States) of sporting populations. This call to action can begin by proactively implementing current evi-
Figure 5: Applied construct recommendations for hip and groin injury risk reduction programs


Evidence-informed interventions, such as global exercise programs with injury-specific construct modifications, within diverse sporting populations. Assessing the residual outcomes and modifying programs accordingly could reverse trends of increasing HAGI in understudied populations. Until then, recommendations and practice will rely on clinical experience and at times liberal interpretations of practice across sporting populations.

CONFLICT OF INTERESTS

Authors declare no conflicts of interest

Submitted: December 19, 2019 CST, Accepted: April 21, 2020

CST

International Journal of Sports Physical Therapy
Figure 6: Implementation of Constructs into Risk Reduction Programs

A. Local hip and trunk strength via adductor side plank  
B. Functional exercises include single leg knee and hip dominant drills, here demonstrated by a lateral lunge  
C. Basic compound movement motor control trained by triplanar single leg tasks and can be monitored as demonstrated by the Y-Balance posterolateral reach  
D. Active assisted mobility exercise with considerations for the individual's hip and lumbopelvic morphology  
E. Sport-specific compound movement motor control. Sport training including practice and adjunct speed, agility, and quickness training can include the monitoring and coaching of desired mechanics while establishing sporting conditioning. Sagittal plane segmental movement goals include increased ankle dorsiflexion, and reduced knee flexion, anterior pelvic tilt, hip flexion and trunk flexion. Frontal plane segmental movement goals include reduced trunk rotation and side flexion, pelvic drop knee valgus, and foot external rotation. This may increase the power and work and the knee and ankle, while decreasing the demands on the hip and lumbopelvis.  
F. Functional exercise that trains hip, trunk, and compound movements as demonstrated by a hexbar deadlift  
G. Monitoring strategies are guided by baseline assessment and continued monitoring. Adduction strength is one variable that can be tracked, as well as other metrics such as additional strength measures, range of motion, and training load variables (i.e. volume, intensity, etc.)
REFERENCES


Clinical Viewpoint

Considerations with Open Kinetic Chain Knee Extension Exercise Following ACL Reconstruction

Kevin E Wilk, PT, DPT, FAPTA, Christopher A Arrigo, MS, PT, ATC, Michael S Bagwell, PT, DPT, OCS, CMPT, Adam N Finck, PT, DPT, SCS, OCS, CSCS

1 Champion Sports Medicine; American Sports Medicine Institute, 2 Advanced Rehabilitation, 3 Champion Sports Medicine

Keywords: rehabilitation, knee, quadriceps, acl

The Journal of Orthopaedic and Sports Physical Therapy (JOSPT) published a clinical viewpoint article in September 2020 authored by Drs. Noehren and Snyder-Mackler, entitled "Who's Afraid of the Big Bad Wolf? Open-Chain Exercises After Anterior Cruciate Ligament Reconstruction." In this article, they advocate for the use of open-chain exercises post anterior cruciate ligament reconstruction (ACL), using the fairy-tale of the "Three Little Pigs" as a metaphor to validate their viewpoint. As noted in the JOSPT clinical viewpoint of Drs. Noehren and Snyder-Mackler, they favor the use of open kinetic chain (OKC) exercises to strengthen the quadriceps post-surgery. In contrast, we are concerned about our patients performing OKC knee extension exercises with significant resistance in an unsuitable range of motion (ROM) and at inappropriate time frames during the rehabilitation process following ACLR surgery. This clinical viewpoint discusses the concerns with using OKC knee extension exercises and strategies to ensure safe, effective quadriceps strengthening post-ACLR.

There is no doubt, as the authors point out, that quadriceps strength and limb symmetry are essential to the restoration of adequate knee function after ACLR, particularly as it relates to the ability to return to sport, incidence of subsequent knee injury, and the long-term development of osteoarthritis. OKC knee extension exercises can be used safely following ACLR and can be an integral part of the rehabilitation process. Fleming et al reported similar ACL strain values with OKC knee extension and CKC squats with very load resistance loads. We routinely prescribe this exercise for our patients following ACL surgery. However, being too aggressive (maximum effort or high force exercise) can be deleterious to the integrity of the ACL graft post-operatively and lead to patellofemoral pain complications.

OKC knee extension when used inappropriately can be harmful to the post-operative integrity of the graft because of the unopposed anterior shear forces placed on the graft. Wilk et al reported during isometric open chain knee extension there is minimal to no hamstring muscle activity, and therefore no co-contraction. Furthermore, near terminal knee extension (40 to 0 degrees of knee flexion), the amount of quadriceps force produced to extend the knee joint is 3-4 times greater, thus resulting in higher ACL strain. Co-contraction of the quadriceps and hamstrings is important in order to reduce anterior tibiofemoral shear forces and ACL strain.

Increased load results in an increased amount of strain placed on the ACL. Beynnon et al placed strain gauges into normal subject's ACLs, reporting the highest amount of in vivo ACL strain from 40 to 0 degrees, and found that as resistance increased, too did the amount of strain placed on the ACL. Grood et al reported that very large quadriceps forces are needed to perform the last 15 degrees of OKC knee extension, and the quadriceps forces increased significantly with added resistance. It has been theorized that as resistance increases, ACL strain incrementally climbs. These forces can be especially detrimental in reconstructions using hamstring grafts due to soft tissue fixation and with allografts, both of which are more susceptible to creep or graft stretch-out. Beynnon et al reported on serial knee laxity test results utilizing accelerated compared to non-accelerated rehabilitation programs following ACL reconstruction. The investigators reported that subjects had an increase in knee laxity when leg extensions were increased in both groups. Thus, care should be exhibited when increasing loads are applied to the leg during OKC knee extension exercises, especially in the 40 to full extension range of motion.

Another closely associated consideration in the appropriate use of resisted OKC knee extension exercises is the significant reaction force and stress placed on the patellofemoral joint in a population that may be prone to developing anterior knee pain. Steinkamp et al both found that the patellofemoral joint reaction and compressive forces were significantly greater between 50-0 degrees of knee flexion during the OKC knee extension exercise when compared to CKC exercises. With the patellofemoral contact surface area significantly decreased near full extension, and the quadriceps forces significantly increased in this range, the patellofemoral joint may be
more susceptible to injury during heavy resisted OKC knee extension.

A frequently seen complication following ACLR is rehabilitation-induced anterior knee pain. Because this complication is difficult to resolve once it is established and can result in deleterious effects on both continued rehabilitation and functional outcomes, the development of anterior knee pain during rehabilitation must be avoided at all costs. In our opinion the judicial use of OKC knee extension is crucial to ensuring that anterior knee pain does not develop as a primary complication during rehabilitation following ACLR.

Isokinetic OKC knee extension exercise has been shown to be safe at higher angular velocities, due to the mechanical ability of the apparatus to accommodate resistance through motion. Wilk et al \textsuperscript{14} reported that at slower speeds, such as 60 degrees per second, there was greater anterior tibial translation than at faster speeds. At higher speeds (180 degrees/second and 500 degrees/second), less torque was produced, thus resulting in less anterior tibial translation during accommodative resistance knee extension. It is important to note that traditional isotonic knee extension is performed at approximately 60 deg/sec.

Our recommendations to the readers are to heed the moral of the three little pigs: Hard work and dedication pay off when resistive exercise is properly applied and controlled. Post-operative rehabilitation of patients who have undergone ACLR should consist of OKC and CKC exercises in combination with a focus on restoring quadriceps symmetry to the recovering limb. Patients should not perform full range OKC knee extensions with significant force for 6 to 9 months following ACLR, until the graft has incorporated into the osseous tunnels and graft maturation has occurred. OKC knee extension exercises performed at low load are safe and are safer to use from 90 to 40 degrees of knee flexion ROM. High loads from 40 to 0 degrees of knee flexion can be harmful to the knee especially for patients following ACLR or with ACL laxity.

In conclusion, our position is that rehabilitation professionals need not be afraid of the big bad wolf or the proper, appropriate use of OKC knee extension. After all, it is a useful and necessary exercise to improve quadriceps strength and a method of performing isolated muscle testing. But, like the little pig that built his house of bricks, make sure you are wise in your selection of the appropriate amount of resistance, arc of motion, time frame from surgery, and the type of patient when incorporating OKC knee extension into exercise programs for your patients following ACLR.

Submitted: November 15, 2020 CST, Accepted: January 26, 2021 CST

This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY-NC-ND-4.0). View this license's legal deed at https://creativecommons.org/licenses/by-nc-nd/4.0 and legal code at https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode for more information.
REFERENCES


IFSPT International Perspective

Worldwide Sports Injury Prevention

Luciana D Mendonça¹, Joke Schuermans², Evi Wezenbeek³, Erik Witvrouw³

¹ Graduate Program in Rehabilitation and Functional Performance, Universidade Federal dos Vales do Jequitinhonha e Mucuri (UFVJM), Diamantina, Minas Gerais, Brazil.; ² Postdoctoral researcher at Department of Rehabilitation Sciences, Faculty of Medicine and Health Sciences, Ghent University, Ghent, Belgium; CAPES Foundation, Ministry of Education of Brazil, Brasília, Distrito Federal, Brazil. ³ Postdoctoral researcher at Department of Rehabilitation Sciences, Faculty of Medicine and Health Sciences, Ghent University, Ghent, Belgium. Keys to: physiotherapy, sports medicine, injury prevention

International Journal of Sports Physical Therapy
Vol. 16, Issue 1, 2021

The number one goal of the sports physical therapist is to make sure that the athlete is in optimal shape to perform, but with a minimal risk for developing an injury at the same time. The aim of this International Federation of Sports Physical Therapy (IFSPT) Perspective is to raise awareness about the importance of contextual and behavioral factors when planning and implementing injury prevention. Also, it outlines the potential role of the IFSPT as a facilitator of data and information exchange among sports physical therapists worldwide.

INTRODUCTION
The risk of injury is inherent in sports and injury is recognized as a major public health issue.¹ In addition to pain, physical disability and absenteeism, the financial costs involved in surgery, and rehabilitation should be considered.¹ As a consequence, injury prevention is imperative in order to decrease an athlete’s risk of injury and reduce costs for the sports team and society.

The number one goal of the sports physical therapist is to make sure that the athlete is in optimal shape to perform, but with a minimal risk for developing an injury at the same time.² The aim of this International Federation of Sports Physical Therapy (IFSPT) Perspective is to raise awareness about the importance of contextual and behavioral factors when planning and implementing injury prevention. Also, it outlines the potential role of the IFSPT as a facilitator of data and information exchange among sports physical therapists worldwide.

DIFFERENT COUNTRIES AND CONTEXTS FOR INJURY PREVENTION
Sports physical therapists implement injury prevention in different sports, contexts and countries, taking into account the different cultures.³ One of the barriers to the effectiveness of a preventive program is lack of consideration regarding interrelations between physical, biological, economic and social aspects.³ Following this reasoning, a study indicated why and how three states from the United States of America were able to facilitate the successful creation and adoption of heat acclimatization guidelines.⁴ Each state had a different reason to change policies regarding heat stroke/heat related illness prevention. Arkansas’ process was initiated due to the death of one high school-aged athlete from exertional heat stroke.⁴ In Georgia, the main reason was the high number of sudden deaths that occurred in sport in that state.⁴ In New Jersey, the policy makers wanted to be proactive and created a policy to protect student-athletes and to protect the state from litigation.⁴ Therefore, considering that differences among sport-teams, countries, and states influence injury risk and preventive actions, it is important to identify how sports injury prevention is being organized and implemented worldwide.

According to Van Mechelen’s sequence of prevention, a standardized injury registration system is imperative for success of an evidence-based injury prevention approach.³ Therefore, it can be expected that this applies to every club or team worldwide. However, this has not been investigated, and could be approached and organized differently among diverse countries and cultures around the world. Nevertheless, a profound insight into injury prevention is essential to be able to improve implementation and adherence strategies worldwide in order to contribute to the athlete’s health and safety.

ATHLETE’S BEHAVIOUR AND EFFECTIVE IMPLEMENTATION
When dealing with sports injury prevention, the athlete’s behavior plays an important, but frequently forgotten, role. Cusimano et al⁵ showed that a previous ankle injury did not significantly increase the odds of using an ankle support device, proposed as the most effective measure for the prevention of ankle sprains,⁶ in basketball athletes. Interestingly, the largest barrier identified by Cusimano et al⁵ to ankle support device use was a lack of aesthetic appeal. Similarly, other authors found major barriers for concussion registration among athletes, such as fear of losing current or future playing time, a misconception that concussive injury is not serious and a fear of letting one’s team down.⁷ Better knowledge regarding athletes’ behaviors is fundamental
in the development and effective implementation of injury prevention programs and education.

THE CHALLENGE OF IMPLEMENTATION AND ADHERENCE

Differences in injury prevention approaches between different sports and countries might contribute to different injury prevention outcomes. However, there is a lack of studies which investigate this issue. Thein-Nissenbaum and Brooks\(^8\) found that female high school basketball players from Wisconsin had a very low adherence to a home-based injury prevention program. The reasons for this low adherence rate included, “I did not have time to do the program,” followed by, “I forgot to do the program.” Luckin et al\(^9\) identified participants who did not complete strength training indicating that (1) perceived time constraints (53.1%), in addition to (2) lack of knowledge on exercise progression and form (52.5%) were prominent perceived barriers to strength training adherence. Thus, education and supervision during the prevention (training) process may be determinant to the success of the program. In this regard, joint engagement of the sports physical therapist, the strength-conditioning coach, and head coach is essential for athlete adherence in prevention strategies.

AN IFSPT ROLE IN WORLDWIDE SPORTS INJURY PREVENTION!

The IFSPT could be the source of information and guidance for the sports physical therapist in processes related to the athlete’s health and safety. The IFSPT could collaborate with its member organizations or other groups to understand the athlete’s behavior and inform injury prevention organization worldwide. With this information, the IFSPT could guide and facilitate the exchange of information between countries, allowing the past experiences of one member (or group) to enable others to successfully deal with barriers or challenges related to injury prevention they discover in their practice.

Submitted: December 01, 2020 CST, Accepted: January 01, 2021 CST

This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY-NC-ND-4.0). View this license’s legal deed at https://creativecommons.org/licenses/by-nc-nd/4.0 and legal code at https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode for more information.
REFERENCES


PT Genie

IN-OFFICE  TELEHEALTH  RPM

A DIGITAL HEALTH SOLUTION FOR HEP | NOT A REPLACEMENT FOR IN-HOUSE PT, IT'S AN ENHANCEMENT!

hello@ptgenie.com  +1 833.784.3643  www.ptgenie.com
PERFORMANCE & RECOVERY

We believe in Powering Motion. Activity is the key to living a healthier lifestyle, better treatment outcomes, and improved healthcare economics for all. We do this by delivering a complete Orthopedic Continuum of Care from performance and mobility to surgical intervention and post-operative rehabilitation. Get and keep people moving—that’s our philosophy.

djoglobal.com