Build on the unrivaled Woodway running experience by adding resistance to your run and reap the benefits of sled pushes, parachute runs and more with the Woodway FTG.

Contact us at 800-WOODWAY or info@woodway.com to experience the Woodway difference.
TARGETED PAIN RELIEF

The Intelect® RPW 2 allows for the treatment of indications with radial, pneumatically-generated, low-energy acoustic waves, or ‘pressure pulses’. The applied pressure pulse propagates radially within the tissue generating a therapeutic effect.

THE INTELECT® RPW 2 IS INDICATED TO TEMPORARILY INCREASE BLOOD FLOW & HELP REDUCE PAIN ASSOCIATED WITH:

• Achilles Tendinopathy¹
• Disorders of Tendon Insertions¹
• Myofascial Trigger Points²
• Plantar Fasciitis³

Scan the QR code to request a quote, or visit learn.chattanoogarehab.com/ijspt-dec-23-journal-quote.
Welcome to the Fifth World Congress of Sports Physical Therapy, presented by the International Federation of Sports Physical Therapy and NFFs Faggruppe for Idrettsfysioterapi og Aktivitesmedisin!

Join us June 14-15, 2024 in beautiful Oslo, Norway for a fantastic experience, whether you are a novice or experienced clinician. You will meet up with colleagues from all around the world, sharing knowledge, best practices, create networks and have a lot of fun. Enjoy an exciting schedule full of interesting lectures and engaging workshops!

Key Dates:
- February 28, 2024: Abstract Submission Deadline
- March 28, 2024: Early Bird Pricing Deadline
- May 14, 2024: Workshops
- June 13, 2024: IFSPT General Meeting
- June 14-15, 2024: Congress

From Research to Clinical Practice
- 18 practical Workshops
- Oral presentations
- Posters
- Networking opportunities

IMPORTANT!
BOOK YOUR HOTEL ROOM NOW WHILE SELECTION AND EXCHANGE RATE ARE IDEAL!

REGISTRATION IS NOW OPEN AT WCSPT.ORG!

Presented by
And
IFSPT

Fifth World Congress of Sports Physical Therapy
Norway

的关键日期：
- 2024年2月28日：摘要提交截止日期
- 2024年3月28日：早鸟定价截止日期
- 2024年5月14日：研讨会
- 2024年6月13日：IFSPT一般会议
- 2024年6月14-15日：大会

从研究到临床实践
- 18个实际研讨会
- 口头报告
- 海报
- 网络机会

重要！
现在预订您的酒店房间！选择和汇率是理想的！

注册现在在WCSPT.ORG上打开！

由
并
IFSPT

第五届世界体育物理治疗大会
挪威


Board of Directors / Business Advisory Board

Turner A Blackburn, APTA Life Member, AT-Ret, AOSSM-Ret, President
Mary Wilkinson, Executive Director
Michael Voight, Executive Editor and Publisher
Joe Black, PT, DPT, SCS, ATC
Eric Fernandez
Jay Greenstein, DC
Skip Hunter, PT, ATC-Ret
Russ Paine, PT, DPT
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

Staff

Executive Editor/Publisher
Michael L. Voight, PT, DHSc, OCS, SCS, ATC, CSCS
Executive Director/Operations and Marketing
Mary Wilkinson
Editor in Chief
Barbara Hoogenboom, PT, EdD, SCS, ATC
Managing Editor
Ashley Campbell, PT, DPT, SCS, CSCS
Manuscript Coordinator
Casey Lewis, PTA, ATC

NORTH AMERICAN SPORTS MEDICINE INSTITUTE
Publisher

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

IJSPT is a monthly publication, with release dates on the first of each month.

ISSN 2159-2896

Underwriting Sponsor
Genie Health

Founding Sponsors
Biodex
Enovis
Exertools
Hyperice
Trazer
Woodway

Platinum Sponsors
ATI
Elvation

Gold Sponsors
Hawkgrips
Kayezen
Structure + Function Education
Winback

Partners
Northeast Seminars
Academy of Human Movement
American Academy of Sports Physical Therapy

IJSPT is an official journal of the International Federation of Sports Physical Therapy (IFSPT). Countries with access to IJSPT as a member benefit. Reach us at www.ifspt.org.

LJSPT is an official journal of the ICCUS Society for Sports Rehabilitation.
www.iccus.org
PiezoWave²T
FASTER. SMARTER. LIGHTER.
The Best Rehab Technology Just Got Better

Discover Why More Clinicians are Choosing PiezoWave²

- Locates and alleviates musculoskeletal pain
- Improves mobility
- Non-invasive, outpatient treatment
- Proven lowest maintenance cost
- Minimal noise during treatment
- Most reliable in the marketplace

Elvation Medical LLC
1475 Alderman Drive • Alpharetta, GA 30005
Office: (770) 295-0049 • Fax: (678) 417 6273
info@elvationusa.com • www.elvationusa.com

© 2023 by Elvation Medical LLC. All rights reserved. This brochure was prepared for use in the USA by medical professionals; it can contain information about products, software and indications which may not be available in other countries. Subject to change without notice/images may vary. Tablet PC and products/components shown may be optional / not included in the scope of delivery. All HIO data is based on positive energy flux density. All specifications relating to other technologies may vary from manufacturer to manufacturer. The Elvation HUB requires an internet connection.


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.
Gold Standard Sports Medicine Solutions

From Pre-Op to Return-to-Play

Biodex™ advanced rehabilitation technology allows clinicians to quantify performance parameters – before and after an injury occurs.

Detailed reports track recovery and provide the medical team with quantitative data to help with the return-to-play decision.

Understand Test Results at a Glance
Return-to-Play Reports help to simplify the RTP decision with clear pass/fail results.
Technology designed for rehabilitation and improving movement regardless of age or level of physical capability.

IMMERSIVE
REACTION-BASED ACTIVITIES
Assessments | Workouts | Injury-Specific Protocols | Drills | Games

MEASURE WHAT MATTERS
Simultaneously measures physical and cognitive function for holistic rehabilitation and improved neuromechanical performance.

ALIGNING CARE, DATA, & ROI
Aligned with CPT 97 Billing Codes
Aligned to deliver better outcomes for end-users, care professionals, and organizations.

www.trazer.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, APTA Life Member, ATC-Ret, AOSSM-Ret
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, DHSc, SCS
Belarmine 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. Johns, 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
Zürich, 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
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

Jay Greenstein, DC
Kaizo Health
Baltimore, MD, USA
EDITORIAL BOARD

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

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 Schuermann, 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 Ummukulthoum, 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, MSc
Lund University
Stockholm, Sweden
# TABLE OF CONTENTS

## VOLUME 19, NUMBER 1

<table>
<thead>
<tr>
<th>PAGE</th>
<th>TITLE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SYSTEMATIC REVIEW</strong></td>
<td></td>
</tr>
</tbody>
</table>
| 1381 | Sink or Swim? Clinical Objective Tests and Measures Associated with Shoulder Pain in Swimmers of Varied Age Levels of Competition: A Systematic Review.  
Kennedy JS, Otley T, Hendren S, et al. |
| 1398 | What is the Injury Incidence and Profile in Professional Male Ice Hockey? A Systematic Review.  
Cattaneo M, Ramponi C, Thorborg K. |
| **SCOPING REVIEW** | | |
| 1410 | Sensorimotor Dysfunction Following Anterior Cruciate Ligament Reconstruction- an Afferent Perspective: A Scoping Review.  
Vithrana TN, King E, Moran K. |
| **ORIGINAL RESEARCH** | | |
| 1438 | Photobiomodulation Therapy Plus Usual Care Is Better than Usual Care Alone for Plantar Fasciitis: A Randomized Controlled Trial.  
| 1454 | Impact of Concussions on Postural Stability Performance Using the Head Shake-Sensory Organization Test.  
Heick JD, Alkithiry AA. |
| 1462 | Physically Active Adults with Low Back Pain Do Not Demonstrate Altered Deadlift Mechanics: A Novel Application of Myotonometry to Estimate Inter-Muscular Load Sharing.  
| 1473 | Effects of a Total Motion Release (TMR®) Protocol for the Single Leg Squat on Asymmetrical Movement Patterns.  
Martonick NJP, Baker RT, McGowan CP, et al. |
| 1484 | Reliability of the EasyAngle® for Assessing Hip Range of Motion in Healthy Children.  
| 1494 | A One Session Gait Retraining Protocol with Metronome Augmentation Increases Cadence in Novice and Recreational Runners.  
Huber AS, Verhof DT. |
| 1503 | Effect of a Novel Training Program in Patients With Chronic Shoulder Pain Based on Implicit Motor Learning: Pilot and Feasibility Study.  
| **MUSCULOSKELETAL ULTRASOUND BITES: TIPS AND TRICKS** | | |
| 1516 | MSK Diagnostic Ultrasound for the Assessment of the Acromioclavicular Joint.  
Manske RC, Voight M, Page P, Wolfe C. |
| **DIGITAL HEALTH CORNER FROM GENIE HEALTH** | | |
| 1521 | Implementing a Hybrid Model of Therapy is a Win for Therapists, Patients and Payers.  
Ben Galin, DPT, Vice President of Strategy, Genie Health |
delivered a virtual therapy solution to your organization

Genie Health at a glance...

Founded by two prominent orthopedic surgeons and leveraged by two of the top 10 largest orthopedic groups in the country, Genie Health is managed by therapists and industry experts.

Featuring a monitored HEP using computer vision, Genie Health offers both fee-for-service and value-based-care models on the same platform.

Tech platform & optional clinical staff turn-key solution

PT genie  
digital physical therapy solution combining remote monitoring and telehealth

Sports genie  
in-clinic and remote sports/functional assessment and management

WoRx genie  
risk assessment and remote management tools for occupational health

Improve

Revenue

Accessibility

Staffing challenges

genie.health | sales@genie.health | 321-558-6855
Most Advanced Electrotherapy Device:

- Powerful, intuitive and user-friendly
- Treat up to three body zones at once on all types of tissues
- Effective in less than 10 minutes

Enter A New Era of Therapy

- TECAR
  - High Frequency
  - Metabolic Action at Cell Level
- Hi-TENS
  - Low Frequency in Pulsed High Frequency
  - Ultimate Pain Management
- Hi-EMS
  - Medium Frequency
  - Deep Muscle Contraction

Access BACK4 Case Studies

Schedule a consultation with a Winback Expert

hello@winback.com
133 Westchester Ave Ste N-220
White Plains NY 10604
www.winback.com
www.winback-academy.org
GOLD STANDARD OF IASTM

NEW TOPICAL SOLUTIONS

CERTIFICATION COURSES

GET A GRIP ON SOFT TISSUE INJURIES

See what’s new at HawkGrips

GET A GRIP ON SOFT TISSUE INJURIES

www.HawkGrips.com • info@hawkgrips.com • 484-351-8050

IMPROVED EXPERIENCES FOR PATIENTS AND YOUR TEAM

AWARD-WINNING DIAL-IN RESISTANCE SYSTEM.

• Instant, dial-in system offers 10-100 pounds of resistance
• More comfortable accessories for targeted resistance from ankle to shoulder
• Ability to anchor ANYWHERE. ANYTIME. IN LESS TIME.

LIMITLESS OPTIONS. FASTER SETUP TIMES.

• Delivers widest range of isometric and dynamic exercise options in a single system
• Quickly swap in VECTORS to address stability, mobility and strength needs
• Optimal solution for smaller spaces or when traveling

“I UTILIZE MY VECTOR EVERY DAY AND I LOVE IT!”

Kevin Wilk, DPT, FAPTA - Champion Sports Medicine

Visit us at www.kayezen.com/ijsp
LEADING CLINICAL RESEARCH AND ADVANCEMENT OF OUR PROFESSION

Thursday, February 15, 2024
- Perceptions of Personalized Clinical Decision Support in Rehabilitation after Total Knee Arthroplasty: A Qualitative Study

Friday, February 16, 2024
- Implementation of a Stepped Care Model Reduces Time to Care in Scholastic Athletes
- Latin American Pitchers Display Greater Arm Injury Rates Compared to North American Pitchers
- Effectiveness of Personalized Clinical Decision Support in Outpatient Rehabilitation after Total Knee Arthroplasty
- The Female Overhead Athlete: Sex- and Sport-Specific Considerations for Rehabilitation
- Implementation of CPGs to Improve Treatment for Patients with Neck Pain
- Implementation of a Stepped Care Model Reduces Time to Care in Scholastic Athletes

Saturday, February 17, 2024
- Patient Experience Measures Demonstrate Association with Discharge Outcomes in Patients with Knee Disorders
- Clinician Productivity Unrelated to Patient Outcomes in Nationally Representative, Outpatient Physical Therapy Sample
We are a mission-driven online community seeking to change outcomes with research while helping direct-access clinicians improve the overall awareness and quality of care for concussion patients across the globe with robust educational programming, open office hours, and non-profit partnerships.

**JOIN US FOR WINTER 2024**

**CONCUSSION: The Patient Rehabilitation Journey PART I**

- **DURATION**: Jan-21 thru Apr-28, 2024
- **CLASS**: 12 Weeks Online
- **CONTENT**: On-Demand | Virtual Live
- **COURSE FEE**: Starting at $997
  - Group Pricing Available
- **CE**: 20 Hours for PT, OT, ATC

A donation will be made to our Non-Profit Partner, Headway Foundation, when you sign up with the IJSPT QR code below.

**REGISTRATION OPEN NOW**

ConcussionCorner.org
JOIN OUR ONLINE COMMUNITY
[QR Code]

**EDUCATIONAL PARTNER**

IJSPT
International Journal of Sports Physical Therapy

**LEARN FROM OUR Interdisciplinary Rehabilitative Faculty Team**

- **Christina Master**: MD, FACSM
- **Lenore Herget**: PT, DPT, SCS
- **Dustin Fink**: MS, ATC
- **Becky Bliss**: PT, DPT, DHSC
- **John Leddy**: MD, FACSM
- **Jessica Schwartz**: PT, DPT, CSCS
Sink or Swim? Clinical Objective Tests and Measures Associated with Shoulder Pain in Swimmers of Varied Age Levels of Competition: A Systematic Review

June Kennedy1, Thomas Otley1, Steph Hendren2, Heather Myers2, Angela Tate3

1 Rehabilitation Services, Duke University Health System, 2 Athletics, University of Miami, 3 Medical Center Library, Duke University. 4 Rehabilitation, Duke University Health System. 5 Arcadia University

Keywords: swimming, shoulder pain, objective tests

https://doi.org/10.26603/001c.90282

BACKGROUND

Swimming is enjoyed by athletes of all ages, and shoulder pain is a common problem. Clinicians identify impairments which impact shoulder pain and these impairments may differ depending on the swimmer’s age competition level.

PURPOSE

The purpose of this study was to investigate objective measures utilized to assess swimmers and assess the relationship of test values to shoulder pain in distinct age groups/competition levels. A secondary aim was to report normative/expected values for these tests.

DESIGN

Systematic review

METHODS

PRISMA methodology was employed to assess studies evaluating clinical tests and measures associated with shoulder pain for swimmers in varied age competition levels. The Methodological Index for Non-Randomized Studies instrument was used to evaluate the quality of the included studies, and a qualitative synthesis of findings was conducted to determine the strength of the evidence in four age competition levels for nine objective measures. Distinct cut points for proposed measures were identified.

RESULTS

Twenty-seven studies were included in the analysis and the majority were of moderate quality in adolescent/adult swimmers. Youth swimmers had limited evidence for the development of shoulder pain associated with scapular position/dyskinesia, weakness of periscapular muscles, low endurance of core muscles, and moderate evidence for shoulder pain associated with laxity and altered range of motion (ROM). Adolescent/ adult swimmers demonstrated limited evidence for a positive association between developing shoulder pain if there is a low eccentric ER:concentric IR ratio, and moderate evidence for pectoralis minor tightness and glenohumeral laxity. There were limited studies regarding masters swimmers to derive conclusive evidence. Cut points were identified from the included studies but these have not been validated in other studies.

Corresponding Author:
June S. Kennedy, PT, DPT
Department of Rehabilitation Services
Duke University Health Systems
Durham, NC 27708, USA
Phone: (919) 681-1656
Fax: (919) 684-8958
Email: june.kennedy@duke.edu
CONCLUSION
Swimmers of various ages may have different objective clinical tests and measures associated with the risk for developing shoulder pain. More studies are needed to fully understand risk factors for shoulder pain in the masters swim competition level, and to validate recommended cut points for various tests and measures.

Key level of evidence
3, Systematic review of mostly Level 3 studies

INTRODUCTION
Shoulder pain in swimmers has consistently been noted to interfere with swimming training and competition. In 1993, McMaster and Troup published the first large scale United States survey documenting the prevalence of shoulder pain interfering with practice or competition to be 10-26% in a group of 1262 swimmers.1 They also identified aspects of training that swimmers reported aggravated their pain, such as use of paddles, kickboards and stretching. Since that time, additional factors associated with shoulder pain and injury have been studied and the prevalence of shoulder pain in swimmers of varied ages and competitive levels has been well documented.2,3 Given this high pain prevalence, it may not be surprising that a study of baseline shoulder function using the Kerlan-Jobe orthopedic clinic score reported that scores of NCAA swimmers are lower than those of athletes in other overhead sports, and are similar to injured athletes in other sports.4 In addition, except for neurolysis for suprascapular neuropathy, arthroscopic surgery has had limited success in returning swimmers to prior competitive training volume and level.5,6 Therefore, the mainstay of treatment for competitive swimmers is conservative management and Khodaee et al. report that most patients with shoulder pain shoulder cases can be treated with rehabilitation, a proper strengthening routine, and correction of stroke flaws.7

In order to provide appropriate rehabilitation, knowledge of the factors associated with shoulder pain and injury is important for health care providers treating competitive swimmers. Both intrinsic and extrinsic variables have been cited in etiology of shoulder pathology. Extrinsic variables include number of years of swim3,8 prior history of shoulder pain or injury,5,9,10 and training variables such as acute:chronic workload ratio, which is calculated using the current training volume in relation to the rolling average of the volume of training over the prior four weeks.11-13 A recent systematic review explored the impact of swim volume on various age competition levels and determined that adolescent swimmers experienced the highest level of shoulder pain although adult swimmers had a comparatively higher swim volume.14 Intrinsic factors are specific to the individual swimmer, such as stroke technique, muscle force capacity and endurance, posture and mobility, and, if appropriately identified, may be amenable to change.15 Although stroke characteristics, such as hand entry crossover during freestyle swimming, have been associated with shoulder pain, the videotaping and complex stroke analysis techniques used by researchers may preclude their use in clinical practice.11,12,16

METHODS
STUDY DESIGN
This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines, and was prospectively registered in Prospero (CRD42021224198)

SEARCH STRATEGY AND ELIGIBILITY
A literature search was conducted by a professional medical librarian (SH) using Medline (via OVID), Embase, CINAHL Complete, SPORTDiscus, and SCOPUS from inception through November 5, 2020. This literature search was updated on May 2, 2022 in order to capture any additional relevant research published since the onset of this project. Search keywords included swimming, shoulder, objective tests and measures. The full search strategy and outcome are summarized in Appendix A. Specific criteria for consideration in the literature search are outlined the Population Intervention Comparison Outcome Time (PICOT) chart in Table 1. Inclusion criteria were articles about swimmers which delineated the age group/competition level, objective tests or measures, and compared measures between groups with and without pain. Exclusion criteria were articles about non-swimming athletes, athletes with history of prior shoulder surgery, studies not reporting on a group that had pain, interventional studies, and non-English publications.
Table 1. Population Intervention Comparison Outcome Time (PICOT) chart

<table>
<thead>
<tr>
<th>Key Concepts, Synonyms</th>
<th>Inclusion Criteria</th>
<th>Exclusion Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient population / problem</td>
<td>Swimmers; Age group, Elite (NCAA, National, Olympic), Masters</td>
<td>Non-swimming UE athletes, Water-polo, Triathletes, Synchronized Swimmers</td>
</tr>
<tr>
<td>Interventions / prognostic factors</td>
<td>Physical examination tests: Rotator cuff and/or scapular strength in any test position (Isokinetic, HHD), Posterior Shoulder Endurance Test (PSET), Athletic Shoulder (ASH) test, ER/IR/ elevation PROM, pectoralis minor/lattissimus dorsi length, core stability (e.g. side bridge), thoracic rotation ROM, YBT-UQ, Hypermobility (e.g. Beighton score), etc.</td>
<td>Subjective measures, Patient questionnaires only (no objective measures); Surgical interventions/procedures</td>
</tr>
<tr>
<td>Comparison</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Outcome</td>
<td>Values/results from tests listed above. Pain, Injury</td>
<td>Qualitative studies</td>
</tr>
<tr>
<td>Time</td>
<td>Pre-season, in-season, post-season screens; other symptomatic/non-symptomatic assessments</td>
<td>Studies reported in a foreign language</td>
</tr>
<tr>
<td>Study Types</td>
<td>Prospective and Retrospective Observational Studies Cohort Cross-sectional Case reports RCT Systematic Reviews Meta-Analyses</td>
<td></td>
</tr>
</tbody>
</table>

UE= Upper Extremity, NCAA= National Collegiate Athletic Association, HHD= Hand Held Dynamometry, ER= External Rotation, IR= Internal Rotation, PROM= Passive Range of Motion, RDM= Range of Motion, YBT-UQ= Y-Balance Test of the Upper Quarter

STUDY SELECTION

Two reviewers (JK and TO) used Covidence systematic review software (Veritas Health Innovation Ltd, Melbourne, Australia) to independently screen titles and abstracts that were identified in the literature search, and the same reviewers screened articles selected for full-text review. Disagreement at the title and abstract review stage as well as the full-text review stage was reached by a third party (AT) who was blinded to the two voters’ selections. Following screening, a hand search of included references was performed to identify articles which may have been missed in the preliminary literature search.

QUALITY ASSESSMENT OF THE INCLUDED STUDIES

Two reviewers independently determined the study level of evidence using the Oxford Centre for Evidence-Based Medicine levels of evidence from I to V. These two reviewers also independently scored the risk of bias for non-randomized studies using the Methodological Index for Non-randomized Studies (MINORS) tool. Consensus on disagreements in score was reached by discussion. The MINORS appraisal tool assigns a score of 0 (not reported), 1 (inadequately reported), or 2 (adequately reported) to eight items for non-comparative studies, and an additional four items for comparative studies. The scores are categorized regarding the quality of study in the following manner: 0-6 is very low; 7-10 is low, 11-16 is moderate, and >16 is strong.

DATA EXTRACTION

A custom data extraction sheet was developed using Microsoft Excel (Microsoft Corporation, Redmond, WA), and extraction was performed by three of the investigators (JK, TO and AT). All of the articles underwent a second assessment of data extraction by one of the same three investigators to reach agreement on extracted data.

Extracted data included study characteristics (lead author, year of publication, time to final end point for follow-up, type of study, and sample size) and patient information (gender, age, competition level), all objective tests and measures associated with shoulder pain, and the what the association of objective tests and measures was to the presence of shoulder pain. The swimming competition age level was determined as follows based on a combination of recommended age divisions by the USA swimming competition levels and age groupings in included studies was based on the mean reported age to arrive at the following breakdown of age levels of competition:

- Youth – less than 14 years of age
- Adolescent/Adult – 15-27 years of age
- Masters – over 27 years of age
- Various age levels – the reported ages studied included at least two of the above levels

DATA ANALYSIS

The agreeability between the two reviewers at the title/abstract and full-text review stages is reported as a Cohen’s
The literature search identified 2180 articles from the data sources, which decreased to 918 studies screened after duplicates were removed. Full text review was conducted on 127 articles. The level of agreement between the two reviewers for the title and abstract phase and full-text review phase was 0.80 and 0.81, respectively, indicating substantial to nearly perfect agreement. Following title and abstract and subsequent full-text review, 22 articles were included for data extraction following the initial search and five additional articles were included after the updated search. Figure 1 provides the PRISMA diagram.

**RESULTS**

Seven studies evaluated the impact of internal and external rotation strength on shoulder pain with four using hand held dynamometry and three using isokinetic testing systems. Moderate evidence was reported using the method described above to determine if the overall evidence is strong, moderate limited, conflicting, or no evidence. The summary of objective variables studied, risk of bias, and strength of evidence by age group is detailed in Table 3. The synthesis of the strength of evidence sorted by level of competition is summarized in Table 4.

**INTERNAL AND EXTERNAL ROTATION STRENGTH**

Table 2. Strength of evidence for objective tests and measures.

<table>
<thead>
<tr>
<th>Strength of Evidence</th>
<th>Two or more studies with low risk of bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong evidence</td>
<td>Two or more studies with moderate or high risk of bias, OR two studies with consistent findings in which one of the studies has a low risk of bias</td>
</tr>
<tr>
<td>Moderate evidence</td>
<td>One study with low risk of bias, OR two studies with moderate or high risk of bias</td>
</tr>
<tr>
<td>Limited evidence</td>
<td>Studies demonstrating differing associations</td>
</tr>
<tr>
<td>Conflicting evidence</td>
<td>No study</td>
</tr>
</tbody>
</table>

Kappa Correlation Coefficient (K). A small correlation is said to exist if the K value is <0.4 moderate agreement 0.41-0.6, substantial agreement 0.61-0.8, and nearly perfect agreement 0.81-1.0.

**QUALITY OF EVIDENCE**

There were four Level IV noncomparative studies that were either case series or prospective cohorts with low numbers, 12 Level III prospective case-controlled studies, three Level III prospective correlational studies, and seven Level II prospective cohort studies. There were no Level I randomized controlled trials.

The MINORS score for the Level IV studies ranged from 7-10, indicating a low quality of evidence. The MINORS score for the Level III prospective case-controlled studies ranged from 11-19 which indicates an overall strong level of evidence although four of the studies in this category were only moderate level. The three Level III prospective correlational studies had a MINORS score which ranged from 10-15 indicating a moderate level of evidence. The eight Level II prospective cohort studies had a MINORS score which ranged from 9-19 with the majority of the studies demonstrating moderate evidence, and one having strong evidence. The Oxford Levels of Evidence and the MINORS scores for all of the studies included for analysis in this systematic review are provided in Appendix B.

The Oxford Levels of Evidence and the MINORS scores for all of the studies included for analysis in this systematic review are provided in Appendix B.

Due to heterogeneity amongst study methods, the overall recommendation for strength of evidence for each objective variable assessed for relationship to shoulder pain is swimmers is reported using the method described above to determine if the overall evidence is strong, moderate limited, conflicting, or no evidence. The summary of objective variables studied, risk of bias, and strength of evidence by age group is detailed in Table 3. The synthesis of the strength of evidence sorted by level of competition is summarized in Table 4.

The influence of scapular position and/or scapular dyskinesia on shoulder pain in swimmers was assessed in seven studies. Methods employed for analyzing the scapula position and dyskinesia included digital inclinometry of scapular position at various points of shoulder range of motion, the Kibler Test for distance from the spinous processes of the seventh and third thoracic vertebrae to the scapula, and visual inspection (dyskinesia present, yes or no). The age groups of the swimmers One study examined youth, four examined adolescents/adults,
Table 3. Summary of levels of evidence for each objective test and measure sorted by age level of competition.

<table>
<thead>
<tr>
<th>Descriptive Characteristic</th>
<th>Study (Author, Year)</th>
<th>Age Competition Level</th>
<th>Gender</th>
<th>Method</th>
<th>Test Type/Position</th>
<th>Pain/Injury</th>
<th>Relationship</th>
<th>ROB</th>
<th>Strength of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment of External Rotation and Internal Rotation Strength</td>
<td>Bak Magnusson, 1997</td>
<td>Adolescent/ adult</td>
<td>Male/Female</td>
<td>KinCom</td>
<td>90 Degree; ECC ER:CON IR</td>
<td>+</td>
<td>Decreased ratio</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Drigny, 2020</td>
<td>Adolescent/ adult</td>
<td>Male/Female</td>
<td>ConTreX loskinetic</td>
<td>45 Degree ECC ER:CON IR</td>
<td>+</td>
<td>Ratio Less Than 0.68</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tate, 2012</td>
<td>Varied age groups (8-77 years)</td>
<td>Male/Female</td>
<td>HHD</td>
<td>90 degrees; Grouped by Age Level</td>
<td>-</td>
<td></td>
<td>Mod</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Harrington, 2014</td>
<td>Adolescent/ adult</td>
<td>Female</td>
<td>HHD</td>
<td>90 Degrees</td>
<td>-</td>
<td></td>
<td>Mod</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>McIlwaine, J Sci Med Sport, 2018</td>
<td>Varied age groups (14-20 years)</td>
<td>Male/Female</td>
<td>HHD</td>
<td>90 Degrees</td>
<td>-</td>
<td></td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Boettcher, 2020</td>
<td>Adolescent/ adult</td>
<td>Male/Female</td>
<td>HHD</td>
<td>Neutral</td>
<td>-</td>
<td></td>
<td>Mod</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Beach, 1992</td>
<td>Adolescent/ adult</td>
<td>Male/Female</td>
<td>Cybex</td>
<td>Prone (60, 240 degrees/second)</td>
<td>-</td>
<td></td>
<td>High</td>
<td>Limited</td>
</tr>
<tr>
<td>Assessment of Scapular Position/ Dyskinesia</td>
<td>Brown, 2016</td>
<td>Adolescent/ adult</td>
<td>Male/Female</td>
<td>Dual Inclinometer</td>
<td>4 Phases of Elevation</td>
<td>+</td>
<td>Decreased Scapular Upward Rotation</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td></td>
<td>McIlwaine, Phys Ther Sport, 2018</td>
<td>Varied age groups (14-20 years)</td>
<td>Male/Female</td>
<td>Digital Inclinometer</td>
<td>90/140 degrees</td>
<td>-</td>
<td></td>
<td>Low</td>
<td>Conflicting</td>
</tr>
<tr>
<td></td>
<td>McKenna, 2012</td>
<td>Youth</td>
<td>Male/Female</td>
<td>Kibler Test</td>
<td>Kibler Grades</td>
<td>+</td>
<td>Decreased Kibler Neutral</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Welbeck, 2019</td>
<td>Adolescent/ adult</td>
<td>Male/Female</td>
<td>Kibler Test</td>
<td>Kibler Grades</td>
<td>-</td>
<td></td>
<td>High</td>
<td>Conflicting</td>
</tr>
<tr>
<td></td>
<td>Bak Fauno, 1997</td>
<td>Adolescent/ adult</td>
<td>Male/Female</td>
<td>Visual Inspection</td>
<td>Yes/No</td>
<td>+</td>
<td>Not Reported</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tate, 2012</td>
<td>Varied age groups (8-77)</td>
<td>Male/Female</td>
<td>Visual Inspection</td>
<td>Yes/No</td>
<td>-</td>
<td></td>
<td>Mod</td>
<td></td>
</tr>
<tr>
<td>Study (Author, Year)</td>
<td>Age Competition Level</td>
<td>Gender</td>
<td>Method</td>
<td>Test Type/ Position</td>
<td>Pain/ Injury</td>
<td>Relationship</td>
<td>ROB</td>
<td>Strength of evidence</td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>------------------------</td>
<td>--------</td>
<td>--------</td>
<td>---------------------</td>
<td>-------------</td>
<td>--------------</td>
<td>-----</td>
<td>---------------------</td>
<td></td>
</tr>
<tr>
<td>Pollen, 2023</td>
<td>Adolescent/ adult</td>
<td>Male/ Female</td>
<td>Visual Inspection</td>
<td>Yes/No</td>
<td>-</td>
<td></td>
<td>Mod</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tate, 2012</td>
<td>Varied age groups (8-77 years)</td>
<td>Male/ Female</td>
<td>HHD</td>
<td>Lower Trapezius, Middle Trapezius, Serratus Anterior</td>
<td>+</td>
<td>Decreased Middle Trapezius Strength in 8-11 year age group</td>
<td>Mod</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harrington, 2014</td>
<td>Adolescent/ adult</td>
<td>Female</td>
<td>HHD</td>
<td>Scapular Depression/ Abduction</td>
<td>-</td>
<td></td>
<td>Mod</td>
<td>Conflicting</td>
<td></td>
</tr>
<tr>
<td>Lippincott, 2018</td>
<td>Adolescent/ adult</td>
<td>Female</td>
<td>HHD</td>
<td>Upper trapezius, Lower Trapezius, Serratus Anterior</td>
<td>-</td>
<td></td>
<td>Low</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tate, 2020</td>
<td>Adolescent/ adult</td>
<td>Male/ Female</td>
<td>PSET</td>
<td>3 Points in Season</td>
<td>-</td>
<td>Increased Endurance, No Effect on Pain</td>
<td>Mod</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thomas, 2021</td>
<td>Masters</td>
<td>Male/ Female</td>
<td>PSET</td>
<td>-</td>
<td></td>
<td></td>
<td>Mod</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feijen, 2021</td>
<td>Youth</td>
<td>Male/ Female</td>
<td>PSET</td>
<td>+</td>
<td></td>
<td></td>
<td>Mod</td>
<td></td>
<td></td>
</tr>
<tr>
<td>McLaine, 2019</td>
<td>Varied age groups (14-20 years)</td>
<td>Male/ Female</td>
<td>Unclear</td>
<td>Flexion: Extension Ratio</td>
<td>+</td>
<td>Males Only (Flexion: Extension strength ratio was higher for the shoulders with pain reported in questionnaire)</td>
<td>Low</td>
<td>Limited</td>
<td></td>
</tr>
<tr>
<td>Harrington, 2014</td>
<td>Adolescent/ adult</td>
<td>Female</td>
<td>Side Bridge, Prone Bridge</td>
<td>Time</td>
<td>-</td>
<td></td>
<td>Mod</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lippincott, 2018</td>
<td>Adolescent/ adult</td>
<td>Female</td>
<td>CKCUEST</td>
<td>Number of Taps</td>
<td>-</td>
<td></td>
<td>Low</td>
<td>Conflicting</td>
<td></td>
</tr>
<tr>
<td>Tate, 2020</td>
<td>Adolescent/ adult</td>
<td>Male/ Female</td>
<td>Prone Bridge, Side Bridge, CKCUEST</td>
<td>Time/ Number of Taps</td>
<td>+</td>
<td>Side Bridge Endurance &lt; 8.5 seconds in 12-14 year age group</td>
<td>Mod</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Descriptive Characteristic

<table>
<thead>
<tr>
<th>Study (Author, Year)</th>
<th>Age/Competition Level</th>
<th>Gender</th>
<th>Method</th>
<th>Test Type/Position</th>
<th>Pain/Injury</th>
<th>Relationship</th>
<th>ROB</th>
<th>Strength of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdelmohsen, 2021</td>
<td>Youth</td>
<td>Male/Female</td>
<td>Trunk extension strength at 60 and 180 deg/sec, Side Bridge and Static Back Endurance Tests, Ball Bridge and Unilateral Bridge Tests</td>
<td>Multiple Core Test</td>
<td>+</td>
<td>Mod</td>
<td>Limited</td>
<td></td>
</tr>
<tr>
<td>Pollen, 2023</td>
<td>Adolescent/adult</td>
<td>Male/Female</td>
<td>Unilateral Bridge, CKCUEST</td>
<td>Time/Number of Taps</td>
<td>-</td>
<td>Mod</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Welbeck, 2019</td>
<td>Adolescent/adult</td>
<td>Male/Female</td>
<td>Thoracic Rotation Inclinometer</td>
<td>Degrees</td>
<td>-</td>
<td>High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pollen, 2023</td>
<td>Adolescent/adult</td>
<td>Male/Female</td>
<td>Trunk Flexion/Extension</td>
<td>Degrees</td>
<td>-</td>
<td>Mod</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bak Fauno, 1997</td>
<td>Adolescent/adult</td>
<td>Male/Female</td>
<td>Degrees</td>
<td>90 degrees</td>
<td>-</td>
<td>High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bansal, 2007</td>
<td>Varied age groups (17-35 years)</td>
<td>Male</td>
<td>Degrees</td>
<td>90 degrees</td>
<td>+</td>
<td>No Statistics Reported</td>
<td>Mod</td>
<td></td>
</tr>
<tr>
<td>Tate, 2012</td>
<td>Varied groups (8-77 years)</td>
<td>Male/Female</td>
<td>Degrees</td>
<td>90 degrees</td>
<td>+</td>
<td>Decreased IR (8-11 years)</td>
<td>Mod</td>
<td></td>
</tr>
<tr>
<td>Walker, 2012</td>
<td>Varied age groups (11-27 years)</td>
<td>Male/Female</td>
<td>Degrees</td>
<td>90 degrees</td>
<td>+</td>
<td>ER &gt; 100 degrees, &lt;93 degrees</td>
<td>Mod</td>
<td></td>
</tr>
<tr>
<td>Harrington, 2014</td>
<td>Adolescent/adult</td>
<td>Female</td>
<td>Degrees</td>
<td>90 degrees</td>
<td>-</td>
<td>Mod</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cejudo, 2019</td>
<td>Adolescent/adult</td>
<td>Male/Female</td>
<td>Degrees</td>
<td>90 degrees</td>
<td>-</td>
<td>Low</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matsuura, 2020</td>
<td>Adolescent/adult</td>
<td>Male/Female</td>
<td>Degrees</td>
<td>90 degrees</td>
<td>-</td>
<td>Mod</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tate, 2020</td>
<td>Adolescent/adult</td>
<td>Male/Female</td>
<td>Degrees</td>
<td>90 degrees</td>
<td>-</td>
<td>Mod</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thomas, 2021</td>
<td>Masters</td>
<td>Male/Female</td>
<td>Degrees</td>
<td>90 degrees</td>
<td>+</td>
<td>Decreased ROM: 10 degree IR; 8 degree ER; 18 degree total arc</td>
<td>Mod</td>
<td></td>
</tr>
<tr>
<td>Descriptive Characteristic</td>
<td>Study (Author, Year)</td>
<td>Age Competition Level</td>
<td>Gender</td>
<td>Method</td>
<td>Test Type/ Position</td>
<td>Pain/ Injury</td>
<td>Relationship</td>
<td>ROB</td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------------------</td>
<td>-----------------------</td>
<td>--------</td>
<td>--------</td>
<td>---------------------</td>
<td>-------------</td>
<td>--------------</td>
<td>-----</td>
</tr>
<tr>
<td></td>
<td>Mise, 2022</td>
<td>Youth</td>
<td>Male/ Female</td>
<td>Degrees</td>
<td>90 degrees</td>
<td>+</td>
<td>For males, Shoulder ER (right) was significantly lower in the pain group than the non-pain</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Pollen, 2023</td>
<td>Adolescent/ adult</td>
<td>Male/ Female</td>
<td>Degrees</td>
<td>GIRD (yes/ no)</td>
<td>-</td>
<td></td>
<td>Mod</td>
</tr>
<tr>
<td>Assessment of Other ROM</td>
<td>Cejudo, 2019</td>
<td>Adolescent/ adult</td>
<td>Male/ Female</td>
<td>Degrees</td>
<td>Horizontal Adduction</td>
<td>+</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Thomas, 2021</td>
<td>Masters</td>
<td>Male/ Female</td>
<td>Degrees</td>
<td>Horizontal Adduction</td>
<td>+</td>
<td>7.8 degree horizontal adduction</td>
<td>Mod</td>
</tr>
<tr>
<td></td>
<td>Ozaldiran, 2002</td>
<td>Youth</td>
<td>Male/ Female</td>
<td>Sum of flexion, extension, abduction, ER, IR, &amp; functional ER</td>
<td>Total ROM Score</td>
<td>+</td>
<td>Increase in total flexibility index (r not reported)</td>
<td>Mod</td>
</tr>
<tr>
<td>Assessment of Muscle Length</td>
<td>Mise, 2022</td>
<td>Youth</td>
<td>Male/ Female</td>
<td>Centimeters</td>
<td>Shoulder Rotation Width</td>
<td>+</td>
<td>Shoulder rotation width of the male higher in pain group and female lower in pain group</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Harrington, 2014</td>
<td>Adolescent/ adult</td>
<td>Female</td>
<td>Length Centimeters at Rest/ Stretch</td>
<td>Pectoralis Minor Length</td>
<td>+</td>
<td>Decreased pectoralis minor length on dominant arm</td>
<td>Mod</td>
</tr>
<tr>
<td>Assessment of Laxity</td>
<td>Tate, 2012</td>
<td>Varied age groups (8-77 years)</td>
<td>Male/ Female</td>
<td>Degrees Flexion; Centimeters at Rest/Stretch</td>
<td>Latissimus Dorsi Length/ Pectoralis Minor Length</td>
<td>++</td>
<td>Latissimus Dorsi 8-11 years, Pectoralis Minor 15-19 years</td>
<td>Conflicting</td>
</tr>
<tr>
<td></td>
<td>Lippincott, 2018</td>
<td>Adolescent/ adult</td>
<td>Female</td>
<td>Length Centimeters</td>
<td>Pectoralis Minor Length</td>
<td>-</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Matsuura, 2020</td>
<td>Adolescent/ adult</td>
<td>Male/ Female</td>
<td>Degrees Flexion</td>
<td>Latissimus Dorsi Length</td>
<td>-</td>
<td></td>
<td>Mod</td>
</tr>
<tr>
<td></td>
<td>Bak Magnusson, 1997</td>
<td>Adolescent/ adult</td>
<td>Male/ Female</td>
<td>Yes/No</td>
<td>Anterior Drawer, Sulcus</td>
<td>+</td>
<td>6/7 Painful Shoulders</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>McMaster, 2018</td>
<td>Adolescent/ Male</td>
<td>Clinical Examination Shoulder</td>
<td>Sulcus, Ant/</td>
<td></td>
<td>+</td>
<td>Increase in total score</td>
<td>Low</td>
</tr>
</tbody>
</table>
## Table: Clinical Objective Tests and Measures Associated with Shoulder Pain in Swimmers of Varied Age Levels of Competition: A Systematic Review

<table>
<thead>
<tr>
<th>Descriptive Characteristic</th>
<th>Study (Author, Year)</th>
<th>Age Competition Level</th>
<th>Gender</th>
<th>Method</th>
<th>Test Type/Position</th>
<th>Pain/Injury</th>
<th>Relationship</th>
<th>ROB</th>
<th>Strength of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1998</td>
<td>adult</td>
<td>Female</td>
<td>Score</td>
<td>Post Translation</td>
<td></td>
<td>associated with interfering pain</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sein, 2010</td>
<td>Varied age groups (13-25 years)</td>
<td>Male/Female</td>
<td>Yes/No</td>
<td>Sulcus, Ant/Post Translation</td>
<td>+</td>
<td>Increase in laxity and extreme pain</td>
<td>Mod</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bak Fauno, 1997</td>
<td>Adolescent adult</td>
<td>Male/Female</td>
<td></td>
<td>Carter/Wilkinson, Anterior Drawer, Sulcus</td>
<td>unclear</td>
<td>No Statistical Analysis</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bansal, 2007</td>
<td>Varied age groups (17-35 years)</td>
<td>Male</td>
<td>Yes/No</td>
<td>Sulcus</td>
<td>-</td>
<td></td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Walker, 2012</td>
<td>Varied age groups (11-27 years)</td>
<td>Male/Female</td>
<td>KT1000</td>
<td>Ant/Post Translation</td>
<td>-</td>
<td></td>
<td>Low</td>
<td></td>
</tr>
</tbody>
</table>

ROM= Risk of Bias, HHD= Hand Held Dynamometry, ECC ER:CON IR= Eccentric External Rotation:Concentric Internal Rotation Ratio, PSET= Posterior Shoulder Endurance Test, CKCUEST= Closed Kinetic Chain Upper Extremity Stability Test, ROM=Range of Motion, GIRD= Glenohumeral Internal Rotation Deficit.
and two examined varied age ranges. There is limited evidence from only a single study of youth swimmers demonstrating greater shoulder pain with swimming if they did not have a neutral position of the scapula with the Kibler Test. In conflict with this finding is limited evidence from one study using Kibler Test and one using visual inspection which both describe no relationship between scapular position/dyskinesia and shoulder pain for youth swimmers. Moderate evidence for no relationship between scapular position and shoulder pain was determined from two studies across age groups, one including youth and adolescent/adult swimmers employed digital inclinometry for assessing the scapula at various intervals of elevation and the other used visual inspection for swimmers across all age levels (age 8-77).

PERISCAPULAR MUSCLE STRENGTH

Seven studies evaluated the influence of periscapular muscle strength on shoulder pain in swimmers. Two studies were on youth swimmers, three were on adolescent/adult swimmers, one studied swimmers across the lifespan (8-77 years), one assessed masters swimmers, and one study assessed both youth and adolescent/adult ages. Handheld dynamometry was utilized to determine the strength of periscapular muscles in three studies, while the posterior shoulder endurance test was used in three studies, and one study did not clearly describe strength testing methods. Overall, there was moderate evidence for no relationship between scapular strength and shoulder pain in swimmers. There is limited evidence from two studies in youth swimmers to support the assertion that decreased scapular strength is associated with the development of shoulder pain. One study found a decrease in lower and middle trapezius strength, and one demonstrated poorer performance on the posterior shoulder endurance test for youth swimmers who developed shoulder pain.

CORE STABILITY/ENDURANCE

Five studies utilized various methods for analyzing core stability and endurance as a risk factor for developing shoulder pain. Methods included use of the closed kinetic chain upper extremity test (number of taps), the timed side bridge, timed prone plank, timed ball bridge, and isokinetic peak torque testing for trunk flexion/exten-
sion. One study reported on youth swimmers, three were on adolescent/adult swimmers, and one included various age groups. There is moderate evidence from two studies in youth swimmers that decreased trunk endurance is associated with the development of shoulder pain.\textsuperscript{26,42} One of these studies suggested that a time of less than 8.5 seconds for side plank in youth swimmers was a risk factor for developing shoulder pain.\textsuperscript{42} In contrast, three studies on adolescent/adult swimmers demonstrated moderate evidence that there was no relationship between core endurance and the development of shoulder pain.\textsuperscript{32,33,41}

THORACIC MOBILITY

Two studies assessed the impact of trunk mobility including thoracic rotation\textsuperscript{44} and trunk flexion/extension\textsuperscript{41} on the development of shoulder pain in adolescent/adult swimmers. These studies demonstrated limited evidence regarding the impact of trunk mobility as a risk factor for developing shoulder pain.

INTERNAL AND EXTERNAL ROTATION RANGE OF MOTION

The most widely studied objective variable as a risk factor for shoulder pain was shoulder internal and external range of motion, which was reported in 11 studies.\textsuperscript{3,10,24,25,30,32,34,40-43} One of the studies reports on youth swimmers, six report on adolescent/adult swimmers, one on masters, and three on swimmers of various ages. All of the studies except one used goniometry, and measured rotation at 90 degrees of abduction, while one study reported the presence or absence of glenohumeral internal rotation deficiency as "yes or no." In the adolescent/adult competition level, six studies demonstrated moderate evidence that there was not a relationship between shoulder rotation measures and the development of shoulder pain.\textsuperscript{24,30,32,34,41,42} In contrast, Walker et al.\textsuperscript{44} suggest that excessive ER (>100 deg) or diminished ER (<93 deg) were risk factors for developing shoulder pain in 11-27 year old swimmers.\textsuperscript{3} In comparison, there is moderate evidence demonstrating that youth swimmers have association between decreased range of motion and shoulder pain, including Tate et al.\textsuperscript{45} who examined 8-11 year olds and Mise et al.\textsuperscript{46} who examined 14 year-old boys and

### Table 4. Summary of synthesized strength of evidence for objective measures studied sorted by age level of competition.

<table>
<thead>
<tr>
<th>Objective variable measured</th>
<th>Youth &lt;14 years old</th>
<th>Adolescent/Adult 15-27 years old</th>
<th>Masters &gt;27 years old</th>
<th>Various Age Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR:ER strength ratio</td>
<td>No evidence</td>
<td>Limited + Ecc ER:Con IR (&lt;0.68 risk) Moderate - ER:IR</td>
<td>No evidence</td>
<td>No evidence</td>
</tr>
<tr>
<td>Scapular position/dyskinesia</td>
<td>Limited +</td>
<td>Conflicting: Limited + 3 studies Limited – 2 studies</td>
<td>No evidence</td>
<td>No evidence</td>
</tr>
<tr>
<td>Periscapular muscle strength</td>
<td>Limited evidence + when weak scapular mm. Moderate -</td>
<td>No evidence</td>
<td>No evidence</td>
<td></td>
</tr>
<tr>
<td>Core stability</td>
<td>Moderate + (&lt;8.5 second side plank) Moderate -</td>
<td>No evidence</td>
<td>No evidence</td>
<td></td>
</tr>
<tr>
<td>Thoracic mobility</td>
<td>Not reported Moderate -</td>
<td>No evidence</td>
<td>No evidence</td>
<td></td>
</tr>
<tr>
<td>Internal Rotation (IR) and External Rotation (ER) Range of motion</td>
<td>Moderate + Decreased IR in 8-11 year olds Increased ER in males Moderate -</td>
<td>No evidence</td>
<td>No evidence</td>
<td></td>
</tr>
<tr>
<td>Other Range of Motion (ROM)</td>
<td>Moderate + Increased ROM</td>
<td>Moderate +</td>
<td>No evidence</td>
<td></td>
</tr>
<tr>
<td>Flexibility</td>
<td>No evidence Moderate + Pectoralis Minor tightness</td>
<td>No evidence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laxity</td>
<td>Moderate + Moderate +</td>
<td>No evidence Conflicting: Moderate + Strong -</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

EccER:ConIR = Eccentric external rotation to concentric internal rotation ratio
ER:IR = External rotation to Internal rotation ratio
described that decrease IR and decreased ER, respectively were associated with greater risk for shoulder pain.\textsuperscript{10,40}

**OTHER RANGE OF MOTION**

Moderate level evidence for having excessive mobility associated with shoulder pain was described in two studies of youth swimmers using novel range of motion methods: one used a total ROM index and found that pain was associated with higher summation of mobility\textsuperscript{45}; the other used a shoulder rotation width index which was associated with shoulder pain if it was decreased in males, and increased in females.\textsuperscript{40} This index is purported to be an index of comprehensive shoulder motion combining glenohumeral and scapulothoracic movements; it is a measure of the minimal distance between the two hands that are holding a dowel while raising the arms as high overhead as possible without elbow flexion. One study on masters swimmers\textsuperscript{45} and one on adolescent/adult swimmers\textsuperscript{30} associated decreased horizontal adduction with shoulder pain. Cejudo et al. propose that a cut point of having less than 39 degrees of horizontal adduction is associated with 3.6 times the risk of developing shoulder pain with swimming in the adolescent/adult age competition level.

**MUSCLE LENGTH**

The influence of flexibility of the pectoralis minor muscles on shoulder pain in adolescent/adult swimmers is reported in three studies\textsuperscript{32-34} and across various age groups in one study.\textsuperscript{10} There was moderate evidence to support that tightness of the pectoralis minor muscle is associated with shoulder pain in the adolescent/adult swimmer. Both studies reporting on pectoralis minor muscle length measured in centimeters the distance from the tip of the coracoid process to the base of the 4\textsuperscript{th} rib.

**LAXITY**

Laxity was assessed for the glenohumeral joint in six studies by using the sulcus sign or the anterior/posterior drawer sign using a “yes or no” laxity score or using a KT1000 instrument.\textsuperscript{1,3,8,25-25} Three studies reported on adolescent/adult swimmers and three report swimmers of various ages. There is strong evidence to support that laxity is associated with pain in adolescent/adult swimmers and in swimmers of various ages.\textsuperscript{1,8,24} In contrast, two studies provided conflicting evidence demonstrating no association between laxity and shoulder pain for swimmers of various ages.\textsuperscript{5,25}

**DISCUSSION**

The primary aim of this systematic review was to investigate objective measures utilized to assess swimmers and assess the relationship of these assessments to shoulder pain in distinct age groups/competition levels. The majority of the studies were prospective cohorts of moderate quality with several being high quality and several low quality. A qualitative synthesis of data was conducted due to heterogeneity of methods of obtaining the objective measures. The secondary aim of determining specific cut off values for risk factors in objective measures was achieved in that several values are reported; however, these have not been tested for validation in other studies.

**YOUTH SWIMMERS**

Youth swimmers had shoulder pain associated with scapular dyskinesis (limited evidence for positive relationship), decreased periscapular muscle strength (limited evidence for positive relationship), reduced core endurance (moderate evidence for positive relationship), internal and external rotation ROM (moderate evidence of relationship if decreased IR or increased ER); and laxity (moderate evidence for positive relationship). A cutoff of <8.5 seconds for side plank was proposed for associated of shoulder pain developing in one study, but this has not been tested for validity in other studies. The trend in these findings suggests that youth swimmers may benefit from more strengthening and neuromuscular control exercises to optimize shoulder stability which may be more lax in this skeletally developing age group.

**ADOLESCENT SWIMMERS**

The majority of studies reported objective measures on adolescent/adult swimmers. This age group had increased risk of shoulder associated with ER:IR strength ratio when eccentric ER and concentric IR were assessed using isokinetic equipment, with a proposed cut off ratio of <0.68 associated with risk of developing shoulder.\textsuperscript{31} This cut-off ratio is also only reported in one study and has not been tested for validity. Moderate evidence for the adolescent/adult swimmers’ ER and IR strength in one static position using handheld dynamometry demonstrated no relationship with shoulder pain development. The conflicting evidence between these strength tests in this age group is likely attributable to the differing methods of assessing strength. Isokinetic strength testing may be a more accurate reflection of the demands of strength needs for swimmers and a better objective test than handheld dynamometry since the testing demonstrates strength throughout the range of motion and can assess both eccentric and concentric muscle strength. It is possible that eccentric posterior cuff activity compared to the concentric internal rotator contractions reflects the swimmer muscle activation patterns more closely than static measures of strength in one position with handheld dynamometry. The role of the scapula in the development of shoulder pain remains unclear in this age group as noted with conflicting evidence. Tightness of the pectoralis minor was associated with shoulder pain, and this may be related to the pectoralis minor creating an anterior scapular tilt which can contribute to impingement of subacromial structures.\textsuperscript{47}

**MASTERS SWIMMERS**

Masters swimmers were only represented in one study\textsuperscript{45} and therefore the ability to synthesize evidence was not attempted for this age group.
SWIMMERS ASSESSED ACROSS VARIED AGE LEVELS OF COMPETITION

The discrepancy of the role of laxity for swimmers across varied age levels may be related to the widespread ages represented in these studies. It is possible that younger swimmers may struggle more with laxity as noted in the youth and adolescent age levels,1,8,24 while older swimmers may not have as much trouble due to the glenohumeral joint becoming less lax with aging. A clinical inference from this could be that youth and adolescent swimmers would benefit from performing band stability exercises, while older swimmers might benefit more from stretching.

A recent systematic review assessed the association of symptom development with objective measures in all regions of the body in elite swimmers, however there was no delineation of age or competition level in that review.48 The authors reported on 17 studies for the upper extremity with similar scores on the MINORs risk of bias assessment to findings in this review which reflect overall moderate levels of evidence. Similar conclusions are reported regarding insufficient evidence regarding scapular static and dynamic positioning on the influence of shoulder pain, and those authors relate the lack of conclusive evidence to the diverse methods of assessing scapular position. The ecc ER:con IR ratio was also supported by moderate evidence in the recent systematic review with one study reporting that a ratio of >1.08 is associated with injury risk24; however, this cut point has not been validated in any prospective studies.

LIMITATIONS

Limitations of this systematic review include that only studies in English were included which may have resulted in studies having been excluded. Also, the heterogeneity of data collection methods precluded data pooling in meta-analysis. However, the rigorous method of synthesizing evidence based on the quality of studies allows for meaningful conclusions regarding objective tests for the varied age levels of competition.

CONCLUSION

Objective tests and measures have been identified which are related to the development of shoulder pain in swimmers of distinct age/competition levels. These clinical tests may prove helpful to assist providers in considering interventions which may prevent the development of shoulder pain. Further research is needed to assess the validity of identified test cut points, and to add to the data pool for the masters level swimmer.

CONFLICTS OF INTEREST

The Authors report no conflicts of interest.

Submitted: May 02, 2023 CST, Accepted: October 12, 2023 CST
© The Author(s)
REFERENCES


Sink or Swim? Clinical Objective Tests and Measures Associated with Shoulder Pain in Swimmers of Varied …

SUPPLEMENTARY MATERIALS

Appendix A

Appendix B
What is the Injury Incidence and Profile in Professional Male Ice Hockey? A Systematic Review.

Marco Cattaneo1,2, Carlo Ramponi1,4,5, Kristian Thorborg3,6,7,8

1 DEASS, University of Applied Sciences and Arts of Southern Switzerland, 2 Hockey Club Lugano, Switzerland, 3 Physiotherapy, Università Campus Bio-Medico, 4 Physiotherapy, University of Padua, 5 Kiné Rehab Center, Treviso, Italy, 6 Department of Orthopedic Surgery, Copenhagen University Hospital, 7 Department of Clinical Medicine, University of Copenhagen, 8 Physical Medicine & Rehabilitation Research-Copenhagen, Copenhagen University Hospital

Keywords: athletic injuries, ice hockey, incidence, professional athletes

https://doi.org/10.26603/001c.90591

BACKGROUND

Professional male ice hockey is characterized by a congested in-season match schedule and by different scenarios where the whole body is exposed to great internal and external forces. Consequently, injuries occur from head to toe. However, there is a lack of data synthesis regarding the injury incidence and profile in this population.

PURPOSE

The aim of this study was to conduct a systematic review to quantify the injury incidence rates in professional male ice hockey.

STUDY DESIGN

Systematic Review

METHODS

The electronic databases PubMed, CINAHL, Web of Science, ProQuest-Sport medicine & Education Index, and Pro-Quest Dissertation and Thesis were searched utilizing terms related to ice hockey and injuries. Studies were included if they provided the incidence of injury in professional male hockey players and reported injuries in terms of time lost. The modified Newcastle Ottawa Scale for cohort studies and the Strengthening the Reporting of Observational Studies in Epidemiology - Sports Injury and Illness Surveillance Statement were used to assess the methodological quality of the studies.

RESULTS

Eleven studies were included in the review. Match injury incidence ranged from 38 to 88.6 injuries/1000 hours of exposure, whereas training injury incidence varied from 0.4 to 2.6 injuries/1000 hours of exposure. Injuries of traumatic origin accounted for 76% to 96.6% of all injuries, with contusions and lacerations being the most common. Severe injuries accounted for 7.8% - 20% of all injuries. The lower extremities were the most susceptible to injury, comprising 27% to 53.7% of all reported injuries.

CONCLUSION

Professional male ice hockey players are exposed to a substantial risk of injury during competitions, with lower extremities being the most commonly affected body part. The majority of injuries are traumatic and severe injuries account for a notable portion of overall injury cases.

Corresponding Author:
Marco Cattaneo
marco.cattaneo@supsi.ch
INTRODUCTION

Men’s ice hockey is growing in popularity with more than 1.6 million athletes in 79 countries playing the sport annually.\(^1\) Although players wear well-developed protective gear, ice hockey is among the team sports with the highest injury incidence rate, particularly those of traumatic origin.\(^2\) Several reasons may explain the sport’s high traumatic injury rate. In men’s ice hockey, body checking is permitted and collisions between players may also happen incidentally. Moreover, fighting is an accepted component of the game in many professional leagues. Other sources of trauma include the aggressive use of carbon-made sticks, collisions with rigid boards or goals, lacerations incurred by skate blades, and contusion due to blocking of the vulcanized rubber-puck with the body. Traumatic injuries are of particular concern at elite levels, where players can skate at speeds close to 50 km/h and can shoot the puck at velocities above 150 km/h.\(^3\) Consequently, the internal and external forces generated by the athlete can be significant and lead to severe injuries.\(^4\) Professional athletes may also be particularly prone to overuse injuries as they are required to play three times a week over a seven to nine month competitive season.\(^5\) In summary, the highly traumatic nature of the sport, the congested match schedule and the competitive environment of the professional sport are all factors that seem to influence both the traumatic and overuse injury rate of ice hockey players at elite levels.\(^6\) In this context, a thorough overview of the injury incidence profile at professional levels may help the support staff to prioritize the application of risk reduction measures within teams to promote safer sport participation. Although a discrete number of studies have described the incidence and types of ice hockey related injuries in different professional leagues and competitions, most of the literature on the subject consist of case report or case series.\(^7-10\) Moreover, published research has often focused on a particular injury type or on a single anatomical location, such as concussions or hip/groin problems.\(^10,11\)

Therefore, the primary objective of the was to conduct a systematic review to quantify the injury incidence rates in professional male ice hockey. The secondary objective was to carry out a sub-analysis to determine the profile of injuries, with specific focus on anatomical location, mechanism, type and severity.

METHODS

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol was followed to conduct this study.\(^12,13\) The PRISMA checklist is presented in Appendix I.

INFORMATION SOURCES AND SEARCH STRATEGY

Eligible studies were identified by using a systematic computerized search performed between February 1\(^{st}\) and November 30\(^{th}\) 2022. PubMed, CINAHL, Web of Science and ProQuest-Sport medicine & Education Index databases were consulted. Pro-Quest Dissertation and Thesis was used to search potential unpublished studies. A two-compartment additive search with the following terms was created: (“Ice hockey” OR “Winter sport” OR “Winter Olympics”) AND (“Injury” OR “trauma” OR “strain” “sprain” OR “wound” OR “fracture”). Additionally, the subject headings terms “hockey”, “athletic injuries”, “wounds and injuries” and “epidemiology” were included. A complete scheme of the search strategies for each database is provided in Appendix II. The reference lists of the review articles recovered were manually searched to screen for potentially eligible studies not captured by the computerized searches.

Two reviewers (MC and CR) independently read the titles and the abstracts of the articles identified by the search strategy and those that did not meet the inclusion criteria were excluded. Thereafter, full text articles were reviewed for final exclusion. A third external reviewer (KT) was consulted to resolve discrepancies throughout the selection process as needed.

ELIGIBILITY CRITERIA AND STUDY SELECTION

To be included in this systematic review, the studies had to fulfill the following criteria:

1. Participants had to be professional male ice hockey players; that is athletes had to play for a team that was engaged in professional national leagues, professional tournaments or winter Olympics.
2. Injuries had to occur because of ice hockey training, professional ice hockey championships, professional international tournaments or winter Olympics.
3. Eligible studies had to report the number of missed training or competition days as result of injury.
4. Injury incidence rate must have been reported, or enough data provided to calculate it using standardized equations.
5. Overall injury incidence rate as a result of ice hockey participation had to be reported.
6. Studies had to be prospective or retrospective cohort studies available in full text and published in English before the 1st of November 2022.

Studies with data pertaining to non-elite competitions or regarding only female ice hockey players were excluded. Research with data including both elite and amateur competitions or male and female ice hockey were excluded unless data for the elite male cohort could be extracted. Studies adopting injury definitions other than time loss were excluded. Research that focused only on a particular injury type or on a single anatomical location were not included.

DATA EXTRACTION

Data from selected studies were extracted using a tailored standardized Microsoft Excel (version 16.29, 2019) spreadsheet. Data were grouped into three categories:

1. General study information: authors, year of publication, length of observation, location.
2. Study population: sample size.
3. Epidemiological information: injury incidence rate (overall vs training vs match injuries rates), anatomical location (lower extremities vs upper extremities vs trunk vs head and neck), mechanism of injury (traumatic vs non-traumatic), type of injury (bone vs joint vs muscle-tendon vs laceration vs contusion vs concussion vs others), severity of injury (1-7 days vs 8-28 days vs >28 days).

QUALITY EVALUATION

Two scales were used to assess the quality of the selected studies. External validity was assessed according to a modified version of the Newcastle Ottawa scale (NOS) for cohort studies. In particular, items number two (selection of the non-exposed cohort) and number five (comparability of cohorts on the basis of the design or analysis) were excluded as all participants of the selected studies were exposed to ice hockey participation. Reporting quality was assessed according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement, which contains the essential items that should be described in observational epidemiological studies and its extension. In particular, the STROBE Sports Injury and Illness Surveillance (STROBE-SIIS), which contains recommendations from the International Olympic Committee regarding observational studies in sports medicine was used. STROBE-SIIS adds 16 sub-items to the 54 included in the original STROBE checklist, therefore a maximum score of 50 indicates that the article fulfilled requirements for high-quality publication.

SYNTHESIS OF RESULTS

Data were aggregated and a narrative critical analysis was conducted. The incidence of injuries during games and training were analyzed separately. A sub-analysis of the same studies was conducted in order to determine the most frequent anatomical location, mechanism, type and severity of injury. A meta-analysis was not attempted because epidemiologic information was not reported consistently among the selected studies.

RESULTS

A total of 9379 references were identified after the search process, of which 3485 were excluded as duplicates. Five thousand, eight hundred and twenty-four studies were eliminated after reading the title and the abstract as the inclusion criteria were not met. Additionally, two articles were not retrieved. Therefore, the full text of 68 articles was reviewed. Twenty-six items were excluded due to a lack of reported data exposure and consequently the incidence rate could not be calculated. Twenty-nine studies were excluded for not meeting criteria and two other articles used duplicate data. Eleven articles were included in this systematic review. The flow chart of the selection process is presented in Figure 1.

QUALITY ASSESSMENT

All studies selected for this systematic review had a low bias risk with 10 possessing the maximum score on the points modified NOS (0 to 6 points). All studies collected data prospectively through a health staff member except Jorgensen et al., where athletes had to retrospectively self-complete a questionnaire on injuries sustained during the past season. For this reason, Jorgensen et al., had a modified NOS score of 5. Appendix III displays the results obtained from the modified NOS for all selected articles. With regard to the reporting quality of the studies, the results obtained with the STROBE-SIIS quality scale are presented in Appendix IV. The mean score was 33 (minimum: 28, maximum: 38), which represents a compliance of 66% of the items. None of the studies reported ethical committee approval and source of funding and study registration was reported only by Brunner et al. Moreover, none of the studies acknowledged potential biases and the validity of the collection tools was only reported by one study. Re-injury and injury burden were not calculated in any of the selected studies.

DESCRIPTIVE CHARACTERISTICS OF THE SELECTED STUDIES

All studies were published between 1986 and 2020 and the length of observation ranged from 1-10 years. One study analyzed the epidemiology of injury during international competitions (winter Olympics) and two studies reported the injury trends in a national team. The remaining studies focused on professional national leagues. The total sample size was 8712 athletes and the total number of injuries was 7502. Table 1 shows the main characteristics of each of the selected studies.

INJURY INCIDENCE RATE

The injury incidence rate during matches was reported by 10 studies and ranged from 38 to 88.6 injuries/1000 hours of exposure. Five studies included the injury incidence rate during training, with values between 0.4 and 2.6 injuries/1000 hours of exposure. Only three studies reported the overall injury incidence rate, which ranged from 2.14 to 5.6 injuries/1000 hours of exposure. Table 2 shows the injury incidence rate data for each of the selected studies.

ANATOMICAL LOCATION

As shown in Table 3, nine studies reported the anatomical location of the injuries. Five studies found that the lower extremities were the most affected by injuries, representing 27%-55.7% of all injuries, whereas four studies reported that injuries to the neck and head were the most common, representing 28%-50% of all injuries. Injuries to the upper extremities ranged from 12% to 25.5% and those to the trunk ranged from 7.8% to 26% of all injuries. The largest difference between study results was found in the neck and head category which ac-
accounted for 6.3% of total injuries in the study of Lorentzon et al., but represented 50% in another study by Lorentzon et al. Only two studies analyzed traumatic and overuse injuries separately. Both showed that the knee was the anatomical area most affected by trauma while the hip/groin region was the most prone to overuse issues.

MECHANISM OF INJURY

The mechanism of injury was reported by eight studies (Table 4). In all of these studies, the primary cause of injury was trauma, with values between 76% and 96.6%. Non-traumatic injuries ranged from 0% to 24%. Body checking and collision were the main cause of injury in six studies. Two studies found stick contact as the most prevalent cause. Three studies analyzed foul play and reported that it was the cause of 8-50% of injuries.

INJURY TYPE

As shown in Table 4, nine studies reported the type of injury that occurred during the observation period. Four studies found contusions as the most prevalent injury type, whereas three studies reported lacerations, one study joint-related injuries, and one study muscle-related injuries to be the most common. In particular, contusion accounted for 15%-46% of all injuries and laceration for 1%-26.8%. Fractures represented 4.7%-14.4% of all injuries, joint sprains or dislocation accounted for 12%-33% and muscle strain for 9%-24%. Concussions accounted for 18% of all injuries in the study of Brunner et al., while Lorentzon et al. did not observe any cases of concussion.

SEVERITY OF INJURY

Seven studies reported the severity of injuries (Table 5). Five studies found that the majority of injuries...
were mild (1-7 days of absence from practices or competitions), whereas two studies found that the majority of injuries were of moderate severity (8-28 days of absence). Severe injuries (> 28 days of absence) ranged from 7.8% in the study of Molsa et al. to 20% in the study of Ornon et al.

DISCUSSION

The aim of this systematic review was to quantify the incidence of injuries in professional male ice hockey, while the secondary objective was to carry out sub-analyses to determine the profile of injuries, with particular regard to anatomy, mechanism, severity, location and type of injury. The review shows that professional male ice hockey players...
Table 3. Anatomical location of injuries of the studies included.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Lower extremities</th>
<th>Upper extremities</th>
<th>Trunk</th>
<th>Head/neck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brunner et al¹⁸</td>
<td>47%</td>
<td>12%</td>
<td>16%</td>
<td>25%</td>
</tr>
<tr>
<td>Groger A.²⁰</td>
<td>Not given</td>
<td>Not given</td>
<td>Not given</td>
<td>Not given</td>
</tr>
<tr>
<td>Jorgensen et al¹⁷</td>
<td>27%</td>
<td>19%</td>
<td>26%</td>
<td>28%</td>
</tr>
<tr>
<td>Lorentzon et al a²²</td>
<td>53.7%</td>
<td>24.2%</td>
<td>15.8%</td>
<td>6.3%</td>
</tr>
<tr>
<td>Lorentzon et al b²¹</td>
<td>27.8%</td>
<td>13.9%</td>
<td>8.3%</td>
<td>50%</td>
</tr>
<tr>
<td>McKay et al²³</td>
<td>45%</td>
<td>24%</td>
<td>11%</td>
<td>20%</td>
</tr>
<tr>
<td>Molsa et al²⁴</td>
<td>Not given</td>
<td>Not given</td>
<td>Not given</td>
<td>Not given</td>
</tr>
<tr>
<td>Ornon et al²⁵</td>
<td>40.5%</td>
<td>25.5%</td>
<td>9%</td>
<td>25%</td>
</tr>
<tr>
<td>Petterson et al²⁶</td>
<td>37.8%</td>
<td>22.8%</td>
<td>8%</td>
<td>31.4%</td>
</tr>
<tr>
<td>Tegner et al²⁷</td>
<td>31.8%</td>
<td>17.6%</td>
<td>11.4%</td>
<td>39.2%</td>
</tr>
<tr>
<td>Tuominen et al²⁹</td>
<td>30.7%</td>
<td>21.8%</td>
<td>7.8%</td>
<td>39.7%</td>
</tr>
</tbody>
</table>

Table 4. Injury mechanism and type of the studies included.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Mechanism of injury</th>
<th>Injury type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T</td>
<td>NT</td>
</tr>
<tr>
<td>Brunner et al¹⁸</td>
<td>76%</td>
<td>24%</td>
</tr>
<tr>
<td>Groger A.²⁰</td>
<td>96.6%</td>
<td>3.4%</td>
</tr>
<tr>
<td>Jorgensen et al¹⁷</td>
<td>Not given</td>
<td>Not given</td>
</tr>
<tr>
<td>Lorentzon et al a²²</td>
<td>80%</td>
<td>20%</td>
</tr>
<tr>
<td>Lorentzon et al b²¹</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>McKay et al²²</td>
<td>85.2%</td>
<td>14.8%</td>
</tr>
<tr>
<td>Molsa et al²⁴</td>
<td>Not given</td>
<td>Not given</td>
</tr>
<tr>
<td>Ornon et al²⁵</td>
<td>Not given</td>
<td>Not given</td>
</tr>
<tr>
<td>Petterson et al²⁶</td>
<td>84.6%</td>
<td>15.4%</td>
</tr>
<tr>
<td>Tegner et al²⁷</td>
<td>85.4%</td>
<td>14.6%</td>
</tr>
<tr>
<td>Tuominen et al²⁹</td>
<td>92.1%</td>
<td>7.9%</td>
</tr>
</tbody>
</table>

T = Traumatic, NT = Non-traumatic, MTU= muscle tendon unit

are exposed to a substantial risk of injury during match play, while training injuries are less frequent. The majority of injuries are traumatic and severe injuries account for a notable portion of overall injury cases.

QUALITY OF THE EVIDENCE

All selected studies showed low bias risk for external validity. There was only 66% compliance with the items of the STROBE-SIIS quality scale. It should be noted that the STROBE-SIIS quality scale has only been proposed since February 2020, whereas all the studies included in the present review have been carried out before that date.¹⁶

INJURY INCIDENCE

The main findings of this study show a match injury incidence of 38 to 88.6 injuries/1000 hours of exposure and a training injury incidence of 0.4-2.6 injuries/1000 hours of exposure. Therefore, professional players have a much higher risk of suffering an injury during a match than during a training session. Compared to other team sports, par-
Table 5. Severity of injuries of the studies included.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Mild 1-7</th>
<th>Moderate 8-28</th>
<th>Severe &gt;28</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brunner et al18</td>
<td>Not given</td>
<td>Not given</td>
<td>Not given</td>
</tr>
<tr>
<td>Groger A.20</td>
<td>Not given</td>
<td>Not given</td>
<td>Not given</td>
</tr>
<tr>
<td>Jorgensen et al17</td>
<td>37.5%</td>
<td>45.5%</td>
<td>17%</td>
</tr>
<tr>
<td>Lorentzon et al a22</td>
<td>72.6%</td>
<td>19%</td>
<td>8.4%</td>
</tr>
<tr>
<td>Lorentzon et al b21</td>
<td>Not given</td>
<td>Not given</td>
<td>Not given</td>
</tr>
<tr>
<td>McKay et al23</td>
<td>Not given</td>
<td>Not given</td>
<td>Not given</td>
</tr>
<tr>
<td>Molsa et al24</td>
<td>68.6%</td>
<td>23.6%</td>
<td>7.8%</td>
</tr>
<tr>
<td>Ornon et al25</td>
<td>32.6%</td>
<td>47.4%</td>
<td>20%</td>
</tr>
<tr>
<td>Petterson et al26</td>
<td>87.9%</td>
<td>9.4%</td>
<td>2.7%</td>
</tr>
<tr>
<td>Tegner et al27</td>
<td>61.1%</td>
<td>22.3%</td>
<td>8.8%</td>
</tr>
<tr>
<td>Tuominen et al19</td>
<td>53.8%</td>
<td>31.7%</td>
<td>14.5%</td>
</tr>
</tbody>
</table>

Injury Profile

Lower extremity is the anatomical region more frequently injured. In particular, the knee was the joint most affected by traumatic injuries, while the hip/groin complex was the most affected by overuse problems. In this context, it should be noted that knee injury prevention programs have been shown to be effective in several sports.34-37 Unfortunately, however, it is still unclear whether they can prevent traumatic injuries or only non-contact ones.38 Therefore, it would be interesting to implement these programs in ice hockey, where unlike other sports, most knee injuries are traumatic in origin. Regarding hip/pelvic overuse issues, it is important to note that this phenomenon is probably more widespread than what was found in this review where only missed training and competitions were considered. In fact, a recent study found that 48 percent of ice hockey players suffered from non-time loss hip/groin problems during a season, with significantly worse hip and groin function than healthy teammates.39 These findings highlight the need for a proper management of training loads during the off-season, preseason, and in-season.40 Moreover, exercises targeting muscle strength and coordination in the hip, groin, and pelvis have shown promise in reducing pain and improving function.41,42

Body checking and collision with another player represented the major cause of injury. Therefore, disallowing body checking could be considered a reasonable initiative to reduce the number of injuries. This policy has already been introduced in several leagues in youth hockey and in women’s hockey and has proven effective in decreasing injury rates.33,43,44 Other sources of trauma include contact with the stick, the puck, or the skate blades, all objects that have the potential to create contusions and lacerations to the athletes. In order to reduce these injuries, improving protective gear with enhanced materials that can better absorb external forces and are constructed of cut-resistant fabric should be considered.

Contusions and lacerations represented the most common injury types. Lacerations to the face were particularly common.24,27 These could be prevented by mandating the use of full facial protection. In fact, this measure, already in place for under-18s and in female hockey, has been shown effective in reducing facial injuries.32,33,45

Contusions and lacerations normally heal in a short time, and this can explain why most of the injuries were reported to be of minimal severity. However, fractures, joint and muscle-tendon injuries were also common and may represent a large percentage of those injuries with moderate or severe recovery time. Severe injuries were present in similar proportion to other collision sports.30,46

Limitations

The main limitation of this study is that none of the included articles reported re-injuries. It was therefore not possible to calculate the incidence of these injuries separately. A second limitation is that some of the athletes in the sample of Tegner and Lorentzon27 and in the sample of Pettersson and Lorentzon26 also has a secondary occupation. However, all the players competed in the highest Swedish hockey division and the reported injuries only concerned hockey practices or matches. A third limitation concerns the reporting of concussion injuries, which in some
studies account for a substantial portion of the injuries while in others did not. An agreed definition of concussion was only reached in 2001, so studies published before this date may have recorded concussion in a different category.

CONCLUSION

In professional male ice hockey, the risk of injury during training is low compared to other sports. However, during competitions, professional male ice hockey players are exposed to a substantial risk of injury, especially to the lower limbs. The vast majority of injuries had a traumatic mechanism, with contusions and lacerations being the most common injury types.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.
REFERENCES


SUPPLEMENTARY MATERIALS

Appendix 1
Download: https://ijspt.scholasticahq.com/article/90591-what-is-the-injury-incidence-and-profile-in-professional-male-ice-hockey-a-systematic-review/attachment/187911.docx?auth_token=Ms9IAwe2DwWXqEAPzV2L

Appendix 2
Download: https://ijspt.scholasticahq.com/article/90591-what-is-the-injury-incidence-and-profile-in-professional-male-ice-hockey-a-systematic-review/attachment/187913.docx?auth_token=Ms9IAwe2DwWXqEAPzV2L

Appendix 3
Download: https://ijspt.scholasticahq.com/article/90591-what-is-the-injury-incidence-and-profile-in-professional-male-ice-hockey-a-systematic-review/attachment/187912.docx?auth_token=Ms9IAwe2DwWXqEAPzV2L

Appendix 4
Download: https://ijspt.scholasticahq.com/article/90591-what-is-the-injury-incidence-and-profile-in-professional-male-ice-hockey-a-systematic-review/attachment/187910.docx?auth_token=Ms9IAwe2DwWXqEAPzV2L
Scoping Review

Sensorimotor Dysfunction Following Anterior Cruciate Ligament Reconstruction- an Afferent Perspective: A Scoping Review

Thilina N Vitharana1,2,*, Enda King3,4, Kieran Moran2,5
1 Sports Medicine, Sports Surgery Clinic, 2 School of Health and Human Performance, Dublin City University, 3 Qatar Orthopaedic and Sports Medicine Hospital, 4 Department of Life Sciences, University of Roehampton, 5 Insight Centre for Data Analytics, Dublin City University

Keywords: Anterior cruciate ligament, sensorimotor dysfunction, afferent dysfunction, visual reliance

https://doi.org/10.26603/001c.90862

International Journal of Sports Physical Therapy

Background

Sensorimotor dysfunction is thought to occur following anterior cruciate ligament (ACL) injury which may have implications on future reinjury risk. Dysfunction has been demonstrated within the efferent component of the sensorimotor system. However, no reviews have examined the two main components of the afferent system: the visual and somatosensory systems.

Hypothesis/Purpose

This study aimed to report differences in function (central processing and local processing) within the (1) somatosensory and (2) visual systems between individuals following anterior cruciate ligament reconstruction (ACLR) and healthy controls (between-subject). The study also aimed to report differences in function within the two systems between the two limbs of an individual following ACLR (within-subject).

Study Design

Scoping review

Methods

A search was conducted in PubMed, SPORTDiscus, CINAHL, Medline and Embase up until September 2021. Level I-IV studies assessing somatosensory and visual systems were included if they compared ACLR limbs to the uninjured contralateral limb (within-subject) or a healthy control limb (between-group). The function of somatosensory and visual systems was assessed across both central processing (processing of information in the central cortex) and local processing (all other assessments outside of central processing of information).

Results

Seventy studies were identified (52 somatosensory, 18 visual). Studies examining somatosensory central processing demonstrated significant differences; 66% of studies exhibited within-subject differences and 100% of the studies exhibited between-group differences. Studies examining local somatosensory processing had mixed findings; 40% of the 'joint position sense (JPS)' and 'threshold to detect motion (TTDM)' studies showed significant within-subject differences (JPS=0.8°-3.8° and TTDM=0.2°-1.4°) and 42% demonstrated significant between-group differences (JPS=0.4°-5° and TTDM=0.3°-2.8°). Eighty-three percent of visual central processing studies demonstrated significant dysfunction between-groups with no studies assessing within-subject differences. Fifty percent of the studies examining local visual processing demonstrated a significant between-group difference.
INTRODUCTION

The sensorimotor system is complex and a central element of the body’s motor control system. It assists with the planning and execution of movement and maintaining postural control (Figure 1). It encompasses afferent sensory pathways, efferent motor pathways and central cortex processing (Figure 2). Sensorimotor functioning is required for every movement; requiring integration of sensory information (in particular somatosensory and visual information) to detect deviations from desired orientations and to subsequently alter motor responses. Given that movement control requires sensorimotor function, as the complexity of movement increases, for example responding to more stimuli in the environment and/or utilising more multiplanar joint actions or muscles, the sensorimotor demands also increase. Therefore, sensorimotor dysfunction, which can occur following musculoskeletal injury (such as anterior cruciate ligament [ACL] injury), may negatively affect movement planning and execution.

The ACL provides: (1) structural stability through limiting excessive tibia anterior translation and internal rotation and (2) sensory information to the sensorimotor cortex. Therefore, ACL injury has negative consequences for knee structural stability and sensorimotor system functions (such as postural control, muscle coordination and supplying afferent information to the central cortex). Despite ACL reconstructive surgery (ACLR) restoring structural stability, there is growing debate to whether sensorimotor dysfunction remains. Sensorimotor dysfunction following ACLR occurs across afferent sensory, central processing and efferent motor pathways. Recent reviews have reported dysfunction of the efferent pathways and certain aspects of that somatosensory system (proprioception and kinaesthesia). Whilst there are six sensory systems within the afferent system (somatosensory, visual, auditory, vestibular, gustation and olfactory), the somatosensory and visual systems are the most important for motor control and will be reviewed here.

The somatosensory system has several important functions, including: (1) informing the central cortex about segment position (proprioception) and movement (kinaesthesia), (2) sensing pain and pressure/vibration, and (3) sensing objects in the environment via touch. The ACL is highly innervated with mechanoreceptors that send proprioceptive afferent information for processing to the spinal cord, lower brain and cerebrum. A full-thickness ACL tear results in disruption of the mechanoreceptor mediated pathways, pain and swelling, thereby driving arthrogenic muscle inhibition. While two systematic reviews have investigated proprioception deficits (one domain of the somatosensory system), which highlighted significant but small functional reductions following ACLR, no study has reviewed the other somatosensory system domains (e.g. central processing and vibration).

The visual system encompasses the eyes, optical neural pathways and the occipital lobe (where processing of the visual information occurs). It has several key functions, including helping to identify objects and providing object spatial location and orientation within their environment. Following the loss of ACL proprioceptive information, postural control is reduced with increased demands placed on motor planning centres within the brain. In particular, an over-reliance on the visual system can occur following ACLR and may contribute to ACL reinjury. While early research into visual system dysfunction was based on functional brain MRI, there is a small but growing body of research examining how processing visual information affects motor control (dual-task loading) following ACLR.

Given that efferent deficits have been reviewed comprehensively, a review examining afferent dysfunction following ACLR, and how it is measured, would help clinicians better assess and effectively target those deficits. Synthesising data from studies assessing ACLR somatosensory and visual system dysfunction is challenging due to the lack of studies and variety of outcome measures used, this paper therefore undertakes a scoping review to map key concepts and identify knowledge gaps.

METHODS

The PRISMA guidelines for systematic reviews were followed with appropriate modifications for a scoping review.

RESEARCH QUESTIONS

The original research questions were:

1. What differences exist within the somatosensory system between both ACLR and healthy controls, and between limbs in the ACLR population?
2. What differences exist within the visual system between both ACLR and healthy controls, and between limbs in the ACLR population?
3. What tests are used to measure the somatosensory and visual systems differences between ACLR and healthy controls?

ELIGIBILITY

The inclusion criteria for studies in the scoping review were: (1) at least one outcome measure which assessed somatosensory or visual sensory performance, (2) included the visual or somatosensory system, (3) used the same population (ACLR and healthy matched controls), (4) used the same outcome measures, (5) included at least one lower limb, (6) were published in the English language in the last 10 years.
Figure 1. Sensorimotor cortex influences an individual’s motor control

Figure 2. Components of the sensorimotor system

subjects post ACLR, (3) published in English, and (4) full-text access. The studies could be of any design.39,40

PARTICIPANTS

Studies needed to include participants with unilateral ACLR. Participants were not excluded if they had concomitant knee injuries that required repair (such as meniscal damage). No restrictions were placed on ACLR technique or time from surgery. Studies were excluded if they included participants who had undergone revision ACLR.

SEARCH STRATEGY

An electronic search was conducted in PubMed, SPORTDiscus, CINAHL, Medline and Embase in September 2021. No restrictions were placed on the date of publication. Two independent reviewers (TV and EK) conducted. The search re-
lated to the somatosensory system was ("ACLR" OR "ACL reconstruction" OR "anterior cruciate ligament reconstruction") AND ("somatosensory" OR "proprioception" OR "somatic sensation")). The search related to the visual system was ("ACLR" OR "ACL reconstruction" OR "anterior cruciate ligament reconstruction") AND ("visual" OR "visual-motor").

STUDY IDENTIFICATION

The two reviewers (TV and EK) independently reviewed the titles and abstracts of the identified studies. If a study matched the eligibility criteria, the full text manuscripts were subsequently reviewed independently. The full reference list of identified studies was searched to locate relevant studies. Studies were downloaded to EndNote reference manager (https://www.endnote.com) and imported into Covidence software (www.covidence.org) to identify potential differences between reviewers and to reach agreement regarding study eligibility. Disagreements were resolved via discussion or third-party mediation (KM).

DATA EXTRACTION

Data were extracted by each reviewer (TV and EK) for all eligible studies, entered into spreadsheets, and combined. Disagreements were resolved via discussion or third-party mediation (KM). The standardized data extraction forms included details on the study design, participant details (age, time after surgery, surgical technique and percentage of the cohort being males), outcome measures, and results. To help with clarity of interpreting the results, the studies were sub-grouped based on the outcome measures utilized. For the somatosensory system results, studies were separated into those which assessed for central processing differences and those which assessed local somatosensory functions. The central processing studies were those that assessed for brain activity during tasks, which allows for interpretation of how information is processed in the central cortex. Local somatosensory functions were separated into studies that examined: proprioception (joint position sense), kinesthesia (threshold to detect motion) and other somatosensory functions (such as light touch and vibration). With regard to the visual system results, the studies were grouped into three categories: central processing, local visual function, and visual contribution to motor control. Central processing are those studies assessing how information is processed within the central cortex. Local visual function encompasses studies which utilized outcome measures that assessed visual functions, such as gaze tracking, visual memory and visual attention. Finally, studies were grouped into ‘visual contribution to motor control’ if their outcome measures assessed motor control during varying degrees of vision (to determine visual contribution) or with dual-cognitive tasks.

RESULTS

OUTCOME MEASURES

Seventy studies were included in this scoping review (Figure 3 and 4).

There was large heterogeneity of the outcome measures, so to assist readers the measures and their purpose are listed in Table 1 (somatosensory system) and Table 3 (visual system).

SOMATOSENSORY SYSTEM

Fifty-two studies (see Tables 2, 3 and 4) were identified which assessed somatosensory function following ACLR. Nine studies examined central processing within the somatosensory system, while 44 examined local somatosensory functions (e.g. proprioception, kinaesthesia and vibration). Some studies examined differences between the uninjured limb and ACLR limb (within-subject differences) (Table S1 in Supplementary information) whilst others compared the ACLR limb to a healthy control’s limb (between-group differences) (Table S2 in Supplementary information). Several papers examined both between-group and within-subject differences.

CENTRAL PROCESSING OF SOMATOSENSORY INFORMATION

Of the nine studies that examined cortical processing, there was heterogeneity in the assessment methods: three studies utilised electroencephalogram (EEG), one utilised functional brain MRI, two utilised vibration perception threshold testing, two utilised posturography and one utilised light touch threshold detection testing. Whilst these techniques assess central processing, there are slight differences in the information obtained. EEG and functional brain MRI assess brain activity during simple motor tasks, with increased activity reflecting somatosensory dysfunction due to greater processing requirements. Posturography assesses postural control under varying circumstances to determine afferent system efficacy (e.g. vestibular, visual, somatosensory). Finally, vibration and light touch perception threshold testing examine central processing changes by comparing thresholds at sites local and distal to an injury. Increased perception thresholds at sites distal to the injury indicate central processing changes.

Six studies examined ACLR within-subject differences with the majority (4/6) demonstrating significant differences in somatosensory central processing (reduction in function).42-47 Two studies found increased EEG activity,45,46 and two posturography studies demonstrated reduced somatosensory function in the ACLR limb.43,44 However, both studies examining vibration perception threshold demonstrated no significant difference between limbs.45,47 Overall, studies suggest there are differences in central processing within the somatosensory systems in the ACLR limb, and vibration perception threshold may not be an appropriate method when examining ACLR within-subject differences.
Figure 3. Flowchart of the search strategy and results of the somatosensory system

Five studies examined somatosensory system central processing between ACLR participants and healthy controls, with all demonstrating significant differences.21,42,45,48,49 One study demonstrated increased vibration perception threshold in the ACLR limb both locally (around the knee) and globally compared to healthy controls.45 This study also demonstrated the uninjured limb of ACLR participants had increased vibration perception thresholds compared to healthy control limbs, further highlighting differences in the central processing of somatosensory information following ACLR. This was also reflected in a case control study48 in which light touch sensation at sites distal to the ACLR knee (medial malleolus and first metatarsal) was reduced as compared to healthy controls. The other two studies (EEG42 and functional brain MRI21) demonstrated increased somatosensory central cortex activity during simple motor tasks (non-weightbearing knee flexion and extension) compared to healthy controls.

Overall, following an ACLR, there are consistent differences in somatosensory system central processing. Not only does the ACLR limb have altered central processing as compared to the uninjured limb, but also as compared to healthy controls.

LOCAL SOMATOSENSORY FUNCTION

Fifty studies examined various afferent pathways of somatosensory function: proprioception (joint position sense [JPS]), kinaesthesia (threshold to detect passive motion [TTDPM]) and vibration. The two most common were JPS and TTDPM, with large heterogeneity in the methods (Table 2).

JOINT POSITION SENSE

Twenty-seven studies examined within-subject JPS function (Table 2 and 3). Across the 27 studies a total of 35 outcomes were measured due to JPS being measured at multiple angles in some studies. Overall, there was mixed evidence with 13 studies demonstrating reduced JPS function in the ACLR limb, 20 demonstrating no significant difference and two demonstrating improved JPS function (Table 2). Participant demographics and time from surgery did not differ between studies with and without a difference. Time from surgery was quite varied across studies, ranging from four to 52.2 months. Of the studies that demonstrated a significant reduction in JPS function...
within-subject, the difference between the two limbs ranged from 0.8° to 3.8°.5,34,60

Twenty-five studies examined JPS function between the ACLR limb and healthy controls (Table 2 and 4). Across the 25 studies a total of 30 outcomes were measured due to JPS being measured at multiple angles in some studies. Similar to the within-subject studies, there were mixed findings, with 13 studies demonstrating significantly reduced JPS function in the ACLR group, 16 studies finding no significant difference and only one reporting improved JPS function in ACLRs.79 Of the studies that demonstrated a significant reduction in JPS function between ACLR limbs and healthy controls, the JPS difference between limbs ranged from 0.4° to 5°.45,57,60,78

The small differences and the similar number of papers identifying JPS performance as being negatively affected as those reporting no difference for both between-group and within-subject differences, highlights the difficulty in measuring this variable. However, with almost 50% of the identified studies demonstrating reduction in proprioceptive function, JPS should be routinely assessed in ACLRs post-surgery. The small differences between-group and within-subject makes it difficult for clinicians to reliably monitor changes over time. Also, large heterogeneity in outcome measures and lack of reporting of the standard error of measurement makes it hard to draw firm conclusions. Future research should report the reliability and standard error of measurement values for the outcome measures utilised to help readers and clinicians interpret the findings better.

**THRESHOLD TO DETECT PASSIVE MOTION (TTPDM)**

Seventeen studies examined within-subject TTPDM performance (Table 2 and 3), with mixed findings. Across the 17 studies a total of 20 outcomes were reported due to some studies having multiple outcome measures. Nine studies reported reduced ACLR limb TTPDM (from 0.2° to 1.4°),45,54 while eleven studies demonstrated no significant difference.

Thirteen studies examined TTPDM performance between the ACLR limb and healthy controls (Table 2 and 4), again with mixed findings. Five studies reported significantly reduced ACLR limb function, while seven studies reported no significant difference. One study reported significantly better ACLR function. Of the studies that

---

**Figure 4. Flowchart of the search strategy and results of the visual system**
Table 1. Outcome measures utilized to assess the somatosensory system

<table>
<thead>
<tr>
<th>Outcome measure</th>
<th>What it measures</th>
<th>Purpose of assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electroencephalogram (EEG)</td>
<td>Measures electrical activity within the brain. Used to highlight brain areas responsible for processing specific information.</td>
<td>Used to identify central processing differences.</td>
</tr>
<tr>
<td>Functional brain MRI</td>
<td>Measures changes in blood flow within the brain which occurs with brain activity. Used to highlight brain areas responsible for processing specific information.</td>
<td>Used to identify central processing differences.</td>
</tr>
<tr>
<td>Vibration perception threshold testing</td>
<td>Used to identify the lowest vibrational intensity that the individual is able to perceive.</td>
<td>Differences between limbs at sites around the knee would suggest local functional deficiencies. Differences between limbs at sites distal to the knee would suggest central processing deficiencies.</td>
</tr>
<tr>
<td>Light touch perception threshold testing</td>
<td>Used to identify the lowest touch pressure intensity that the individual is able to perceive.</td>
<td>Differences between limbs at sites around the knee would suggest local functional deficiencies. Differences between limbs at sites distal to the knee would suggest central processing deficiencies.</td>
</tr>
<tr>
<td>Posturography</td>
<td>Used to measure an individual’s postural control during upright standing under varying conditions (static or dynamic)</td>
<td>Used to identify central processing differences.</td>
</tr>
<tr>
<td>Joint position sense</td>
<td>Used to measure an individual’s ability to perceive the position of their joints without utilising their vision.</td>
<td>Identifies differences in local function related to proprioceptive information</td>
</tr>
<tr>
<td>Threshold to detect passive motion</td>
<td>Used to measure an individual’s ability to detect motion of their joint without utilising their vision.</td>
<td>Identifies differences in local function related to kinaesthetic information</td>
</tr>
</tbody>
</table>

Table 2. Number and distribution of studies examining the somatosensory system. Listed underneath is the testing tool used in the identified studies

<table>
<thead>
<tr>
<th>Domain</th>
<th>Within-subject studies</th>
<th>Between-group studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central processing</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>• EEG= 242,46</td>
<td>• EEG= 242,49</td>
</tr>
<tr>
<td></td>
<td>• Posturography= 243.44</td>
<td>• Functional MRI= 152 Light touch perception threshold= 148</td>
</tr>
<tr>
<td></td>
<td>• Vibration perception threshold= 245.47</td>
<td>• Vibration perception threshold= 145</td>
</tr>
<tr>
<td>Joint position sense</td>
<td>27</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>• Continuous passive motion device= 150</td>
<td>• Continuous passive motion device= 150</td>
</tr>
<tr>
<td></td>
<td>• Custom built apparatus= 425.45</td>
<td>• Custom built apparatus= 425.45,45</td>
</tr>
<tr>
<td></td>
<td>• Electrogoniometer= 447.64,64</td>
<td>• Electrogoniometer= 557.59,77,88</td>
</tr>
<tr>
<td></td>
<td>• Image calculated angulation software= 560,64</td>
<td>• Image calculated angulation software= 560,62,52,45</td>
</tr>
<tr>
<td></td>
<td>• Isokinetic dynamometer= 71152,62,54</td>
<td>• Isokinetic dynamometer= 1430,70,37,80-86</td>
</tr>
<tr>
<td>Threshold to detect passive motion</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>• Continuous passive motion device= 150</td>
<td>• Continuous passive motion device= 150</td>
</tr>
<tr>
<td></td>
<td>• Custom built apparatus= 425,65,42,45</td>
<td>• Custom built apparatus= 425,52,54,87-89,94</td>
</tr>
<tr>
<td></td>
<td>• Isokinetic dynamometer= 67455,71,62,</td>
<td>• Isokinetic dynamometer= 62572,85,91</td>
</tr>
<tr>
<td></td>
<td>90-93</td>
<td></td>
</tr>
<tr>
<td>Vibration</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>• Vibration perception threshold= 145</td>
<td>• Vibration perception threshold= 245.47</td>
</tr>
</tbody>
</table>

Abbreviations: EEG= electroencephalogram and MRI= magnetic resonance imaging

demonstrated a significant reduction in TTDPM performance between ACLR limbs and healthy controls, the JPS difference between limbs ranged from 0.3° to 2.8°. 45,91

Akin to JPS studies, a similar number of papers for both between-group and within-subject differences identified TTDPM performance as being negatively affected as those reporting no significant difference. In addition, the differences are also small. This may suggest that TTDPM is a function that should be routinely assessed in ACLRs as it may be negatively affected but that it is a variable that

International Journal of Sports Physical Therapy
Table 3. Studies examining within-subject differences (ACLR limb versus uninjured limb) in the somatosensory system.

<table>
<thead>
<tr>
<th>Somatosensory level</th>
<th>Studies reporting significantly decreased function in ACLR group (p&lt;0.05)</th>
<th>Studies reporting no significant difference</th>
<th>Studies reporting significantly increased function in the ACLR group (p&lt;0.05)</th>
</tr>
</thead>
</table>
| Proprioception (JPS) | Anders et al\(^{56}\)  
Angoules et al\(^{95}\)  
Bonfh et al\(^{50}\)  
Büyükafşar et al\(^{57}\)  
Fischer-Rasmussen et al\(^{54}\)  
Fremerey et al\(^{51}\)  
Fremerey et al\(^{53}\)  
Ghaderi et al\(^{66}\)  
Hoshiba et al\(^{59}\)  
Jurevičienė et al\(^{67}\)  
Relph et al\(^{57}\)  
Silva et al\(^{61}\) | An et al\(^{74}\)  
Anders et al\(^{56}\)  
Angoules et al\(^{95}\)  
Blackburn et al\(^{57}\)  
Büyükafşar et al\(^{57}\)  
Co et al\(^{52}\)  
Dvir et al\(^{55}\)  
Fischer-Rasmussen et al\(^{54}\)  
Fremerey et al\(^{51}\)  
Furlanetto et al\(^{64}\)  
Hopper et al\(^{63}\)  
Hoshiba et al\(^{59}\)  
Karasel et al\(^{73}\)  
Kaya et al\(^{68}\)  
Mir et al\(^{62}\)  
Nagai et al\(^{92}\)  
Ozenci et al\(^{72}\)  
Reider et al\(^{65}\)  
Suner Keklik et al\(^{58}\)  
Zult et al\(^{69}\) | Dvir et al\(^{55}\)  
Reider et al\(^{65}\) |
| Kinaesthesia (TTDPM) | Angoules et al\(^{95}\)  
Bonfh et al\(^{50}\)  
Co et al\(^{52}\)  
Courtney et al\(^{45}\)  
Fischer-Rasmussen et al\(^{54}\)  
Laboute et al\(^{71}\)  
MacDonald et al\(^{89}\)  
Nagai et al\(^{92}\)  
Valeriani et al\(^{46}\) | Angoules et al\(^{95}\)  
Laboute et al\(^{91}\)  
Muaidi et al\(^{87}\)  
Nagai et al\(^{92}\)  
Ordahan et al\(^{101}\)  
Ozenci et al\(^{72}\)  
Reider et al\(^{65}\)  
Relph et al\(^{27}\)  
Risberg et al\(^{88}\)  
Risberg et al\(^{93}\)  
Shidahara et al\(^{90}\) | |
| Vibration | Courtney et al\(^{45}\) | Blackburn et al\(^{47}\)  
Courtney et al\(^{45}\) | |

would be hard for clinicians to monitor for recovery due to the small magnitude in the differences. Also, there is large heterogeneity in testing methodology with limited reporting on standard error of measurement for each outcome measure which makes firm conclusions difficult.

**OTHER AFFERENT COMPONENTS OF LOCAL SOMATOSENSORY FUNCTION**

Other measures of somatosensory function can include vibration perception threshold testing (of local sites around the knee). However, only two studies examined this, with conflicting findings. Courtney et al\(^{45}\) found significantly greater perception thresholds in the ACLR limb compared with both the uninjured limb and healthy controls, while Blackburn et al\(^{47}\) reported no significant difference between the ACLR limb and the uninjured limb. Greater vibration perception thresholds around the knee can indicate local negative changes within the somatosensory system. The lack of research in this area makes it difficult to make firm conclusions regarding the potential effect of ACLR on this somatosensory function.

**VISUAL SYSTEM RESULTS**

Eighteen studies (Table 6) assessed visual system differences following ACLR. Across the 18 studies a total of 20 outcomes were reported due to some studies having multiple outcomes measures. Fifteen studies examined differences between ACLR participants and healthy controls, whilst five studies examined differences between limbs in the ACLR participants. The studies identified assessed specific visual processes (both local and central) and/or the contribution of the visual system during motor control.

**CENTRAL PROCESSING**

Six studies\(^{21,35,83,99-101}\) assessed differences in visual system central processing between ACLR participants and healthy controls. No studies assessed within-subject differences in the ACLR population. Five of the six studies\(^{21,35,83,100,101}\) demonstrated increased activity in visual processing regions of the brain, via either functional brain MRI or EEG, in ACLR participants during simple movements (Z-max scores of greater than 4). Increased activity may be a sign of compensation with regards to altered somatosensory information or a sign of dysfunction within...
Table 4. Studies examining between group differences (ACLR limb versus healthy controls)

<table>
<thead>
<tr>
<th>Somatosensory level</th>
<th>Studies reporting significantly decreased function in ACLR group (p&lt;0.05)</th>
<th>Studies reporting no significant difference</th>
<th>Studies reporting significantly increased function in the ACLR group (p&lt;0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibration</td>
<td>Courtney et al[45]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Outcome measures utilized to assess the visual system

<table>
<thead>
<tr>
<th>Outcome measure</th>
<th>What it measures</th>
<th>Purpose of assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>EEG</td>
<td>Measures electrical activity within the brain. It is used to highlight areas of the brain responsible for processing specific information.</td>
<td>Used to identify central processing differences.</td>
</tr>
<tr>
<td>Functional brain MRI</td>
<td>Measures changes in blood flow within the brain which occurs with brain activity. It is used to highlight areas of the brain responsible for processing specific information.</td>
<td>Used to identify central processing differences.</td>
</tr>
<tr>
<td>Neurocognitive tests</td>
<td>Used to assess different aspects of brain function. A number of tests exist that can provide results regarding visual memory performance, visual processing performance and reaction times to visual stimuli.</td>
<td>Used to identify local and central visual processing differences.</td>
</tr>
<tr>
<td>Trail making test</td>
<td>Used to assess an individual’s visual attention and ability to task switch.</td>
<td>Used to identify differences in local visual function.</td>
</tr>
<tr>
<td>Gaze tracking</td>
<td>Assesses the motion of the eye relative to the head or where the individual’s gaze is focusing on.</td>
<td>Used to identify differences in local visual function.</td>
</tr>
<tr>
<td>Posturography</td>
<td>Used to measure an individual’s postural control while upright under varying conditions (static or dynamic)</td>
<td>Used to identify central processing differences.</td>
</tr>
<tr>
<td>Reaction to visual stimuli</td>
<td>Used to measure an individual’s ability to react to a visual stimulus. The task required of the individuals may vary between research papers (eg, pressing a button in response to the visual stimulus or making a postural adjustment)</td>
<td>Used to identify differences in local visual function.</td>
</tr>
</tbody>
</table>

the visual system.24,36 These studies were completed over a large time range post-surgery (1.5 ± 0.2 months101 to 45.3 ± 33.3 months100). This may indicate that differences in visual processing activity are persistent and may develop quite early post-surgery. The remaining study demonstrated no significant difference.99 Various visual processing areas within the brain have been identified as areas of greater activity within the ACLR population. Grooms and colleagues demonstrated significantly greater activation of the lingual gyrus, which is responsible for visual process-
ing and visual memory, suggesting a compensatory mechanism for reduced somatosensory information described earlier (somatosensory results). The results from Criss and colleagues further supports this. They found increased activation of regions responsible for visual processing and combined visuospatial perception and attention.

Overall, there are differences in ACLR visual system central processing. It is unknown if these differences are present prior to ACLR or if it is a result of ACLR. Future prospective studies (assessment pre-ACLR injury and then post-ACLR) are required to determine this.

LOCAL VISUAL FUNCTION

Six studies examined local visual function differences between ACLR participants and healthy controls with conflicting results.37,38,76,85,102 One study38 assessed local visual function with multiple outcome measures, so there is some overlapping of results. There are numerous methods to assessing local visual function including computer-based visual memory tasks,83 gaze tracking37 and measuring reaction times to visual stimuli38 (Table 3). Three studies37, 76,102 demonstrated ACLR significantly reduced local visual function (related to gaze tracking of multiple objects, visual attention and reaction to visual stimulus), three studies37, 38,83 demonstrated no significant difference (related to visual memory, gaze tracking stationary object and reaction time to visual stimulus), and one study38 demonstrated ACLR improved function (related to visual attention). The contrasting findings may be due, at least in part, to the large heterogeneity in outcome measures (table 5). Some studies utilised neurocognitive tests to assess visual attention (the ability to select specific objects in the environment and filter out the irrelevant information) and visual memory (the ability to store and recall visual information,83 whilst others utilised tests to assess the qualities of vision such as gaze tracking (ability to track objects in the environment)37 and reactions to visual stimulus.38,76,102 Bodkin and colleagues37 found that their ACLR group had large differences (Cohen d = 0.96) when tasked with tracking a moving object, resulting in a greater number of visual gaze errors, but no differences when focusing on a stationary object. This contrasting finding has significant relevance when playing sport. ACLR are also slower to react to visual information and adjust their posture accordingly.76 With the majority of ACL injuries being non-contact in nature and heavily influenced by movement strategy,103,104 the changes to visual information processing in ACLR may influence their motor strategy with consequences for performance and re-injury susceptibility.

Only one study102 assessed within-subject differences in local visual function demonstrated reduced function. Roelofsen et al.102 assessed the effect of visual feedback on leg amplitude movement during a visual tracking task. They demonstrated that ACLRs had significantly decreased leg amplitude in response to visual feedback in comparison to not only healthy controls but also to their limb prior to surgery. This result may indicate that there are changes in the way visual information is processed but they may also be the result of reduced proprioception.

VISUAL CONTRIBUTION TO MOTOR CONTROL

Nine studies44,85,102,105-110 examined the contribution of vision to motor control in ACLR population as compared to healthy controls, with six44,85,102,106,109,110 finding ACLR had increased contribution. During both postural and movement tasks, visual reliance was determined by a participants’ balance and movement control worsening, respectively, with the removal or alteration of visual input. Contrastingly, four studies105-108 reported no significant difference. This conflict may be due to large heterogeneity in testing methodologies and data analysis techniques. A systematic review with meta-analysis105 demonstrated no significant difference between ACLRs and healthy controls in their performance during a single leg postural control task which compared eyes open to eyes closed; both groups experienced similar declines in performance when their vision was blinded (ACLR= 42.9% decline versus controls= 44.4% decline). The studies included in this meta-analysis used traditional centre of pressure metrics (path, amplitude, and calculated stability indexes). However, posturography and frequency analysis during double leg standing utilised in three studies demonstrated increased reliance on the visual system (via assessment of ultra-low frequencies) in the ACLR population as compared to healthy controls.44,110,111 This was further support by Chaput et al.83 who demonstrated higher performance on a visual motor sub-scale in a neurocognitive test was strongly associated with better time-to-stability performance during a jump-landing task (r = -0.61, p=0.05) in an ACLR population, whilst no such association was found in healthy controls.83

Four studies102,108,111,112 examined within-subject differences in the ACLR vision contribution to motor control with mixed findings. Two studies102,111 demonstrated significant reductions in posturography111 and leg positioning task102 performance whilst two studies108,112 demonstrated no significant difference during a change of direction112 and hopping110 task. The two studies102,111 demonstrating significant differences compared the ACLR limb post-surgery to the limb prior to surgery, while the two studies108,112 demonstrating no significant difference examined differences between the ACLR limb and uninjured limb, potentially indicating that individuals become more reliant on visual information following ACLR. The two studies108,112 which demonstrated no significant difference utilised functional tests such as hop for distance (blinded versus full vision)108 and a change of direction (full vision versus disrupted vision)112 while the two studies102,111 demonstrating a difference utilized tests requiring small adjustments in posture. This may suggest that whole-body functional tasks could allow for compensatory movements from other body segments which mask the altered motor control within the ACLR limb.

DISCUSSION

The aim of this scoping review was to summarize any differences in somatosensory and visual systems following ACLR. The results identified both within-subject and between-

International Journal of Sports Physical Therapy
Table 6. Studies examining changes to the visual system following ACLR

<table>
<thead>
<tr>
<th>Level of visual system</th>
<th>Authors</th>
<th>Participant information</th>
<th>Time from surgery (months)</th>
<th>Outcome measure used</th>
<th>Task</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central visual processing</td>
<td>Chaput et al.98</td>
<td>ACLR (n=16, 37.5% male) 21.5 ± 2.6 yrs Healthy Controls (n=15, 40% male) 22.9 ± 3.0 yrs</td>
<td>41.4 ± 33</td>
<td>ImPACT and functional brain MRI</td>
<td>ImPACT: computer based Functional brain MRI: supine knee flexion and extension</td>
<td>† activity in visual sensory cortical area in ACLR group and significantly associated with visual memory and visual motor scores on ImPACT</td>
</tr>
<tr>
<td></td>
<td>Criss et al.100</td>
<td>ACLR (n=15, 47% male) 20.9 ± 2.7 yrs Healthy Controls (n=15, 47% male) 22.5 ± 2.5 yrs</td>
<td>43.3 ± 33.1</td>
<td>Functional brain MRI</td>
<td>Supine heel slide</td>
<td>Greater activation in ipsilateral superior parietal lobule lateral occipital cortex and angular gyrus as compared to controls (z-max= 5.26) Greater activation in ipsilateral occipital fusiform gyrus and white matter optic radiation compared to controls (z-max= 4.12) Greater activation in bilateral intracalcarine cortex and lingual gyrus (z-max= 6.73)</td>
</tr>
<tr>
<td></td>
<td>Grooms et al.21</td>
<td>ACLR (n=15, 47% male) 21.7 ± 2.7 yrs Healthy Controls (n=15, 47% male) 23.2 ± 3.5 yrs</td>
<td>38.1± 27.2</td>
<td>Functional brain MRI</td>
<td>Supine knee flexion/extension</td>
<td>†activation of visual-motor region (mean signal change ACLR= 0.67%, controls= 0.28%)</td>
</tr>
<tr>
<td></td>
<td>Grooms et al.35</td>
<td>ACLR (n=1, 100% male) 25 yrs</td>
<td>10</td>
<td>Functional brain MRI</td>
<td>Supine knee flexion/extension</td>
<td>Greater activation in contralateral lingual gyrus as compared to healthy control (peak z value= 4.50)</td>
</tr>
<tr>
<td>Level of visual system</td>
<td>Authors</td>
<td>Participant information</td>
<td>Time from surgery (months)</td>
<td>Outcome measure used</td>
<td>Task</td>
<td>Results</td>
</tr>
<tr>
<td>------------------------</td>
<td>---------</td>
<td>-------------------------</td>
<td>---------------------------</td>
<td>---------------------</td>
<td>------</td>
<td>---------</td>
</tr>
<tr>
<td>case study</td>
<td>Lehmann et al\textsuperscript{113}</td>
<td>Healthy Control (n=1, 100% male) 26 yrs</td>
<td>1.5 ± 0.2</td>
<td>EEG</td>
<td>Single leg standing</td>
<td>↑ alpha-2 connectivity within or linking somatosensory and visual cortical areas when standing on the ACLR limb and not uninjured limb</td>
</tr>
<tr>
<td></td>
<td>Giesche et al\textsuperscript{99}</td>
<td>ACLR (n=10, 100% male) 28 ± 4 yrs</td>
<td>63 ± 35</td>
<td>EEG</td>
<td>Jump landing</td>
<td>No significant difference. However, trend for greater activation in supplementary and primary motor cortex</td>
</tr>
</tbody>
</table>

**Local visual processing**

<table>
<thead>
<tr>
<th>Significant reduction in function (p&lt;0.05)</th>
<th>Armitano-Lago et al\textsuperscript{76}</th>
<th>ACLR (n=16, 50% male) 29.3 ± 6.9 yrs</th>
<th>106.9 ± 71.6</th>
<th>Reaction time to visual stimulus</th>
<th>Stepping task in reaction to visual stimulus</th>
<th>Slower reaction time in ACLR group during simple task (ACLR= 484 ± 3.17ms, controls= 399 ± 1.95ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Healthy Controls (n=16, 50% male) 28.9 ± 6.2 yrs</td>
<td></td>
<td></td>
<td></td>
<td>Slower reaction time in ACLR group during choice basted reaction time task (ACLR= 550 ± 43ms, controls= 445 ± 43ms)</td>
</tr>
<tr>
<td>Level of visual system</td>
<td>Authors</td>
<td>Participant information</td>
<td>Time from surgery (months)</td>
<td>Outcome measure used</td>
<td>Task</td>
<td>Results</td>
</tr>
<tr>
<td>-----------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>---------------------------</td>
<td>----------------------</td>
<td>-----------------------------</td>
<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Bodkin et al(^{37})</td>
<td>ACLR (n=10, 40% male)</td>
<td>22.3±15.4</td>
<td>Gaze tracking</td>
<td>Tracking moving target</td>
<td>↑visual gaze errors in ACLR group (ACLR= 0.52± 0.23m, controls= 0.35± 0.14m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19.9 ± 1.7 yrs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Healthy Controls (n=10, 40% male)</td>
<td>21.1 ± 1.4 yrs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roelofsen et al(^{102})</td>
<td>ACLR (n=14, 79% male)</td>
<td>4.5 to 5</td>
<td>Leg amplitude differentiation</td>
<td>Leg amplitude differentiation under various visual feedback conditions</td>
<td>↓Leg amplitude variability in ACLR limb as compared to healthy control limb in both visual enhanced and visual veridical conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.2 ± 4.8 yrs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Healthy Controls (n=15, 67% male)</td>
<td>23.1 ± 3.4 yrs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bodkin et al(^{37})</td>
<td>ACLR (n=10, 40% male)</td>
<td>22.3±15.4</td>
<td>Gaze tracking</td>
<td>Tracking stationary target</td>
<td>No difference in visual gaze score or visual gaze velocity between groups</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19.9 ± 1.7 yrs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Healthy Controls (n=10, 40% male)</td>
<td>21.1 ± 1.4 yrs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chaput et al(^{98})</td>
<td>ACLR (n=16, 37.5% male)</td>
<td>41.4 ± 33</td>
<td>ImPACT</td>
<td>ImPACT: computer based</td>
<td>No difference in visual motor composite score and visual memory composite score between groups</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level of visual system</td>
<td>Authors</td>
<td>Participant information</td>
<td>Time from surgery (months)</td>
<td>Outcome measure used</td>
<td>Task</td>
<td>Results</td>
</tr>
<tr>
<td>------------------------</td>
<td>---------</td>
<td>-------------------------</td>
<td>---------------------------</td>
<td>----------------------</td>
<td>-----</td>
<td>---------</td>
</tr>
<tr>
<td>Comparative study</td>
<td>Stone et al\textsuperscript{38}</td>
<td>ACLR (n=20, 40% male) 22 ± 3 yrs</td>
<td>unclear</td>
<td>CogState neurocognitive test and Purdue pegboard test</td>
<td>Reaction time to visual stimulus. &amp; No difference in reaction time</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Healthy Controls (n=20, 40% male) 22 ± 3 yrs</td>
<td></td>
<td></td>
<td>Manual dexterity and bimanual coordination</td>
<td>No difference in Purdue pegboard performance</td>
</tr>
</tbody>
</table>
| Significant increase in function (p<0.05) | Stone et al\textsuperscript{38} | ACLR (n=20, 40% male) 22 ± 3 yrs | unclear | Trail making test | Visual attention and task switching | ACLR group completed Trail A faster than healthy controls ($F_{(1,37)}=5.61$)  
ACLR group completed Trail B faster than healthy controls ($F_{(1,37)}=6.27$) |
<p>|                        | Bartels et al\textsuperscript{44} | ACLR (n=30, 47% male) 32 ± 12.2 yrs | 24 | Posturography | Double leg standing | ↑activity in visual systems to maintain stability ($\eta^2 = 0.179$) |
|                        | Chaput et al\textsuperscript{98} | ACLR (n=16, 37.5% male) 41.4 ± 33 yrs | 41.4 ± 33 | ImPACT and time to stability test | ImPACT: computer based | Higher performance on visual motor composite score strongly associated with better time to stability performance in ACLR group ($r = -0.61, p=0.03$) |</p>
<table>
<thead>
<tr>
<th>Level of visual system</th>
<th>Authors</th>
<th>Participant information</th>
<th>Time from surgery (months)</th>
<th>Outcome measure used</th>
<th>Task</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparative study</td>
<td>21.5 ± 2.6 yrs</td>
<td>Healthy Controls (n= 15, 40% male) 22.9 ± 3.0yrs</td>
<td>Time to stability following single leg landing task</td>
<td>No association in control group</td>
<td>ImPACT and joint position sense test</td>
<td>Higher performance on visual memory composite score was strongly associated with lower JPS error (r= -0.63). No association in controls</td>
</tr>
<tr>
<td>Clark et al.110</td>
<td>ACLR (n=45, 67% male) 26 ± 9.8 yrs</td>
<td>Healthy Control (n= 45, 67% male) 26.4± 9.8 yrs</td>
<td>Frequency analysis</td>
<td>Single leg standing</td>
<td>↑ value on visual system frequency (ACLR= 0.04± 0.01 cm/s, Controls= 0.03± 0.01 cm/s)</td>
<td></td>
</tr>
<tr>
<td>Grooms et al.106</td>
<td>ACLR (n= 15.47% male) 21.4 ± 2.6 yrs</td>
<td>Healthy Controls (n= 15.47% male) 23.2 ± 3.5 yrs</td>
<td>Stroboscopic vision</td>
<td>Drop jump with vision obscured</td>
<td>↑ knee flexion excursion with stroboscopic vision (ACLR= 3.1 ± 3.8°, controls= -0.8 ± 4.5°)</td>
<td></td>
</tr>
<tr>
<td>Miko et al.109</td>
<td>ACLR (n=14, 33% male) 20.7 ± 1.9 yrs</td>
<td>Healthy Controls</td>
<td>Single leg balance</td>
<td>Single leg balance with dual-cognitive task</td>
<td>↓ postural control in ACLR group with greater ellipse area (Cohen's d= 0.44) and Root mean square in medial to lateral plane (Cohen's d= 0.49)</td>
<td></td>
</tr>
<tr>
<td>Level of visual system</td>
<td>Authors</td>
<td>Participant information</td>
<td>Time from surgery (months)</td>
<td>Outcome measure used</td>
<td>Task</td>
<td>Results</td>
</tr>
<tr>
<td>------------------------</td>
<td>-----------------------------</td>
<td>-------------------------</td>
<td>---------------------------</td>
<td>---------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Roelofsen et al(^{102})</td>
<td>ACLR (n=14, 79% male)</td>
<td>4.5 to 5</td>
<td>Leg amplitude differentiation and temporal variability</td>
<td>Task</td>
<td>Temporal variability in the ACLR limb and uninjured limb as compared to healthy control limb in both visual enhanced and visual veridical conditions.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.2 ± 4.8 yrs</td>
<td></td>
<td></td>
<td></td>
<td>Temporal variability during treadmill walking.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Healthy Controls (n=15, 67% male)</td>
<td>23.1 ± 3.4 yrs</td>
<td></td>
<td></td>
<td>↑ Temporal variability in the ACLR limb and uninjured limb post-operatively as compared to pre-operatively in both visual enhanced and visual veridical conditions. Main effect for ACLR limb= F(<em>{(1, 12)})=11.00, p=0.006, uninjured limb F(</em>{(1,12)})=17.93</td>
</tr>
<tr>
<td></td>
<td>Wein et al(^{111})</td>
<td>ACLR (n=50, 76% male)</td>
<td>At least 6 months</td>
<td>Posturography</td>
<td>Task</td>
<td>↓ visual ratio and increased reliance on visual cues for balance post-operatively (post-op= 3.1± 2.0 vs pre-op 5.7 ± 4.1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27 ± 6.2 yrs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No significant difference</td>
<td>Bjornaraa et al(^{114})</td>
<td>ACLR (n=17, 0% male)</td>
<td>55.2</td>
<td>3D motion capture with shutter glasses</td>
<td>Task</td>
<td>No difference in biomechanics variables (such as absolute displacement, peak absolute velocity, average absolute velocity and percent of cut to reach peak ground reaction force) between full vision and disrupted vision</td>
</tr>
<tr>
<td></td>
<td></td>
<td>26.5 ± 6.3 yrs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Friden et al(^{108})</td>
<td>ACLR (n=20, 50% male)</td>
<td>24</td>
<td>One leg hop</td>
<td>Task</td>
<td>No difference between groups in hop distance when vision from one or both eyes was obstructed. No difference in hop distance between ACLR limb and uninjured limb when vision from one or both eyes was obstructed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>26 yrs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level of visual system</td>
<td>Authors</td>
<td>Participant information</td>
<td>Time from surgery (months)</td>
<td>Outcome measure used</td>
<td>Task</td>
<td>Results</td>
</tr>
<tr>
<td>------------------------</td>
<td>---------</td>
<td>-------------------------</td>
<td>---------------------------</td>
<td>---------------------</td>
<td>------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td>Grooms et al.</td>
<td>ACLR (n=15.47% male) 21.4 ± 2.6 yrs</td>
<td>36.2 ± 26.5</td>
<td>Stroboscopic vision</td>
<td>Drop jump with vision obscured</td>
<td>No difference in knee adduction excursion, peak vertical ground reaction force, peak knee external knee flexor moment and peak external knee abductor moment</td>
</tr>
<tr>
<td></td>
<td>Lion et al</td>
<td>ACLR (n=19.74% male) 24.8 ± 6.4 yrs</td>
<td>9.2 ± 1.6</td>
<td>Double leg balance</td>
<td>Double leg balance under varying visual conditions</td>
<td>No difference in postural control performance between groups</td>
</tr>
<tr>
<td></td>
<td>Wikstrom et al.</td>
<td>ACLR (n=120-133)</td>
<td>unclear</td>
<td>Single leg balance</td>
<td>Single leg balance eyes open versus eyes closed</td>
<td>Similar decline in performance between ACLR and controls when eyes are closed (ACLR= 42.9% decline and controls= 44.7% decline). Hedges g effect size= -0.61</td>
</tr>
</tbody>
</table>
group differences in central processing (somatosensory and visual systems) in the ACLR cohort which may represent sensorimotor dysfunction. However, when assessing somatosensory functions (such as JPS and TTDPM) and the visual system (processing central and local visual information, and the contribution of vision on motor control) there were mixed findings with a tendency for between-group (ACLR versus healthy controls) differences to be present.

CHANGES THAT OCCUR IN THE SOMATOSENSORY AND VISUAL SYSTEMS FOLLOWING ACLR

Previous reviews have focused on the negative efferent changes within the sensorimotor system following ACLR which have been hypothesized to occur in response to dysfunction within the afferent pathways. It has also been hypothesized that an over reliance on the visual system to maintain postural control and execute movements may develop in response to dysfunction within the somatosensory system. The results of this review confirm that there are significant differences between the afferent pathways, both somatosensory and visual, of ACLR participants and healthy controls, and also between limbs in the ACLR cohort with studies assessing central processing demonstrating alterations in somatosensory processing and increased activity in the visual system.

However, it is not possible to determine if the differences are a reflection of dysfunction that occurs as a result of the ACLR surgery or is present prior to surgery due to the lack of prospective research available.

As previously mentioned, the ACL is highly innervated with mechanoreceptors with damage leading to a reduction in somatosensory functions such as proprioception and kinesthesia. However, somatosensory functions are thought to improve once the afferent fibers regrow into the ACL graft over the following three to six months. This review supports the notion of a reduction in proprioception and kinaesthesia in the ACLR limb as compared to the participants’ uninjured limb. While some of these findings were reported for participants who were less than six months post-surgery, there was an almost equal number of studies which demonstrated persistent reduced function in participants whose ACLR graft should have been reinnervated (36 to 64 months post-surgery). The persistent reduced function could indicate that some individuals do not experience reinnervation of their graft. Another more likely explanation is that these participants have ongoing dysfunction in central processing of the somatosensory information, as evidenced by the functional brain MRI and EEG studies, despite having received rehabilitation.

Motor control requires the afferent systems to continuously obtain information regarding the body and its position within the environment so that appropriate motor responses can be made to account for any perturbations. Dysfunction within the somatosensory system may result in greater reliance being placed on the other afferent systems such as the visual system to obtain information from the environment. This has been previously shown in injuries, such as chronic ankle instability. The results of this review appear to support the notion that increased reliance on the visual system also occurs in the ACLR cohort. Four studies utilizing methods to assess central processing in the visual centers demonstrated greater activity in these centers as compared to healthy controls during simple motor tasks. It has been suggested that increased reliance on the visual system may increase the risk of sustaining a primary ACL injury, potentially as a result of the athlete either missing environmental cues or reacting slowly to a stimulus, thereby executing a movement with poorer technique. Therefore, increased reliance on the visual system identified in individuals following ACLR may have an implication for increased risk of second ACL injury.

Bodkin et al reported that ACLR participants exhibited significantly greater visual gaze errors as compared to healthy controls when tracking a moving target. The findings may provide some support for the notion of ACLRs being more visually reliant than they found it to track a moving target, although it may also represent that this population has poorer visual function, which is pertinent for picking up cues in a chaotic environment which is encountered in most field-based sports. The findings were supported by Armitano-Lago et al who reported that ACLR participants responded more slowly to a visual stimulus than healthy controls when tasked with making a postural adjustment. Slower reaction times were seen in the ACLR group when performing a stepping task but not so when completing a task whilst seated, suggesting that as task complexity increases, then individuals with dysfunction within motor planning and execution cortical areas will begin to demonstrate differences.

A REFLECTION ON ASSESSING SOMATOSENSORY AND VISUAL DYSFUNCTION

Although differences have been found to exist in the somatosensory and visual systems following ACLR, a common issue for clinicians is having the tools to identify this dysfunction in their athletes. Central processing changes are identifiable via methods such as functional brain MRI and EEG. However, both methods are not feasible for many clinicians due to the cost and lack of access to the technology. An alternative approach to identifying somatosensory dysfunction may be possible by identifying JPS or TTDPM deficits in athletes greater than six months post-surgery. The most appropriate method to measure JPS would be image-calculated angulation because most clinicians do not have access to isokinetic dynamometers. However, very few studies have published the reliability of the outcome measures they used which can make it difficult for clinicians to utilise in clinical practice. One study which utilized image-calculated angulation to measure JPS published the reliability (ICC= 0.86–0.92) and minimal detectable change (1.5° to 2.4°) for their testing methodology, therefore allowing it to easily be employed in clinical practice. With regards to TTDPM, there are a limited number of methods to assess TTDPM without using isokinetic dynamometers. Hence, more research is required to find reliable methods to assess TTDPM that are also easy for clinicians to employ within their clinics. So, the reality for clinicians is that
deficits likely occur in some, if not all, individuals following ACLR. However, they are unlikely to be able to assess these deficits in the clinic, so clinicians should consider employing exercises which redevelop these qualities.

With regards to assessing the visual system, there was again large heterogeneity in the outcome measures used. This is especially evident in the variety of outcome measures used to assess local visual processing function (e.g. trail making test, gaze tracking and neurocognitive testing). Whilst there may be differences identified in gaze tracking, it is still not clear what impact this has on the ACLR cohort with regards to risk of reinjury or sporting performance. More prospective research is needed to identify the attributes of visual processing that are most pertinent for athletes following ACLR to minimise the risk of reinjury and to return to preinjury performance levels. Previous research has identified visual memory, processing speed and reaction times on a neurocognitive test as factors associated with greater risk sustaining a primary ACL injury. The greater availability of sensory stations (mobile tablet technologies with preloaded visual assessments) which assess these factors plus a number of other local visual processing attributes may make it easier for not only clinicians to assess athletes with a single tool but also for researchers to have a consistent outcome measure to measure athletes for prospective studies. When assessing the effect of vision on movement control, posturography with analysis of frequencies currently appears to be a consistent method to identify if there is an over-reliance on the visual system during static tasks but it may not be feasible for clinicians as there are only a few commercially available systems. In summary, visual reliance most likely exists along with some dysfunction of visual processing in the ACLR population but methods of measurement are limited for clinicians. Clinicians should look to include training modalities that improve visual processing.

CLINICAL IMPLICATIONS FOR REHABILITATION

Current ACLR rehabilitation programs follow a common path of: (1) regaining range of motion and control of the knee, (2) strength and hypertrophy training, (3) plyometric training, (4) running (linear and multi-directional) and (5) sports-specific drills. Alongside the structured rehabilitation program, athletes go through a process of gradual reintroduction to training in the sport itself prior to a reintroduction to competition. However, much of the literature which identified dysfunction within the central processing of somatosensory and visual information was conducted in patients who had already completed rehabilitation (although the specific makeup of their rehabilitation programs was not reported) and returned to sport (average time from surgery ranged between 12 and 48 months). If the participants had completed rehabilitation that would be expected as standard care, then this continued dysfunction could suggest that there is a missing element in either current rehabilitation programs or the long-term follow up care of athletes. Hence, future research is required to identify (1) methods applicable to a clinical setting to identify individuals with a deficit and then (2) methods to reduce the reliance on the visual system.

Along with identifying methods to reduce visual reliance, knowing when to implement these methods is important as well. Proprioception deficits have been identified within the first four weeks following ACLR, and et al have also demonstrated that increased reliance on the visual system (at the central processing level) may begin within six weeks following ACLR. The results suggest that clinicians aiming to reduce reliance on the visual system need to implement interventions very soon post-operatively. Therefore, future research should aim to identify effective methods to reduce reliance on the visual system.

LIMITATIONS

There are several limitations to this scoping review. Firstly, much of the research identified was retrospective in nature meaning that it is not possible to determine if any of the identified somatosensory and visual dysfunction in the ACLR cohort was present prior to the injury or prior to the ACLR. Second, no critical appraisal of the studies was performed due to the small number of studies in area of somatosensory and visual dysfunction, so threats of bias were not identified within the selected studies, and this may affect the results obtained. However, because visual dysfunction is quite a new area of research in the ACLR literature, the decision was made to include all available studies so that trends could be observed. As this area of science matures, future studies could be more selective in the quality of studies that they use for review. Furthermore, the review predominantly examines somatosensory and visual variables but not how it relates to patient outcomes. Future research should assess how these variables are associated to patient outcomes. Another limitation was that there were several studies utilizing participants who were greater than two years post-ACLR. This may potentially introduce confounders to the results as the participants had been discharged from rehabilitation and returned to general activity. Therefore, it is unknown what influence returning to general activity may have on afferent function. Lastly, the reliability of a number of the outcome measures used in the selected studies were not reported, making it difficult to confidently trust the statistical and clinical significance of the differences observed.

CONCLUSION

This scoping review highlights the within-subject (ACLR limb vs uninjured limb) and between-group (ACLR versus healthy controls) differences within the somatosensory and visual systems. The evidence highlighting differences in central processing of the somatosensory and visual systems demonstrates the potential impact that ACL injury and/or ACLR has on individuals. Within the somatosensory system, reduced proprioceptive and kinesthetic function has been demonstrated in the ACLR limb as compared to the contralateral uninjured limb. Similarly, the ACLR limb has reduced proprioceptive and kinesthetic function as com-
pared to healthy controls. Increased reliance on the visual system occurs in response to somatosensory dysfunction as evidenced by altered central processing, potentially resulting in errors in visual processing and adversely affecting motor control.

Future large-scale studies are required to examine if there are differences in visual processing between athletes following ACLR and healthy controls. Similarly, more research is required to examine the effect of visual reliance on biomechanics and the effectiveness of interventions in treating these dysfunctions as well.

FUNDING

No funding was received for the completion of the study.

CONFLICTS OF INTEREST

No conflicts of interest exist for the authors.

ACKNOWLEDGMENTS

The authors would like to Luis Arias for producing the illustrations for the study.

Submitted: January 30, 2023 CST, Accepted: October 19, 2023 CST
© The Author(s)
REFERENCES


SUPPLEMENTARY MATERIALS

Appendix- somatosensory results table
Photobiomodulation Therapy Plus Usual Care Is Better than Usual Care Alone for Plantar Fasciitis: A Randomized Controlled Trial

Ann K Ketz, Juanita Anders, Judy Orina, Betty Garner, Misty Hull, Nicholas Koreerat, Jeff Sorensen, James Johnson

1 Recovery Sciences, Enovis. 2 School of Medicine, Department of Anatomy, Physiology, and Genetics, Uniformed Services University of the Health Sciences. 3 The Geneva Foundation. 4 Betty K. Garner Sole Proprietorship. 5 Landstuhl Regional Medical Center. 6 Colorado State University

Keywords: photobiomodulation therapy, plantar fasciitis, tendinopathy, low level laser therapy, pain, function

https://dx.doi.org/10.26603/001c.90589

International Journal of Sports Physical Therapy

Background
Plantar fasciitis (PF) results in pain-related disability and excessive healthcare costs. Photobiomodulation therapy (PBMT) has shown promise for decreasing both pain and disability related to PF.

Purpose
The purpose was to assess the clinical impact of PBMT on pain and function in people with PF.

Study Design
Prospective, randomized controlled clinical trial

Methods
A convenience sample of adults with PF were randomly assigned to one of three groups: (1) usual care, (2) usual care plus nine doses of PBMT with 25W output power over three weeks, or (3) usual care plus nine doses of PBMT with 10W output power over three weeks. Both 10W and 25W PBMT participants received the same total dose (10J/cm²) by utilizing a simple area equation. Pain (with Defense and Veterans Pain Rating Scale) and function (by Foot and Ankle Ability Measure) were measured at baseline, weeks 3, and 6 for all groups, and at 13 and 26 weeks for PBMT groups.

Results
PBMT groups experienced a reduction in pain over the first three weeks (from an average of 4.5 to 2.8) after which their pain levels remained mostly constant, while the UC group experienced a smaller reduction in pain (from an average of 4 to 5.8). The effects on pain were not different between PBMT groups. PBMT in both treatment groups also improved function more than the UC group, again with the improvement occurring within the first three weeks.

Conclusions
Pain and function improved during the three weeks of PBMT plus UC and remained stable over the following three weeks. Improvements sustained through six months in the PBMT plus UC groups.

Level of Evidence
Level II- RCT or Prospective Comparative Study

Corresponding Author:
Dr. Ann K. Ketz, 5501 Lillehammer Lane, Apt 4305, Park City, UT 84098
Email: annketz@gmail.com
Phone: 435-901-5014
INTRODUCTION

Plantar fasciitis (PF) is the leading cause of heel pain in ambulatory settings, affecting up to 10% of adults.1-3 Though the name is misleading, PF is not primarily an inflammatory condition.4 Repetitive trauma to the connective tissue causes acute inflammation. However, it is the combination of tissue inflammation, fascial thickening, collagen necrosis, matrix calcification, peri-fascial edema, and alterations in vasculation that lead to the debilitating pain associated with PF.4,5-9

Conservative PF treatment (e.g., reduced activity/loading, icing, stretching, orthotics, and taping/bracing) typically spans 6-12 months, and improvements are not often seen before six weeks of therapy.1,2,10 In some resistant cases, more aggressive, sometimes painful and invasive treatments are required, such as corticosteroid injections, radiation,11 platelet-rich plasma injections,6 and surgery.1,2,10

Photobiomodulation (PBM) is an emerging therapy that uses non-ionizing, visible and near-infrared light to affect endogenous chromophores and elicit photochemical events at the cellular level.13 PBM therapy (PBMT) has been shown to improve other tendinopathies in studies of lateral epicondylitis, shoulder tendinopathy and Achilles tendinopathy when using optimized wavelengths and dosing parameters.14-16 The clinical benefit of PBMT for tendinopathies is thought to be mediated by collagen production,17 alignment of collagen fibers,18 and other mechanisms.19

Recent meta-analyses have reported positive findings supporting PBMT as an effective treatment modality for PF, though the conclusions are somewhat heterogeneous due to inconsistent dosing parameters (e.g., wavelength, power, application duration, intensity) and study methodologies.20,21 Specifically, the "dose" of PBMT is denoted by the intensity (J/cm²) of the light delivered to the target area. However, the intensity is a product of the power (W) and application duration (sec); thus, equivalent "doses" could be achieved by proportionately increasing or decreasing both the power and application duration. Unfortunately, many studies do not adequately report these values, making direct comparisons difficult. As with any treatment, choosing the correct dose is essential to optimizing safety and efficacy.22 Of the multiple parameters for PBMT, wavelength and power are likely the most important, as wavelength determines the depth of photon penetration and power determines the number of photons delivered to the target tissue. PBM in the 810-980 nm wavelength range is known to penetrate the skin and superficial tissues to reach underlying tissues, such as muscle and tendon, including the target tissue of the plantar fascia.23

PBMT is non-invasive and has potential to address the root cause/dysfunction of the injury, decrease the pain of PF quickly, and return individuals to increased function and physical activity. The goal of this study was to assess the clinical impact of PBMT on pain and function in people with PF.

MATERIALS AND METHODS

TRIAL DESIGN & PARTICIPANTS

This prospective, randomized controlled trial was conducted at a United States military medical center in Germany. Recruitment and enrollment of participants (n = 114) targeted adults between 18-65 years of age with symptoms of PF for at least three months (diagnosed by their primary healthcare providers, e.g., MD, DO, PA, NP), able to read and understand English language for consent purposes, and able to commit to six-week intervention and three and six month follow-up. Candidates were excluded for having a history of trauma, fracture, previous corticosteroid injections or other invasive treatment for PF to the symptomatic foot. Candidates with neuropathy or altered detection of skin temperature were excluded (including use of medication that may lead to the same), as well as those with greater than 15% of calf covered in tattoos, since pigment in ink absorbs light and can cause overheating of skin. Additionally, pregnant females and candidates with pacemakers were excluded.

The study protocol conforms to the Declaration of Helsinki and was approved by the Institutional Review Board of record (M-10548) and registered at ClinicalTrials.gov (registration number NCT03015116). Informed consent was obtained from all participants prior to enrollment in the study. Upon study enrollment, patients were allocated to study groups by the principal investigator, ensuring no healthcare provider bias. A parallel assignment study intervention model was employed. Due to the nature of the intervention, healthcare provider and patient blinding was not plausible, thus this study was conducted as open label.

INTERVENTIONS

USUAL CARE PROTOCOL

All participants were instructed to complete a usual care (UC) protocol daily for six weeks, beginning on day one, based on recommendations by current Clinical Practice Guidelines for PF treatment (Figure 1).24-26 The UC group participants were given the opportunity to receive PBMT outside of the study protocol for their affected foot after the completion of the 6-week study period.

PBMT PROTOCOL

Both intervention groups received PBMT three times a week for three weeks for a total of nine treatments and completed the UC protocol daily for six weeks, beginning on day one. All participants in both PBMT groups received the same dose at each treatment session. The only difference between groups was whether PBMT was delivered fast or slow. Here, "fast" PBMT refers to a dose of 10 J/cm² delivered for one second per square centimeter of skin at 10W, while "slow" PBMT refers to the same dose of 10 J/cm² but it was delivered for 0.4 seconds per square centimeter of skin at 25W.
To achieve a standardized PBMT dose of 10 J/cm², the study team calculated the area of each participant’s foot and calf at baseline and varied the time over which the total dose was delivered by calibrating to the output power (10W or 25W). Providers used a diode laser (LightForce EXPI, LiteCure/LightForce Medical, New Castle, DE, USA), with a blend of 20% 810nm and 80% 980 nm wavelength, continuous wave light delivered via a hand piece with an approximately 7 cm massage ball. Participants lay in a prone position, and the provider treated the plantar foot and dorsal calf surfaces in a serpentine movement, with the massage ball in perpendicular contact with the skin, slightly compressing underlying tissues. Treatment time was split equally between the foot and the calf, with intermittent passive range of motion of the ankle.

OUTCOMES

The primary outcomes were pain, assessed by the Defense and Veterans Pain Rating Scale (DVPRS)²⁷-²⁹ and function, assessed by the Foot and Ankle Ability Measure (FAAM).³⁰ The 5-item DVPRS integrates a numeric pain rating scale with visual facial cues and word descriptors and four supplemental questions measuring pain interference (Figure 2).²⁷,²⁸ Permission is granted for clinicians and researchers to freely use the DVPRS as is, without alteration. All participants completed a daily DVPRS diary for six weeks, be-
In addition, four DVPRS supplemental outcomes were tracked: self-reported activity, mood, sleep interference, and stress.

The FAAM is a 29-item self-report instrument that assesses physical function in foot and ankle impairments. There are two subscales: activities of daily living (ADL) (21-item) and sports (8-item). The subscale items are scored on a 5-point Likert scale (4 = “no difficulty at all” to 0 = “unable to do”) and then the points are converted to a percentage (100% = no dysfunction). To measure the long-term outcomes in the PMBT groups, the study team sent a password-protected fillable PDF file of the DVPRS and FAAM to the PBMT participants via email so participants could report their pain and function at 13 and 26 weeks. Participants also completed a daily medication and activity diary for descriptive analysis.

SAMPLE SIZE

Glaser Consulting performed power analysis using G*Power software. Considering the exploratory nature of the study and estimated population of participants, a small to medium effect size of 0.15 and autocorrelation of 0.3 was chosen, requiring n = 96 participants, or n = 32 participants per group. Participants were over-recruited by 20% (n = ~114, or n = 38 participants per group) to account for the potential attrition.
RANDOMIZATION

An Excel random number generator was used to assign participants to UC, UC plus 10W PBMT, or UC plus 25W PBMT, yielding 38 participants in each group.

STATISTICAL METHODS

Descriptive statics reported distributions of baseline demographics, daily activity and medication diary data. Inferential statistics used a nonlinear extension of generalized linear models, Hierarchical generalized additive models (GAM) using patient-level random effects with Gaussian distribution families. The hierarchical modeling with patient-level random effects handles the correlation of within-patient repeated measures, and the nonlinear GAM captures nonlinear effects. Where appropriate, hypothesis tests were two-sided and considered significant at the putative threshold (alpha=0.05). Due to their nature, non-linear effects are not interpreted in terms of coefficient $p$-values. Only linear effects have coefficient $p$-values that are readily interpretable. Nonlinear effects are interpreted graphically—that is, by inspecting partial dependence plots. These partial dependence plots are intuitive because they display the average patient-level effect in terms of its mean and confidence band. To assess whether effects are different between groups, simply look at their partial dependence plots; where the groups' confidence bands overlap, their effects are not statistically different; and where their confidence bands do not overlap, the effects are statistically different. In this way, partial dependence plots are intuitive and carry more information than coefficients and $p$-values from linear models. In other words, a modeling approach is used that is interpreted by looking at graphs, not $p$-values. Data normality and homoscedasticity were verified by Kolmogorov-Smirnov and Breusch-Pagan tests prior to analysis, respectively.

RESULTS

PARTICIPANT FLOW AND NUMBERS ANALYZED

By the end of the initial six weeks, seven, two and two participants had withdrawn from the UC, 10W, and 25W group respectively, leaving 31, 36, and 36 participants in each group with complete data for analysis of primary and secondary outcomes. UC group participation in the study ended after six weeks. For long-term follow-up, 88% of the PBMT groups were retained at three months and 76% by six months (Figure 5).

BASELINE DATA

Baseline demographic data showed representation among males (43.8%) versus females (56.3%); among Caucasian (58.8%) versus non-Caucasian (38.7%); and among military (47.4%) versus non-military (52.7%) (Supplemental File 1). The mean age of the participant population was 43.4 years old. While the study population showed a high percentage of overweight and obese participants based on self-reported data, there was no significant difference between groups.

OUTCOMES AND ESTIMATION

PAIN

Because there was no difference in outcomes between the two treatment groups, for the primary analysis, the PBMT groups were pooled. Both PBMT groups received the same dose (10 J/cm²), with the only difference being the "speed" at which the total dose was delivered: either "slow" at one second per square centimeter, or "fast" at 0.4 seconds per square centimeter.

The pooled PBMT groups experienced a reduction in pain over the first three weeks, with a patient-level average change from $4.47 \pm 0.15$ to $2.84 \pm 0.07$. The UC group experienced a small reduction in pain over the same period, having a patient-level average change from $4.05 \pm 0.15$ to $3.76 \pm 0.08$. The effects on pain were not meaningfully different between PBMT groups, which were assessed graphically (Figure 4). Recall, the statistical significance of non-linear effects are interpreted not by coefficient estimates but by comparing confidence bands in partial dependence plots.

From three to six weeks, pain reduction appeared to plateau in the pooled PBMT groups (six-week mean 2.70, SE 0.1) and in the UC group (six-week mean 3.70, SE 0.15, n=24). When stratifying the 10W and 25W PBMT groups apart, no significant difference was observed, which is illustrated by their confidence bands (2*SE) overlapping in the partial dependence plot (Figure 4).

FUNCTION

Functional outcomes also showed some improvements in PBMT groups compared to UC (Figure 5). Patient-level average function per the FAAM sports subscale improved in the pooled PBMT groups from baseline (mean 0.45, SE 0.03, n=75) to six weeks (mean 0.66, SE 0.03, n=70), while functional improvement was slight, at best, in the UC group from baseline (mean 0.45, SE 0.04, n=37) to six weeks (mean 0.50, SE 0.04, n=52). There was no measured difference between the 10W and 25W PBMT groups in terms of FAAM sports.

Function, per the FAAM ADL subscale, did not seem to improve more in the pooled PBMT groups from baseline (mean 0.71, SE 0.02, n=76) to six weeks (mean 0.82, SE 0.01, n=70) than it improved in the UC group from baseline (mean 0.57, SE 0.02, n=58) to six weeks (mean 0.75, SE 0.03, n=52).

In contrast to the UC group, individuals in both PBMT groups reported notable (but non-significant) enhancements in the FAAM ADL subscale, surpassing validated thresholds for clinically meaningful changes at both 6-week and 6-month intervals. PBMT group participants met both the Minimal Detectable Change and Minimal Clinical Important Difference cutoff change scores of 6 and 8, respectively, when calculated at both six weeks and six months after treatment. These findings indicate that there is rea-
Figure 3. Recruitment and Retention Flow Diagram

ANCILLARY ANALYSES

SUPPLEMENTAL DVPRS

The pooled PBMT groups demonstrated improved average patient-level changes to activity interference (from baseline 4.4 (SE 0.1) to six weeks 2.5 (SE 0.1)) compared to UC (from baseline 3.9 (SE 0.1) to six weeks 3.6 (SE 0.1)). Similar trends were observed for mood interference, sleep interference and stress contribution (Figure 6).

FITZPATRICK SKIN TYPE SUBGROUPS

Fitzpatrick Skin Type was significant in both the FAAM sports (b = -.05, p = .03) and FAAM ADL (b = -.04, p = .002) subscales, with the negative coefficient indicating a higher Skin Type score was associated with a lower FAAM score. Findings for pain outcomes were not significant between Fitzpatrick categories.

LONG-TERM FOLLOW-UP

Participants in both PBMT groups reported stable pain and function outcomes at 13 and 26 week follow-up time points. (Figures 7-9)
Figure 4. Short-term Defense and Veterans Pain Rating Scale Results

Figure 5. Short-term Foot and Ankle Ability Measure Results
Figure 6. Short-term Defense and Veterans Pain Rating Scale Supplemental Results
DISCUSSION

There were three main findings as relates to the study's primary aims: 1) PBM therapy at both power levels (i.e., 10W and 25W; both administered to achieve 10J/cm² dose) resulted in clinically relevant significant reductions in pain, whereas the UC group did not exhibit reductions in pain, 2) PBM therapy at both power levels resulted in some increases in the FAAM Sports subscale; however, this did not achieve the level of statistical significance and no differences were noted in FAAM ADL between both PBM groups and the UC group, 3) no statistically significant differences were noted in pain, FAAM Sports, or FAAM ADL between the 10W and 25W PBM groups.

Two recent systematic reviews and meta-analyses reported significant improvements in pain (Visual Analog Scale) and function (Foot Function Index) in favor of PBM over control. Other PBM studies for PF, including those in recent meta-analyses, used different outcome measures, wavelengths, and other parameters, and often did not report their methods completely making direct comparison challenging. However, the findings are consistent in that pain and function are improved over time when the appropriate wavelength and other treatment parameters are chosen (i.e., power, application time).

Participants in this study reported a mean baseline pain level between 4.1-4.3, and the UC group reported this consistent level of pain through the end of the protocol. In contrast, participants in both PBM groups reported clinically relevant and significant decreases in pain throughout the 6-week protocol period. Additionally, both PBM group participants reported a two-point decrease in the pain scale by long-term follow-up. While long-term data were not collected for the UC group, their consistent pain scores through the study period stand in stark contrast to the decreases noted in the PBM groups. Salaffi and colleagues analyzed clinically meaningful change in numeric pain rating scale scores in chronic musculoskeletal injuries and reported that patients considered their pain to be "much better" when their scores decreased by 2 points. This cutoff was reached in both PBM groups at their long-term follow-up demonstrating clinical improvements in pain and long-term relief of PF symptoms. While it was not a direct aim of this study, medication diary descriptive statistics indicated that daily non-steroidal anti-inflammatory drug consumption decreased in the treatment groups but remained steady or increased in UC participants. This is an interesting finding that warrants further study considering the risks of long-term non-steroidal anti-inflammatory drug use.

While this study did not explore the underlying biological mechanisms for decreased pain in the PBM groups, other works have investigated the impact of PBM on various tendinopathies and may inform the results seen herein. It is well known that effective treatments for PF and other tendinopathies must address the underlying injury mechanism versus the symptoms only. Chronic PF (and other tendinopathies) results in a recurring cycle of degeneration. Animal studies using PBM in other tendinopathy models support that correctly dosed PBM penetrates to the fascia and results in beneficial changes to the degenerated tissue. These changes include synthesis, organization, and strengthening of damaged collagen fibers, activation of matrix metalloproteinases, cellular proliferation and new blood supply growth. In clinical trials, investigators have reported significant decreases in plantar fascial thickness, indicating restructuring of damaged fascia. Taken together, these findings provide support to explain the self-reported improvement in functional outcomes in this and other studies, and future studies should include these objective measures of structural change.

Selection of wavelength and other treatment parameters is essential for effective treatment. The vast majority of PBM studies in PF select wavelengths in the near-infrared range. At lower wavelengths (500nm to 800nm), melain in the skin is the primary chromophore, limiting penetration to deeper structures, however light in the 800nm to 1000nm range is ideal for reaching the injured tissue in PF.

Because study patients were treated over both the plantar surface of the foot, which typically has less melanin than other skin, as well as the dorsal calf and ankle, the impact of Fitzpatrick skin type on outcomes was evaluated. The study had a significant finding that higher Fitzpatrick category was predictive for poorer outcomes in the FAAM ADL and sports subscale, but had no significant impact on pain. Though these results should be interpreted cautiously due to the small number of participants in higher Fitzpatrick categories, it is important to remember when designing treatment protocols to consider using a longer wavelength option (e.g., 980 nm) for those individuals.

IMPLICATIONS

With advances in technology making devices with higher power outputs available, understanding appropriate use of PBM parameters is more essential than ever before. The current study utilized a simple area equation to ensure all

Figure 7. Long-term Defense and Veterans Pain Rating Scale Results
Figure 8. Long-term Foot and Ankle Ability Measure Results

Long-term treatment effect on FAAM

- FAAM ADL
- FAAM Sports

- 10W PBMT
- 25W PBMT
participants received a standardized energy density of 10 J/cm², regardless of power output. Participants in the both the 10W and 25W groups tolerated the treatment well with no adverse outcomes related to the treatment and reported similar improvements in pain and function. The primary difference between the treatment groups was in the time required to complete the treatment – given the same surface area treated, using 25W is 2.5 times quicker than 10W. In a clinical setting, this equates to being able to treat more patients safely and effectively, while reserving the option to decrease the power output at their discretion without jeopardizing patient outcomes.

LIMITATIONS

The positive outcomes of this study are limited by the absence of a sham treatment group; however, at the time of the study, an indistinguishable sham control option was not available. Secondly, the lack of long-term follow-up in the UC group does limit the utility of the long-term data from both PBM groups. Finally, though conducted in a military treatment facility setting, the demographic distribution of participants are consistent with similar trials, and therefore, supports this treatment protocol for future studies and clinical treatment. Future studies should investigate the impact of even higher-powered lasers (e.g., 40W) to ensure the lack of difference between power groups reported herein persists with even higher laser powers.

CONCLUSION

The standardized PBMT protocol plus UC resulted in statistically and clinically significant decreased pain and improvements in function in the FAAM sports subscale compared to usual care alone. Additionally, there was no difference in outcomes between the groups receiving 10W and 25W output power with a standardized energy density of 10 J/cm² over the long-term, with improvements being sustained at the 6-month follow-up point. The lack of adverse events and significantly and clinically meaningful decreases in pain scores support previous work that PBMT is a safe, innovative treatment targeting the root cause of injury to the PF.
ACKNOWLEDGEMENTS

TriService Nursing Research Program (N16-P09) provided the funding to conduct this study, and the device was provided via a Cooperative Research and Development Agreement between LiteCure, LLC, and the Clinical Investigation Regulatory Office, U.S. Army Medical Research and Materiel Command.

Ann Ketz, RN, PhD is currently employed by Enovis, DJO Global (now Enovis), who acquired LiteCure, LLC; she was not employed by them for the duration of the study. Juanita Anders, BA, MS, PhD, has received Cooperative Research and Development Agreement (CRADA) between USUHS and Lite Cure, LLC; received equipment from B&W Tek, Irradia, Lite Cure, Nitto Denko, PhotoThera; serves on advisory board for Lite Cure, LLC. The remaining 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 the article.

The study was registered at ClinicalTrials.gov (registration number NCT03015116) and was carried out in accordance with ICH/GCP guidelines.

DISCLAIMER

The information, content, and conclusions in this paper do not represent the official position or policy of, nor should any official endorsement be inferred by, the TriService Nursing Research Program, Uniformed Services University of the Health Sciences, Landstuhl Regional Medical Center, the Department of Defense, or the U.S. Government.

Submitted: January 05, 2023 CST, Accepted: October 30, 2023 CST

© The Author(s)
REFERENCES


5. Orchard J. Plantar fasciitis. *BMJ.* 2012;344:e6603. doi:10.1136/bmj.e6603


Photobiomodulation Therapy Plus Usual Care Is Better than Usual Care Alone for Plantar Fasciitis: A Rand...

SUPPLEMENTARY MATERIALS

Supplemental File 1
Original Research

Impact of Concussions on Postural Stability Performance Using the Head Shake-Sensory Organization Test

John D Heick1, Abdulaziz Alkathiry2

1 Physical Therapy and Athletic Training, Northern Arizona University, 2 Physical Therapy and Health Rehabilitation, Maimah University

Keywords: Concussion, Balance, foam cushion, Head Shake Sensory Organization Test

https://doi.org/10.26603/001c.90705

International Journal of Sports Physical Therapy

Background
A concussion is a traumatic brain injury that can result in vestibular and oculomotor dysfunctions. The Head Shake-Sensory Organization Test was developed from the original Sensory Organization Test to measure a subject’s ability to maintain balance while moving their head.

Purpose
The purpose of this study was to compare the performance of adults with no history of concussion to those with a history of concussion on the Head Shake-Sensory Organization Test to determine if long-standing balance deficits are present after concussion.

Study Design
Cross-sectional study

Methods
Subjects with a history of concussion and healthy normal controls completed the Dizziness Handicap Inventory, the Activities-Specific Balance Confidence Scale, the sensory organization test, the head shake SOT, and the Foam Head Shake Sensory Organization test in a single testing session. Scores were analyzed for differences between the two groups.

Results
Twenty-five participants (nine patients with history of concussion and 16 healthy controls; mean age, 21.08±4.10 years) completed testing. The equilibrium scores in both groups significantly decreased with more complex tasks. Furthermore, the concussion group had significantly worse equilibrium scores than the control group during the Head Shake (p = 0.007) and Foam Head Shake-Sensory Organization Test (p = 0.002) tasks but not during the Sensory Organization Test task.

Conclusion
Adding head shake and foam cushion conditions to postural stability tests improves sensitivity in detecting balance deficits in individuals with a concussion.

Level of Evidence
3
INTRODUCTION

A concussion is defined as a traumatic brain injury induced by biomechanical forces.1 It is estimated that 1.6–3.8 million sports-related concussions (SRCs) are sustained each year – with up to 60% of these cases presenting with vestibular and oculomotor dysfunctions.2 Common complaints related to vestibular abnormalities include dizziness, impaired balance, vertigo, difficulty in busy environments, and motion discomfort.3 Vision, somatosensory, and vestibular systems are responsible for postural stability and dynamic balance. Thus, deficits in one or more of these systems would result in difficulty maintaining one’s balance. A component of the vestibular system, the vestibulospinal reflex (VSR) coordinates movements of the head and neck with the body in order to maintain the head in an upright position – for example as the head tilts to the left or right.4

The Head Shake–Sensory Organization Test (HS-SOT) was developed from the original Sensory Organization Test (SOT) with the purpose of measuring an individual’s ability to use vestibular input to maintain balance while moving the head.5 The HS-SOT has been examined under different parameters in several populations including: young healthy adults, young adults with peripheral vestibular hypofunction, young athletic populations, and an aging population.6–9 The HS-SOT was evaluated in a healthy population in a study performed by Cripps et al. where the test-retest reliability was found to be excellent (0.78–0.85) in healthy asymptomatic adults aged 20 to 26 years.10 Honaker et al. tested individuals with and without peripheral vestibular asymmetry to determine the sensitivity and specificity of the HS-SOT for indicating peripheral vestibular hypofunction.7 It was determined that the sensitivity of Condition 5 of the HS-SOT with horizontal head turns at 15 degrees per second was 70%, and the specificity was 100%.7 This suggests the effectiveness of Condition 5 of the HS-SOT with head turns of 15 degrees per second for confirming peripheral vestibular dysfunction, or asymmetry. Another study confirmed the reliability of the HS-SOT in healthy young adults (ICC=0.85, 0.78 for Conditions 2 and 5 respectively) compared to lesser reliability in older populations.5 The HS-SOT has not been tested in populations with a known history of concussion. Because vestibular dysfunction has been implicated in those with concussions, clinical tools should be used to fully assess the resulting impairments. The purpose of this study was to compare the performance of adults with no history of concussion to those with a history of concussion on the Head Shake–Sensory Organization Test to determine if long-standing balance deficits are present after concussion.

The hypothesis is that individuals with a history of concussion will score lower (not as well) than those without a history of concussion.

METHODS

This cross-sectional study was approved by the Northern Arizona University Institutional Review Board and all subjects gave informed consent.

PARTICIPANTS

Participants were recruited through flyers distributed to a public university in a metropolitan community. Participants were required to be 18 to 35 with a history of concussion(s) or no history of concussion(s) and possess sufficient English language skills to complete questionnaires. Participants were excluded if they were: under 18 or over 35 years, had a lower extremity musculoskeletal injury in the prior three months; history of a head injury in the past year; or diagnosis of a visual, vestibular, or balance disorder, had limited cervical range of motion that would interfere with horizontal head movements, were unable to complete the SOT or had fall reactions to SOT Conditions 5 and 6, had an acute concussion within seven days of participation in the study, had a history of migraines or severe motion intolerance. Participants were had to have not consumed alcohol for 24 hours before participating in testing.

Telephone screening was used to ascertain eligibility. Participants meeting study criteria were provided information about the purpose of the research and the potential risks. Participants provided written informed consent. Experimental procedures were approved by the institutional review board associated with the study. Participants completed a personal/medical history form prior to testing to ensure there were no reasons for exclusion.

INSTRUMENTATION

SENSORY ORGANIZATION TEST (SOT)

The SOT evaluates sensory interactions during six conditions that selectively remove or disrupt visual, somatosensory, or vestibular systems with the participant attempting to maintain steady state standing balance while wearing a harness. The conditions are the following: (1) eyes open standing on a firm surface; (2) eyes closed while standing on a firm surface; (5) sway-referenced vision standing on a firm surface; (4) eyes open standing on a sway-referenced surface; (5) eyes closed standing on a sway-referenced surface; and (6) eyes open, sway-referenced vision standing on a sway-referenced surface. Three trials are performed for each condition to generate a composite equilibrium score. The SOT uses a computerized system with a servo-controlled dual force plate and visual surround to determine whether an individual can effectively use inputs from visual, somatosensory, and vestibular systems to maintain balance while suppressing inaccurate sensory information11,12 The SOT was performed using the NeuroCom Equitest BalanceMaster, following a standardized procedure in the literature (Neurocom International, Inc., Clackamas, OR, USA.13 The SOT has good-to-moderate test-retest reliability and has assessed sensory contributions to balance control in children, young adults, older adults, and individu-
als with neurological disorders.\textsuperscript{14-17} It has also been used to evaluate the effectiveness of interventions for improving balance.\textsuperscript{18-20} Although the SOT is a commonly used balance assessment tool, its ability to detect subtle balance deficits has been challenged.\textsuperscript{19,21-23}

**HEAD SHAKE SENSORY-ORGANIZATION TEST (HS-SOT)**

The HS-SOT is an enhancement of the SOT and was developed to improve the delineation of balance performance.\textsuperscript{5,24,25} In the HS-SOT, dynamic head movements are incorporated into standard SOT Condition 2 and Condition 5.\textsuperscript{5,24} Unlike the SOT where the head is static, the HS-SOT requires active head movements in the horizontal plane, as if saying no repeatedly, to correspond with visual and auditory feedback while maintaining a fixed head velocity at approximately 100° per second as measured by an accelerometer. In addition to assessing the possible influence of head movements on postural stability, the HS-SOT also stimulates the semicircular canals.\textsuperscript{24} This stimulation creates additional vestibular input that must be integrated during the balance task.\textsuperscript{25} Therefore, the HS-SOT may expose subtle balance deficits and enhance the clinical standard use of the SOT.\textsuperscript{5} The HS-SOT has been shown to have excellent test-retest reliability in healthy, younger adults and moderate-to-good test-retest reliability in healthy, older adults.\textsuperscript{26} At least five separate trials of each condition of the HS-SOT are required to calculate composite fixed (Condition 2) and sway (Condition 5) scores.

**THE DIZZINESS HANDICAP INVENTORY (DHI)**

The DHI is a self-assessment questionnaire intended to measure the impact of dizziness on an individual’s everyday functioning. The DHI questionnaire has 25 questions about the physical, emotional, and functional effects of dizziness on a person’s life.\textsuperscript{27} Three subscales are assigned to the questions. The physical subscale consists of nine items that measure the physical effects of vertigo, such as unsteadiness, loss of balance, and nausea. The emotional subscale consists of nine items that measure the emotional effect of vertigo, such as anxiety, depression, and frustration. The functional subscale is comprised of seven items that measure the impact of vertigo on daily activities, such as walking, driving, and working. The overall score runs from 0 to 100, and each question is graded on a 5-point scale (yes, sometimes, no). Higher ratings reflect a larger impact of vertigo on the individual’s everyday life. The DHI can be used to measure the severity of vertigo and to monitor symptomatic changes over time.\textsuperscript{27}

**THE ACTIVITIES-SPECIFIC BALANCE CONFIDENCE (ABC) SCALE**

The ABC scale is a questionnaire developed to measure a person’s confidence in their ability to conduct a variety of daily activities without losing their balance or falling. The 16-item ABC scale asks individuals to assess their confidence in accomplishing particular tasks on a scale ranging from 0% (no confidence) to 100% (complete confidence).\textsuperscript{28} The items encompass a variety of tasks, such as walking up and down stairs and reaching for an object on high shelves. Higher scores on the ABC scale indicate greater trust in balancing.\textsuperscript{28}

**PROCEDURES**

All testing was conducted at a university research laboratory at the same location and completed in a single session. Participants were permitted to use glasses or contact lenses. Participants completed a personal/medical history form, the DHI, and the ABC. Instructions were provided before each test was performed, and participants were asked to demonstrate their understanding of the test before proceeding. Participants were offered rest breaks and water between tests to ensure hydration and adequate rest. Per SOT manufacturer recommendations, participants were placed in an appropriately sized harness that did not restrict sway, and their malleoli were aligned with the axis of rotation based on their height. Participants were told to stand as steadily as possible while performing SOT Condition 2 (standing eyes closed on fixed surface) and SOT Condition 5 (standing eyes closed on sway surface) under three conditions. The three conditions were the standard SOT protocol, the HS-SOT protocol, and the HS-SOT protocol while standing on a foam pad. The order of the three conditions was randomized for each participant. Three trials of the SOT were performed for each condition to calculate a composite score, ranging from 0 to 100. A score of 0 was given to participants who required the harness to prevent a fall.

After completing each of the three conditions, participants were disengaged from the BalanceMaster and offered a seated rest break. Participants were assisted in donning the head accelerometer, and their malleoli were realigned in the proper axis. Participants were instructed to move their head in the horizontal axis at a velocity of approximately 100° per second that corresponded with an auditory tone and visual feedback on the computer monitor. Participants practiced maintaining the horizontal cervical spine motion at the appropriate velocity using the visual feedback until they were able to maintain the motion with their eyes closed and using the auditory feedback. Three trials of each condition were performed to calculate the composite fixed and sway scores.

**STATISTICAL ANALYSIS**

A sample size calculation was performed to estimate modest relationships between the SOT and HS-SOT tests using PASS version 12 software indicating 24 participants would be required for a power of at least 0.80. (NCSS Statistical Software, Kaysville, UT). A p-value of less than .05, two-tailed was considered statistically significant. SPSS version 23.0 (IBM Corp., Armonk, NY) was used to analyze the data. A linear mixed-effects model was performed as the groups were unbalanced. A post hoc analysis was completed to identify any differences between the groups.
RESULTS

Twenty-five individuals participated: nine patients with history of concussion (20.33 +/- 3.35 years, age range: 18–28) and 16 healthy controls (21.50 +/- 4.52 years, age range: 18–33). The groups were not significantly different (Table 1).

The participants’ equilibrium scores during each balance test are presented in Table 2.

The linear mixed model (5 Tasks x 2 SOT conditions x 2 groups) showed that there was a significant effect of task, F (2, 100.584) = 55.372, p < 0.001, a significant effect of SOT condition, F (1, 98.930) = 179.653, p < 0.001, and a significant effect of group, F (1, 28.367) = 14.701, p < 0.001. No significant 2- or 3-way interactions were found (p > 0.05). A post hoc analysis of task effect with Sidak adjustment showed that the average equilibrium scores (average of SOT2 and SOT5) in both groups significantly decreased with more complex tasks. Furthermore, the concussion group had significantly worse equilibrium scores than the control group during HS-SOT (p = 0.007) and Foam HS-SOT (p = 0.002) tasks but not during the standard SOT task (See Figure 1).

In the patient group, there was a significant within-subject effect between the tasks (F (2, 97.66) = 42.96, p < 0.001), with higher average equilibrium scores observed on standard SOT (81.41, 95% CI: 76.60–86.21) than HS-SOT (72.62, 95% CI: 67.81–77.42) and both SOT and HS-SOT showed higher average equilibrium scores than Foam-HS-SOT (M = 52.90, 95% CI: 47.48–58.32).

DISCUSSION

The main findings were that the SOT equilibrium score decreased with the addition of head shake and decreased further when participants stood on the foam cushion, and equilibrium scores of participants with a history of concussion were lower during HS-SOT as well as Foam-HS-SOT than scores of healthy participants. However, no group differences were found during SOT. The results of the current study are clinically important because standardized postural stability tests may not detect subtle differences of disruption of the integration of vision with the vestibular system needed to maintain balance.

Researchers have reported that the HS-SOT has good reliability and may be more useful in discriminating subtle postural instability in healthy younger adults compared to healthy older adults. Park et al. investigated SOT and HS-SOT performance in adults aged 20 to 39, adults aged 40 to 59, and older adults aged 60 to 79 reporting decreased performance on Condition 5 for the SOT and HS-SOT compared to Condition 2 for the SOT and the HS-SOT. The current study differs from these studies by the addition of a foam cushion to increase the difficulty and by focusing on healthy younger adults that had sustained a concussion and comparing differences in healthy younger adults that did not have a concussion.

In the clinic, clinicians often assess balance of a patient by challenging balance such as asking a patient to stand on one leg or by the use of a foam cushion. A foam cushion distorts somatosensation and forces the use of vision and the vestibular systems. The literature is sparse on comparing foam cushions to challenge balance. A foam cushion is used in the concussion balance test (COBALT). DeFeo et al. investigated differences between the SOT, modified Bal--

---

Table 1. Healthy Control and Concussion Groups’ Characteristics and Comparisons.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Concussion n=9</th>
<th>Control n=16</th>
<th>Total n=25</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7 Female (78%)</td>
<td>10 Female (62.5%)</td>
<td>17 Female (68%)</td>
<td>0.432*</td>
</tr>
<tr>
<td>Age m(SD) (range)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20.33 (3.35) (18-28)</td>
<td>21.50 (4.52) (18-33)</td>
<td>21.08 (4.10) (18-33)</td>
<td>0.507*</td>
</tr>
<tr>
<td>DHI m(SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.56 (3.28)</td>
<td>2.13 (5.49)</td>
<td>1.92 (4.74)</td>
<td>0.780*</td>
</tr>
<tr>
<td>ABC m(SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>95.24 (2.69)</td>
<td>95.82 (4.98)</td>
<td>95.61 (4.24)</td>
<td>0.749*</td>
</tr>
</tbody>
</table>

DHI: Dizziness Handicap Inventory; ABC: Activities-Specific Balance Confidence; *: Chi square test; #: Independent samples t- test

Table 2. Equilibrium Scores for Conditions 2 and 5 with and without head shake and while standing on foam pad.

<table>
<thead>
<tr>
<th>Task</th>
<th>Condition</th>
<th>Concussion M (SD)</th>
<th>Control M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOT</td>
<td>2</td>
<td>91.7 (1.8)</td>
<td>93.6 (1.4)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>55.2 (17.7)</td>
<td>69.2 (9.0)</td>
</tr>
<tr>
<td>HS-SOT</td>
<td>2</td>
<td>81.0 (12.1)</td>
<td>91.4 (2.6)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>42.0 (16.0)</td>
<td>53.9 (12.6)</td>
</tr>
<tr>
<td>Foam HS-SOT</td>
<td>2</td>
<td>50.4 (20.0)</td>
<td>63.4 (20.2)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>19.7 (2.4)</td>
<td>43.8 (16.2)</td>
</tr>
</tbody>
</table>

SOT: Sensory Organization Test; HS: Head Shake; M: Mean; SD: Standard Deviation
Figure 1. Comparison of Average Equilibrium Score Between Healthy and Concussed Groups.

SOT: Sensory Organization Test, HS: Head shake
*: significant difference between groups difference (p<0.05)

In the current study, the two patient reported outcome measures used were the DHI and ABC scores. Interestingly, there were no differences in DHI and ABC scores between the control (mean age 21.50 +/- 4.52 years) and the concussed (mean age 20.35 +/- 3.35 years) groups. As these subjective outcome measures are measuring perceived dizziness (DHI) and perceived confidence in balance (ABC) across functional activities in 20-year-olds, perhaps the young adults did not perceive to have dizziness or lack confidence in balance during functional activities. Specific to the control group, there were two participants that influenced the overall mean for the control group with one participant noting a DHI score of 4 and a separate participant noting a DHI score of 10. Although the participants did not have a history of concussion it is apparent that these two participants may have misinterpreted the questions relative to a complaint of dizziness. An example of this is question 2 of the DHI that asks "because of your problem, do you feel frustrated" or question 7 that asks "because of your problem, do you have difficulty reading?" Perhaps the participant interpreted these questions without considering that this questionnaire was only relevant to dizziness. The exclusion criteria for the study did not limit those with attention deficit disorder or a learning disability so it is possible that this influenced these two participants, but this information was not collected in this study.

LIMITATIONS

There were potential limitations in the current study. First, there was a small sample size of prior concussed participants. When considering the number of concussions re-
ported in an athletic season, the Centers for Disease Control estimates that five to 10% of athletes will be diagnosed with a concussion. In the current study, 36% of the participants had a concussion history and were not athletes. The authors of the current study suggest that future studies should investigate a larger athletic population using the HS-SOT to identify potential subtle balance deficits. Second, the National Collegiate Athletic Association and the Department of Defense Concussion Assessment, Research, and Education (NCAA-DOD CARE) trials investigated the impact of attention deficit/hyperactivity disorder, learning disability, and the combination of these two neurodevelopment disorders. The NCAA-DOD CARE trial suggests that athletes with these neurodevelopment disorders have a greater risk of incurring a concussion (Relative Risk range of 1.369 to 2.245) compared to controls. In the current study, these neurodevelopment disorders were not assessed and therefore it is possible that participants with these disorders were included in the study. It is currently unknown how neurodevelopment disorders impact postural stability in this population. A limitation of the current study is that it was performed in a controlled research lab as the SOT and the HS-SOT conditions are impacted by noisy environments such as the athletic training room. Authors have suggested that both the SOT and HS-SOT should be performed in a quiet environment as participants are attempting to maintain their balance and uncontrolled noise may startle the participant and impact their ability to maintain their balance. Results may differ in more typical athletic environments.

CONCLUSION

Standardized postural stability tests are commonly used to assess balance deficits; however, these tests may not be sensitive enough to detect subtle differences in balance disruption. In the current study, the HS-SOT and Foam-HS-SOT conditions were more challenging than the SOT for the participants suggesting that the addition of head motion or a foam cushion may assist with identification of balance impairments. Participants with a concussion history had lower equilibrium scores in the HS-SOT and Foam-HS-SOT conditions than healthy participants. This suggests that these tests discriminate subtle postural instability in individuals with a concussion. Clinicians should consider using more challenging postural stability tests to better assess balance deficits in individuals with a concussion.

CONFLICTS OF INTEREST

The authors have no conflicts of interest to report. The authors have no sources of funding to declare.

Submitted: August 21, 2023 CST, Accepted: November 06, 2023 CST
© The Author(s)
REFERENCES


Original Research

Physically Active Adults with Low Back Pain do not Demonstrate Altered Deadlift Mechanics: A Novel Application of Myotonometry to Estimate Inter-Muscular Load Sharing

Jared M. McGowen1, Stephanie R. Albin2, Carrie W. Hoppes3, Jeffrey S. Forsse1, John Abt1, Shane L. Koppenhaver4

1 Health, Human Performance, and Recreation, Baylor University, 2 School of Physical Therapy, Regis University, 3 Army-Baylor University Doctoral Program in Physical Therapy, Baylor University, 4 Children's Health Andrews Institute for Orthopaedics and Sports Medicine, 5 Doctoral Program in Physical Therapy, Baylor University

Keywords: Muscle stiffness, neuromuscular function, rehabilitation, clinical decision making

https://doi.org/10.26603/001c.90707

International Journal of Sports Physical Therapy

Background
Rehabilitation clinicians that work with physically active populations are challenged with how to safely return patients back to performing deadlift movements following low back injury. Application of reliable and valid tests and measures to quantify impairments related to low back pain (LBP) enhances clinical decision making and may affect outcomes. Myotonometry is a non-invasive method to assess muscle stiffness which has demonstrated significant associations with physical performance and musculoskeletal injury.

Hypothesis/Purpose
The purpose of this study was to compare the stiffness of trunk (lumbar multifidus [LM] and longissimus thoracis [LT]) and lower extremity (vastus lateralis [VL], and biceps femoris [BF]) muscles between individuals with and without LBP during the lying, standing, and deadlifting body positions.

Study Design
Cross-sectional cohort comparison

Methods
Muscle stiffness measures were collected in the VL, BF, LM, and LT muscles with participants in lying (supine and prone), standing, and the trap bar deadlift position. Separate analyses of covariance were conducted to compare absolute and relative muscle stiffness between the groups for each muscle and condition.

Results
Sixty-eight participants (41 female, 21.3 years, 34 LBP) volunteered for the study. Within the deadlift condition there was a significantly greater increase in the percent-muscle stiffness change in the VL (p = .029, 21.9%) and BF (p = .024, 11.2%) muscles in the control group than in the LBP group. There were no differences in percent-muscle stiffness changes for the standing condition nor were there any absolute muscle stiffness differences between the two groups for the three conditions.

Conclusion
No differences in muscle stiffness were identified in the lying, standing, or deadlifting conditions between participants with and without LBP. Differences in percent stiffness changes were noted between groups for the deadlift position, however the differences were modest and within measurement error. Future studies should investigate the utility

a Corresponding author:
Jared McGowen
661-342-6783, mcgowenj@gmail.com
of myotonometry as a method to identify LBP-related impairments that contribute to chronic and/or recurrent low back injury.

Level of Evidence
Level 3

INTRODUCTION

Low back pain (LBP) is one of the most commonly reported musculoskeletal conditions amongst adults in the United States. Although populations that consistently engage in physically demanding activities such as athletes, tactical professionals (law enforcement, first responders, military), and manual laborers may sometimes possess higher levels of fitness, they too have demonstrated high rates of low back injuries. The responsibility of musculoskeletal providers to effectively manage LBP and make appropriate return to activity decisions is arguably more challenging in physically active than in sedentary populations due to the physically demanding requirements of their sport or occupation. Deadlift variations are common movement patterns that are present within strength and conditioning programs and within physically demanding occupations. Deadlift training is intended to strengthen the musculature of the lumbopelvic region and lower extremities to help individuals prepare for and improve upon the specific physical demands of their sport, occupation, and active lifestyle. However, little evidence exists to inform rehabilitation clinicians about when neuromuscular impairments resulting from low back injury may preclude an individual from safely returning to deadlift training or when using deadlift variations as a rehabilitation exercise is indicated. The high incidence of low back injuries amongst individuals who are expected to return to perform deadlift or deadlift-like movements (e.g. hip-hinge) places an urgent requirement on researchers and clinicians to further identify neuromuscular impairments that may be prohibitive of a safe return to deadlift training following low back injury.

Stiffness is a mechanical property of muscle that has been suggested as an important measure of muscle health and function. Myotonometry is a non-invasive, objective method of quantifying muscle stiffness through portable, handheld devices called myotonometers. During isometric contractions, muscle stiffness has demonstrated a stronger, positive linear relationship with force production than the linear relationship demonstrated between electromyography (EMG) and force. The relationship between muscle stiffness and force indicates that stiffness may be a superior metric than EMG to determine the relative force that an individual muscle is contributing to a multi-muscle task. Furthermore, the ability of myotonometry to quantify muscle stiffness under relaxed and contracted states makes it a more versatile method for identifying neuromuscular impairments than EMG which can only measure neural drive from an actively contracting muscle. The ability to reliably identify impairments under passive conditions is not a trivial matter as numerous studies have demonstrated that abnormal passive muscle stiffness levels are present in individuals with a variety of neuromusculoskeletal disorders, including LBP, The MyotonPRO Digital Palpation Device (Myoton AS, Tallinn, Estonia) is a myometer that can quantify active and passive muscle stiffness in a quick and reliable manner that is necessary for obtaining tests and measures in clinical settings. Utilization of the MyotonPRO in individuals with LBP may help clinicians identify and monitor neuromuscular impairments to improve plan of care decisions that improve outcomes and help to reduce LBP re-injury rates.

Increased stiffness of lumbar spine muscles has been demonstrated in those with LBP, but this has only been demonstrated with the participants lying in prone. No study has investigated muscle stiffness in LBP populations in body positions relevant to sport and occupational function such as in the standing and deadlifting positions. Investigating muscle stiffness of both the lumbar spine and the lower extremities during these positions will help researchers and clinicians better understand how muscle stiffness behaves during loaded body positions and how this may be altered in those with LBP. Therefore, the primary purpose of this study was to compare the stiffness of trunk (lumbar multifidus [LM] and longissimus thoracis [LT]) and lower extremity (vastus lateralis [VL] and biceps femoris [BF]) muscles between individuals with and without LBP during the lying, standing, and deadlifting body positions. The secondary purpose was to compare percent-muscle stiffness changes that occur as participants transition from a relaxed condition to the standing (trunk musculature only) and deadlifting positions (trunk and lower extremity musculature). Participants with LBP were hypothesized to demonstrate increased trunk muscle stiffness in the relaxed and standing conditions, but for the deadlift conditions individuals with LBP were hypothesized to exhibit decreased trunk and hamstring muscle stiffness with increased vastus lateralis muscle stiffness secondary due to pain-induced compensatory deadlift mechanics.

METHODS

PARTICIPANTS

Sixty-eight physically active adults were recruited for the study through word of mouth and flyers distributed across the university campus. Healthy volunteers were included if they had no complaint of lower extremity or spine pain that limited their participation in physical activity over the prior six months and were able to achieve the body position required to perform a trap bar deadlift (Figure 1). Healthy volunteers were excluded if they were pregnant or had a body mass index (BMI) categorized as obese (30 kg/m²). Individuals with BMI that qualified as obese were excluded because subcutaneous adipose exceeding 20 mm in thickness may
interfere with the MyotonPRO’s ability to accurately measure muscle stiffness. Volunteers with LBP were included if they were currently experiencing pain between the 12th rib and the gluteal fold, had moderate LBP-related disability (defined as a score of ≥ 20 on the Oswestry Disability Index [ODI]), and were able to achieve the trap bar deadlift position. Volunteers with LBP were excluded if they were pregnant, had a BMI that qualified as obese, or any current medical conditions of a serious nature (fracture, cancer, systemic disease, lower quarter neurological deficits). Participants were first screened for study eligibility (ODI score and BMI) via email and again the day of study participation. Prior to data collection, all participants signed an informed consent form approved by the university’s Institutional Review Board (Project ID: 1921195-3) and the study was performed in accordance with the ethical standards of the Declaration of Helsinki.

PROCEDURES

Prior to collection of muscle stiffness measures, participants had their height and weight recorded with a stadiometer (Seca 777, Hamburg, Germany), then completed self-report questionnaires for demographic, activity level, exercise frequency, LBP-related disability, pain, and anxiety. Physical activity level was assessed with a single question, “Over the last year, how would you assess your activity level?” with possible responses being “inactive”, “somewhat active”, “active”, and “very active.” This question has demonstrated adequate reliability and validity to assess activity level when compared to more comprehensive questionnaires. Furthermore, activity level assessed with this single question has been shown to have a positive relationship with lumbar muscle stiffness. Weekly participation in aerobic and resistance exercise was assessed with a training frequency question that asked participants, “Over the last year, how frequently (on average) did you participate in at least 30 minutes of aerobic or resistance training?” with possible answers being “less than 1 day per week”, “1-3 days per week”, and “greater than 3 days per week.” The numeric pain rating scale (NPRS) is an 11-point (0-10) scale that is a reliable and responsive measure in people with LBP. Participants with LBP rated their pain in every body position that stiffness measures were collected. The ODI is a reliable and valid 0-100 scale measuring LBP-related disability where higher scores relate to higher disability. Anxiety was assessed with the Beck Anxiety Inventory (BAI) which is a 21-item questionnaire that scores somatic symptoms of anxiety on a 0-63 point scale (higher scores represent more anxiety). The BAI has demonstrated adequate reliability and validity when compared to other anxiety questionnaires and anxiety assessed with this measure has been shown to demonstrate a negative relationship with muscle stiffness. Upon completion of questionnaires, participants with LBP received a subjective and neuromusculoskeletal exam to determine their appropriateness for the study.

Stiffness measurements were collected on the VL, BF, LM (L5 spinal segment), and LT (L1 spinal segment) muscles during the lying (prone/supine) and contracted (standing and trap bar deadlift positions) conditions. These muscles were selected due to their demonstrated importance to deadlift performance as well as spinal health and function in individuals with LBP. Measurement locations were determined using documented electromyography (EMG) sites that were consistent with recommendations stated on the device manufacturer’s website (myoton.com). Measurements were acquired with the participant’s shoes off, recorded from the more symptomatic side in individuals with LBP, and randomized to the left or right side in asymptomatic individuals. Measurements were only collected on the more symptomatic side in participants with LBP to reduce the number of deadlift repetitions that participants had to perform. Furthermore, higher muscle stiffness measurements have been found on the more symptomatic side in people with LBP. Participants with LBP were asked to withhold from receiving any therapeutic interventions for their back pain and from taking any back pain specific medications (pain relievers, anti-inflammatory, muscle relaxers) 12 hours prior to study participation. All participants were asked to maintain their usual level of physical activity 24 hours prior to study participation.

MYOTONPRO MEASUREMENTS

Stiffness measures were obtained using a single measure with the single tap mode of the MyotonPRO to reduce the time required to obtain the measurements in the deadlift position. A previous study found good to excellent test-retest reliability (intraclass correlation coefficients = 0.81 to 0.97) using this method in the same muscles and body positions. Muscle stiffness measures were acquired by the examiner positioning the probe of the MyotonPRO perpendicularly on the belly of the targeted muscles at the recom-

Figure 1. Trap bar deadlift position.
mended locations. The examiner lowered the device into measurement range which was identified by illumination of a green light on the device (Figure 2). A quick (15 ms) and light (0.4 N) device-initiated mechanical impulse force was transmitted through the probe, causing the targeted tissue to respond with a damped oscillation that was registered by the device accelerometer. The tissue’s stiffness measurement (Nm) was computed and displayed on the device screen.

Figure 2. Obtaining stiffness measure of the lumbar multifidus muscle with the MyotonPRO.

STANDARDIZATION OF MEASURES

Measures were first obtained in the lying (supine and prone) position then measured in the standing and trap bar deadlift positions. Lying measures were obtained in supine for the VL muscle and in prone for the BF, LM, and LT muscles. Prior to collecting stiffness measures, trunk angles were collected with an inclinometer at the T12 spinal segment in both the standing and deadlift positions to assess for spinal angle differences between groups. Lying and standing measures were collected in the same order (VL, BF, LM, LT) whereas the deadlift measurements were randomized to account for a possible order effect. Standing measures were obtained with the participants standing with a cone positioned between their feet to standardize stance width. Plastic cones were used to simulate the width and height of trap bar handles to prevent participants from lifting or resting on the trap bar while in the deadlift position (Figure 3). Participants were positioned between two cones that were 63.5 cm apart (width of the trap bar handles). Participants self-selected a stance width that was most comfortable for them to achieve the trap bar deadlift position. The stance width was recorded and maintained for all subsequent deadlift repetitions. Participants were required to squat to a depth that allowed them to contact the top of the cones with closed fists. The height of the cones (22.8 cm) was selected because it is the approximate height of the top of a trap bar handle when loaded with bumper plates. Furthermore, it was reasoned that abnormalities in muscle stiffness were most likely to occur when LBP participants were in the starting position of the deadlift where the highest spine loads have been shown to occur. Participants were required to squat and hold the trap bar deadlift position for approximately 2-5 seconds during four separate repetitions while the examiner obtained muscle stiffness measures on each muscle.

Figure 3. Trap bar deadlift set-up position. Cone dimensions represent height and width of trap bar handles.

STATISTICAL ANALYSIS

Data analyses were performed using SPSS, version 28.0 software (IBM Corp, Armonk, New York) and included data from all 68 participants for the VL, BF, LM, and LT for the relaxed and deadlift positions and the LM and LT for the standing position. Sixty-eight participants ensured at least 80% power to detect an effect size of 0.7 (28 Nm) between groups when using a 2-tailed alpha of .05. Baseline characteristics were summarized by treatment group and compared with independent t-tests for parametric data and Mann-Whitney-U and Chi-squared tests for categorical and dichotomous data, respectively. Variables that were significantly different per group were used in linear regression analyses with each muscle stiffness outcome to assess for use as a covariate. Variables that were statistically different between groups and linearly related to the dependent variable were used as covariates. Additionally, variables such as physical activity that have demonstrated a linear relationship with muscle stiffness were assessed for use as a covariate with linear regression analyses. Separate analyses of covariance were conducted to compare absolute and
Table 1. Characteristics of participants per group

<table>
<thead>
<tr>
<th></th>
<th>Asymptomatic Controls</th>
<th>LBP</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants</td>
<td>34</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>% Female</td>
<td>44%</td>
<td>76%</td>
<td>0.01*</td>
</tr>
<tr>
<td>Age</td>
<td>20.7 (5.1)</td>
<td>21.9 (4.5)</td>
<td>0.97</td>
</tr>
<tr>
<td>Body Mass Index</td>
<td>23.4 kg/m² (2.7)</td>
<td>22.5 kg/m² (2.6)</td>
<td>0.98</td>
</tr>
<tr>
<td>Physical Activity Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inactive</td>
<td>0 (0%)</td>
<td>3 (9%)</td>
<td>0.05</td>
</tr>
<tr>
<td>Somewhat active</td>
<td>7 (21%)</td>
<td>4 (12%)</td>
<td></td>
</tr>
<tr>
<td>Active</td>
<td>4 (12%)</td>
<td>14 (41%)</td>
<td></td>
</tr>
<tr>
<td>Very active</td>
<td>23 (67%)</td>
<td>13 (38%)</td>
<td></td>
</tr>
<tr>
<td>Aerobic Frequency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 1 x per week</td>
<td>2 (6%)</td>
<td>8 (24%)</td>
<td>0.02*</td>
</tr>
<tr>
<td>1-3 x per week</td>
<td>17 (50%)</td>
<td>18 (52%)</td>
<td></td>
</tr>
<tr>
<td>&gt; 3 x per week</td>
<td>15 (44%)</td>
<td>8 (24%)</td>
<td></td>
</tr>
<tr>
<td>Resistance Frequency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 1 x per week</td>
<td>7 (21%)</td>
<td>10 (29%)</td>
<td></td>
</tr>
<tr>
<td>1-3 x per week</td>
<td>10 (29%)</td>
<td>16 (47%)</td>
<td></td>
</tr>
<tr>
<td>&gt; 3 x per week</td>
<td>17 (50%)</td>
<td>8 (24%)</td>
<td></td>
</tr>
<tr>
<td>ODI</td>
<td>N/A</td>
<td>14.0 (3.9)</td>
<td>N/A</td>
</tr>
<tr>
<td>NPRS</td>
<td>N/A</td>
<td>4 (2)</td>
<td>N/A</td>
</tr>
<tr>
<td>BAI</td>
<td>4.5 (5.4)</td>
<td>11.4 (8.4)</td>
<td>&lt; 0.001*</td>
</tr>
</tbody>
</table>

ODI, Oswestry Disability Index for low back pain disability (scored 0-50 with higher scores indicating greater disability). NPRS, numeric pain rating scale (scored 0-10 with higher scores indicating greater pain). BAI, Beck’s Anxiety Inventory (scored 0-63 with higher scores indicating greater anxiety). LBP, low back pain. Values reported as mean (SD) except where noted. *Statistically significant difference at p < 0.05.

Results

Table 1 displays demographic, physical activity, pain, and low back disability data for each group. Sex and physical activity were identified as significant covariates. Comparisons of adjusted means and 95% confidence intervals (CI) are displayed for each muscle across the three conditions in Table 2. The only difference between the two groups was in the VL muscle with the LBP group demonstrating a higher adjusted mean stiffness of 22 Nm (95% CI, 0.21 to 43.8) in the relaxed position. Table 3 and Figure 4 displays percent-muscle stiffness changes that occurred as participants transitioned from the relaxed to the standing and deadlifting positions. There were no significant differences in percent-muscle stiffness change between the lying and standing positions between the two groups. Within the trap bar deadlift position there was a significantly greater increase in the percent-muscle stiffness change that occurred in the VL (p = .029, 21.9%) and BF (p = .024, 11.2%) muscles in the control group than in the LBP group. No between group differences were identified for standing and deadlifting trunk angles or for deadlifting stance widths (p-value range = .205 to .573). Mean LBP intensity was 4/10 (SD = 2) for each body position and 11 (32%) of the participants with LBP reported at least a 1-point increase in pain when they were in the deadlift position.

Discussion

Little is known about how thigh and trunk muscle stiffness behave in individuals with LBP under loaded conditions. The results of this study demonstrate that in young, physically active adults with moderately disabling LBP, stiffness of the VL, BF, LM, and LT muscles are not statistically different than healthy controls during standing and deadlifting positions. Although significant percent-muscle stiffness increases were found in the control group for the VL and BF muscles for the deadlift position, these increases were modest and within measurement error.29 These findings contribute to the growing body of literature regarding how muscle stiffness relates to LBP and how myotonometry may be used to monitor for neuromuscular deficits that have been difficult to reliably quantify with other clinical methods.43 Furthermore, these findings have important implications for rehabilitation providers managing physically active individuals who have LBP and will be returning...
to deadlift training and/or performing similar deadlift-like movements upon completion of rehabilitation.

The lack of statistically significant differences in muscle stiffness between the two groups across all conditions was not an expected finding. Earlier studies have shown increased erector spinae stiffness in those with LBP and demonstrated that muscle stiffness was positively related to pain scores and negatively related to function.\textsuperscript{27,30} In contrast, this study found no between group differences for LM or LT stiffness in the relaxed condition despite the participants with LBP exhibiting higher levels of LBP-related disability than in previous studies (Table 1). However, it is worth highlighting that in younger individuals with LBP, Ilahi et al.\textsuperscript{30} found that only females demonstrated an increase in relaxed erector spinae stiffness compared to age- and activity-matched controls. Moreover, Wu et al.\textsuperscript{27} found statistically significant increases in a mixed-sex group of elderly with LBP, but the mean muscle stiffness differences (42.1 Nm) between the healthy and LBP groups did not exceed minimal detectable differences reported in their study (47.2-50.2 Nm). The inconsistency in findings clearly highlights that further research is necessary to better understand the relationship between lumbar musculature stiffness and LBP.

The hypotheses that participants with LBP would demonstrate differences in the standing and deadlift pos-

### Table 2. Muscle stiffness comparisons per condition, all values are reported in Newton-meters.

<table>
<thead>
<tr>
<th></th>
<th>Mean Stiffness (SD)</th>
<th>Adjusted Mean Differences\textsuperscript{a} (95% Confidence Interval)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control (n = 34)</td>
<td>LBP (n = 34)</td>
<td></td>
</tr>
<tr>
<td>VL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relaxed</td>
<td>303.9 (32.5)</td>
<td>314.8 (57.8)</td>
<td>22.0 (0.21 to 43.8)</td>
</tr>
<tr>
<td>Standing</td>
<td>427.3 (115.0)</td>
<td>375.2 (102.9)</td>
<td>19.0 (-66.6 to 28.7)</td>
</tr>
<tr>
<td>Deadlift</td>
<td>640.1 (175.0)</td>
<td>553.5 (186.5)</td>
<td>26.1 (-49.6 to 101.8)</td>
</tr>
<tr>
<td>BF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relaxed</td>
<td>263.0 (50.4)</td>
<td>251.9 (51.6)</td>
<td>6.3 (-14.8 to 27.4)</td>
</tr>
<tr>
<td>Standing</td>
<td>291.0 (86.6)</td>
<td>272.5 (68.2)</td>
<td>7.4 (-25.3 to 40.1)</td>
</tr>
<tr>
<td>Deadlift</td>
<td>285.7 (106.6)</td>
<td>230.6 (55.2)</td>
<td>8.0 (-8.3 to 64.3)</td>
</tr>
<tr>
<td>LM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relaxed</td>
<td>234.1 (71.5)</td>
<td>237.3 (66.4)</td>
<td>11.1 (-23.4 to 45.6)</td>
</tr>
<tr>
<td>Standing</td>
<td>291.7 (153.7)</td>
<td>301.3 (156.5)</td>
<td>29.6 (-43.8 to 109.0)</td>
</tr>
<tr>
<td>Deadlift</td>
<td>675.2 (279.1)</td>
<td>612.7 (244.6)</td>
<td>62.5 (-121.7 to 123.0)</td>
</tr>
<tr>
<td>LT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relaxed</td>
<td>316.5 (50.5)</td>
<td>312.6 (55.7)</td>
<td>2.4 (-24.7 to 29.4)</td>
</tr>
<tr>
<td>Standing</td>
<td>366.1 (105.4)</td>
<td>364.0 (124.0)</td>
<td>2.1 (-50.6 to 65.4)</td>
</tr>
<tr>
<td>Deadlift</td>
<td>645.0 (173.1)</td>
<td>614.2 (216.6)</td>
<td>30.8 (-94.4 to 99.0)</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Mean stiffness differences and confidence interval values are adjusted for sex and activity level. \textsuperscript{*}Statistically significant difference at p < 0.05.

### Table 3. Percent muscle stiffness changes between relaxed and deadlift conditions, all values are reported in Newton-meters

<table>
<thead>
<tr>
<th></th>
<th>Percent Mean Stiffness Change (SD)</th>
<th>Adjusted Mean Differences\textsuperscript{a} (95% Confidence Interval)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control (n = 34)</td>
<td>LBP (n = 34)</td>
<td></td>
</tr>
<tr>
<td>Standing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM</td>
<td>21.5 (42.1)</td>
<td>22.3 (38.2)</td>
<td>12.0 (-14.1 to 25.9)</td>
</tr>
<tr>
<td>LT</td>
<td>15.2 (26.5)</td>
<td>14.9 (26.3)</td>
<td>2.7 (-11.1 to 15.5)</td>
</tr>
<tr>
<td>Deadlift</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VL</td>
<td>107.9 (43.3)</td>
<td>73.6 (44.6)</td>
<td>21.9 (2.3 to 41.4)</td>
</tr>
<tr>
<td>BF</td>
<td>6.7 (24.6)</td>
<td>-8.0 (13.8)</td>
<td>11.2 (1.5 to 21.0)</td>
</tr>
<tr>
<td>LM</td>
<td>184.9 (78.0)</td>
<td>155.7 (74.2)</td>
<td>12.0 (-23.8 to 47.8)</td>
</tr>
<tr>
<td>LT</td>
<td>101.9 (41.8)</td>
<td>95.2 (59.7)</td>
<td>2.7 (-22.2 to 27.7)</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Mean stiffness and confidence interval values are adjusted for sex and activity level. \textsuperscript{*}Statistically significant difference at p < 0.05.
Percent of Muscle Stiffness Change, Relaxed to Deadlifting

![Graph depicting percent-muscle stiffness change per muscle for the trap bar deadlift in healthy controls and participants with low back pain (LBP).](image)

*Statistically significant difference at $p < 0.05$.

The relationship between deadlift performance and lower back pain (LBP) was also mostly unsupported by the results. Movement and motor control impairments are known to occur secondary to pain.\textsuperscript{44,45} Thus, it was expected that LBP symptoms would be exacerbated under these relatively loaded conditions, leading to compensatory motor control strategies that would manifest as altered stiffness in the muscles of interest. The absence of muscle stiffness differences in these positions suggests there may have been an insufficient level of pain intensity and/or LBP-related disability to result in muscle dysfunction. It is also possible that the MyotonPRO measures were not sensitive enough to detect mild differences that may have been present between the two groups. Specific to the deadlift position, pain data analysis demonstrated that only 32% (n = 11) of the LBP group reported an increase in pain while they were in the deadlift posture. Furthermore, only two participants reported a 2-point increase in pain that is necessary for clinical significance.\textsuperscript{54} Though speculative, it may be that a compensatory deadlift posture (e.g. adopting a more upright trap bar deadlift set-up) may only be found in individuals who experience a clinically meaningful increase in LBP symptoms that are specific to the deadlift set-up position. Another explanation could be that individuals with mild to moderate levels of spinal pain and disability only demonstrate compensatory trap bar deadlift mechanics with deadlift attempts of higher intensities. Future studies should seek to answer these questions as they could help to further clarify when individuals with LBP may be safe to return to deadlift training and at what capacity.

This is the first study to use muscle stiffness to determine inter-muscular load sharing percentages while performing a variation of the deadlift. Figure 4 and Table 3 demonstrate the relative change in muscle stiffness as participants transitioned from the lying (relaxed) position to the deadlift position. The substantial increases in stiffness for the VL, LM, and LT muscles suggests that these muscles are important force producing muscles during performance of the trap bar deadlift. These results are supported by previously recorded deadlift muscle activation patterns measured with EMG,\textsuperscript{38} and demonstrates the versatility of myotonometry as a method to estimate individual muscle contributions (through the surrogate of muscle stiffness) to a compound movement such as the deadlift.

Finally, this is the first study to compare performance of a deadlift variation between healthy and LBP cohorts using muscle stiffness as an outcome. The results are largely consistent with a similar study that used force production and EMG to compare isometric deadlift performance between individuals with and without LBP.\textsuperscript{16} Stock et al.\textsuperscript{16} demonstrated that individuals with acute, non-specific LBP had the same force output and muscle excitability patterns as healthy controls. Collectively, these findings suggest that within young, active individuals with mild to moderate pain levels and LBP-related disability, deadlift variation training may be able to be performed without any added concern for re-injury secondary to lumbar spine or lower extremity neuromuscular impairments. Additionally, this study adds to the growing body of literature evaluating if and how myotonometry may be a useful clinical method to assist clinicians with detecting neuromuscular deficits.
LIMITATIONS

The present study had several important limitations. First, the generalizability of this study is limited to young, active individuals with mild to moderate levels of LBP-related disability. Similarly, the deadlift variation used in this study was specific to the trap bar and the starting (“initial pull“) position of the lift and therefore does not apply to other deadlift variations, positions, or to dynamic movements. Additionally, the deadlift inter-muscular stiffness percentages identified in this study occurred under minimal load (body weight) and may not accurately represent individual muscle contributions as isometric deadlifts are performed at higher intensities. Finally, the MyotonPRO measurements are limited by subcutaneous fat thickness that exceeds 2 cm and can only target superficial tissues that can be palpated. Despite attempts to combat these limitations by requiring participants to have BMIs less than 30 kg/m² and using recommended muscle stiffness measurement locations it is possible that fat, non-target muscle, and fascia located over the target muscles may have interfered with some muscle stiffness measures.

CONCLUSION

The results of this study indicate that no significant differences in muscle stiffness exist between participants with LBP and healthy controls in the lying, standing, or deadlifting conditions. Although differences in percent-muscle stiffness changes were noted between groups for the deadlift position, the differences were within measurement error. Future studies should seek to expand on these findings by using myotonometry to further investigate the relationships between muscle stiffness and deadlift performance in LBP populations of varying degrees of pain and/or disability.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

Submitted: June 22, 2023 CST, Accepted: November 06, 2023 CST
© The Author(s)

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


Effects of a Total Motion Release (TMR®) Protocol for the Single Leg Squat on Asymmetrical Movement Patterns

Nickolai JP Martonick1, Craig P McGowan2, Russell T Baker1, Lindsay W Larkins, Jeff G Seegmiller3, Joshua P Bailey3

1 Movement Sciences, University of Idaho, 2 Department of Integrative Anatomical, University of Southern California, 3 Department of Movement Sciences, University of Idaho

Keywords: Lower limb asymmetry, Statistical Parametric Mapping, Single Subjects, Rehabilitation

BACKGROUND
Improving single leg squat (SLS) movement symmetry may benefit rehabilitation protocols. The Total Motion Release® (TMR®) protocol has been theorized to evaluate and improve patient-perceived movement asymmetries.

HYPOTHESIS/PURPOSE
The purpose of this study was to evaluate whether perceived asymmetries identified by a TMR® scoring protocol were related to biomechanical asymmetries and whether improving perceived asymmetries influenced movement mechanics. It was hypothesized that participants with perceived asymmetries would also present with biomechanical asymmetries. A secondary hypothesis was that participants would reduce their perceived asymmetries after performing the TMR® protocol and subsequently have greater biomechanical symmetry.

STUDY DESIGN
Descriptive Cohort (Laboratory Study).

METHODS
Twenty participants (10 female, 10 male) with self-identified bilateral differences of 10 points or greater on the TMR® scoring scale were recruited for the study. The non-preferred side was defined as the side that scored higher. 3Dimensional motion capture was used to bilaterally assess baseline SLS depth as well as hip, knee, and ankle kinematics and kinetics. For the TMR® protocol, sets of 10 SLSs were performed on the preferred leg until their perceived asymmetries were resolved (i.e., both sides scored equally), or four sets had been completed. Kinematics and kinetics were collected immediately after the intervention and after a 10-minute rest period.

RESULTS
Participants had biomechanical asymmetries at baseline for knee flexion, ankle flexion, and knee moments. Following the intervention, participants had reduced TMR® scores on the non-preferred leg, and this coincided with increased knee joint moments on that side. Although perceived asymmetries were resolved after the intervention, kinematic and kinetic asymmetries at the knee and ankle were still present.

CONCLUSIONS
A TMR® intervention could benefit rehabilitation protocols by reducing factors of dysfunction and increasing the ability of patients to load the non-preferred knee. Further investigations are necessary to elucidate the importance of asymmetrical movement patterns.

Corresponding Author
Nickolai J.P. Martonick, nmartonick@uidaho.edu
LEVEL OF EVIDENCE

INTRODUCTION

Lower extremity movement symmetry is often established as a goal of return to sport protocols when unilateral musculoskeletal injuries impair movement on one side. The single leg squat (SLS) can be utilized as both an examination tool and a therapeutic exercise due to its potential to identify movement asymmetries\(^1\) as well as rehabilitate lower extremity injury.\(^2\) Similarities in joint kinematics between the SLS and high-velocity sports maneuvers like jogging and jumping have been also been demonstrated.\(^3,4\) Improving biomechanics during the SLS may therefore facilitate rehabilitative goals for movements during athletic tasks. Various injuries have been found to disrupt SLS biomechanics, eliciting decreased measures in overall squat depth, knee flexion angle, and hip flexion angle.\(^5,6\) However, little is known about how patient reported symptoms that are often related to injury (i.e., pain, tightness, weakness) influence SLS mechanics and movement symmetry.

Total Motion Release® (TMR®) is a rehabilitation protocol theorized to reduce symptoms of dysfunction such as pain, tightness, and limited range of motion (ROM) by performing movements on the side contralateral to the symptomatic limb.\(^7,8-9\) When using TMR®, a baseline series of six upper (arm raise, trunk twist, arm press) and lower extremity motions (single leg squat, straight leg raise, single leg sit-to-stand), are first performed and each motion is then rated by the patient on both sides using a scale from 0-100.\(^5,8,10\) The higher the rating, the greater the patient’s symptoms, which may be related to subjective measures of stability, range of motion, pain, tightness, etc.\(^7\) As the protocol aims to identify imbalances based on patient-reported symptoms during the movements, it may have utility for identifying dysfunction related to a variety of underlying injury mechanisms. After an imbalance or imbalances are identified (i.e., a difference in scores between sides), the patient will self-treat by using the movement with the greatest imbalance and performing that motion on the side that scored lower (i.e., the preferred side).\(^5,11\) Performing the exercises on the preferred side is thought to improve symptoms on the non-preferred side (i.e., the side that scored higher); thus, practitioners can reduce the risk of exacerbating symptoms in the early phases return to sport protocols.

The TMR® protocol is theorized to work from a model of regional interdependence that infers a connectedness across body segments.\(^7\) This theory is supported by studies that have found increased internal and external shoulder ROM by performing movements such as the trunk twist and arm raise\(^10,11\); and a TMR® protocol\(^9\) using a trunk twist and straight leg raise has demonstrated the ability to increase hip internal rotation. In addition to TMR® protocols, researchers\(^12\) have found increased reach during a star excursion balance test (SEBT) on the unstable leg of participants with chronic ankle instability, as well as improvements in participant reported functional activities of daily living on the unstable leg after exclusive training on the stable leg. Prior studies provide evidence that both a mechanical and cognitive change related to the untrained side may occur following unilateral training protocols.

Of the six primary TMR® movements, the SLS requires the most strength and coordination to perform and may be most applicable when gauging readiness for return to sport. Therefore, the purpose of this study was to evaluate whether perceived asymmetries identified by a TMR® scoring protocol were related to biomechanical asymmetries during a SLS and whether improving perceived asymmetries influenced movement mechanics. The hypothesis for the study was that participants with perceived asymmetries would also present with biomechanical asymmetries. A secondary hypothesis was that participants would reduce their perceived asymmetries after performing the TMR® protocol and subsequently have greater biomechanical symmetry.

METHODS

PARTICIPANTS

Twenty-seven participants were recruited from a convenience sample for the current study. Individuals with a history of musculoskeletal conditions (e.g., anterior knee pain, hamstring strain, hip impingement) or prior orthopedic surgery were eligible for inclusion. Exclusion criteria included not having at least a 10-point difference between legs on the single leg squat (SLS) test, inability to perform the SLS within a self-selected pain tolerance on the non-preferred side, bilateral pain during SLS screening, or use of medications affecting proprioception. Although participants may have experienced symptoms potentially related to musculoskeletal issues, researchers did not clinically diagnose or confirm any specific injuries or pathologies. All participants provided informed consent approved by the University’s institutional review board prior to participation.

INSTRUMENTATION

Three-dimensional kinematic data were captured with an eight-camera motion capture system at 200 Hz (VICON, Oxford Metric Ltd., Oxford, UK). Forty-five retro-reflective markers were used to create a custom cluster-based model for the pelvis and lower extremities. Markers were attached to the participants using double sided and elastic tapes. The markers defined segments for the trunk and pelvis, as well as the thigh, shank, and foot bilaterally. All markers used to create joint centers (i.e., pelvis, knee joint, and ankle joint) were placed by a single member of the research team to maintain consistency across participants and between the participant’s legs. Kinetic data were captured at 1000 Hz by a force plate (ORG-6, AMTI Inc., Watertown, MA, USA) temporally synchronized with the motion capture system.
Effects of a Total Motion Release (TMR®) Protocol for the Single Squat on Asymmetrical Movement Pat...

Figure 1. Flow chart of procedures from intake to the end of the data collection.

TMR® PRE-POST PROCEDURES

The following procedures expand upon the flow chart (Figure 1). Prior to motion capture, participants performed the SLS, and identified preferred and non-preferred sides using the TMR® protocol. The participants were first shown the TMR® rating scale which considers pain, tightness, range of motion (ROM), strength, tension, nervousness, quality, etc. (Figure 2). Participants were asked to rate their SLS on the 0-100-point scale using the above criteria. The SLS began in a position with hip of the non-stance limb in a partially flexed position and the knee extended, with their hands on their waists. Hand position was to be maintained for the duration of the squat. Participants were then asked to squat down as far as they could without pausing at the bottom of the squat and without allowing the heel of their non-stance limb to touch the ground. This was performed a maximum of three times on each leg to identify their scores on each leg as well as the location of their symptoms. The leg that scored higher was defined as the non-preferred leg and the leg that scored lower was defined as the preferred leg. A difference score was calculated between the two limbs by subtracting the lowest from the largest self-reported score. Participants who reported a bilateral difference score of 10 or greater were invited to continue through the remainder of the study. Participants with a reported difference of less than 10 were excluded from further study participation. To limit response bias, participants were not informed that either symmetry or asymmetry during the screen was part of the inclusion criteria for continued participation in the study.

Following marker placement, participants performed one SLS on each limb (starting with the non-preferred side) and rated each leg again on the 0-100 scale. This was performed to account for the potential of the attachments of the retro-reflective markers and clusters to affect the participants perception of the movement. This was the baseline score that was used for subsequent analyses. Partic-
Participants then performed SLSs on the force plate in the 3D capture space. Motion capture data were collected on each leg (starting with the non-preferred) to achieve eight ‘good’ trials to be used as their baseline data prior to the intervention. Due to the TMR® protocol using the preferred leg to perform the treatment, the non-preferred side was collected first to remove the potential of a treatment effect by continuing to perform repetitions of the SLS on the preferred leg. A trial was deemed as ‘not good’ and recollected if the participant performed the trial in a non-continuous manner (i.e., pausing at the bottom), or lost balance as determined by the stance foot moving out of its original position, or their hands came off their waist. The number of trials was based on prior statistical models that determined a minimum of seven trials was necessary to reach a statistical power of 0.8 for kinematic data during a Statistical Parametric Mapping (SPM) analysis.13 Trials were performed at a participant selected rate to limit fatigue and squat velocity was not controlled for.

Following the collection of baseline data, participants performed the SLS TMR® intervention. This consisted of performing the SLS in sets of ten repetitions only on the preferred side. Participants were allowed to perform these squats at their own pace as long as they were able to complete them within 90 seconds. Symmetry of TMR® scores between the two legs was reassessed with one SLS on each leg (starting on the non-preferred side) after each set. Following the completion of the ten repetitions and reassessment of the TMR® scores, a rest period of 30 seconds was given between sets. If the self-reported score imbalances were resolved (i.e., the difference between sides was equal to zero) the intervention was completed, and participants moved on to perform the first post treatment assessment. The intervention was also stopped if the maximum number of four sets were performed without a symmetrical score being achieved. Participants were not informed that achieving a symmetrical score between legs was necessary to complete the intervention. After the TMR® intervention, the participants were reassessed bilaterally using the same motion capture procedures. Participants performed eight good trials on each leg, starting with eight on the non-preferred side. These SLSs were performed in the same manner as the baseline testing which allowed them to be performed at a self-selected rate. Following the first set of post-treatment SLSs, participants were asked to sit on a treatment table for 10-minutes to observe the potential of immediate treatment effects to dissipate. After 10-minutes had elapsed, participants reassessed their score by performing one SLS on each leg. Then, eight more single leg squats were collected bilaterally, starting on the non-preferred side, following the same instructions as the baseline and first post-treatment protocol.

DATA ANALYSIS

Angular kinematics and kinetics were computed using a Cardan (X-Y-Z) rotation sequence with Visual 3D software (v6, C-Motion Inc., Germantown, MD, USA). Marker trajectories were filtered using a low-pass, fourth-order Butterworth filter at 6 Hz.14,15 Ground reaction force data were filtered using a low-pass, fourth order Butterworth filter with a cutoff frequency of 10 Hz.16 Kinematic marker positions and ground reaction force data were used to calculate internal joint moments from an inverse dynamics model within the Visual 3D software. Moments were normalized to body mass and calculated so that internal flexion moments for the hip, knee, and ankle were represented by positive values.

The SPM analyses were used to assess joint angles and moments. The kinematic and kinetic time-series were interpolated to 101 data points (100% of cycle) using a custom MATLAB script (MathWorks, Natick, MA, USA). During the first second of each task, participants were asked to hold their position to achieve a quiet stance period. During this period, the standard deviation of hip flexion for the stance limb was calculated. The beginning of the task was identified when hip flexion of the stance limb exceeded a change at least 3 standard deviations from the waveform during the quiet stance period.16 The end of the task was defined as the point when hip flexion angle returned to that starting value. Center of mass (COM) vertical displacement was used to determine squat depth.17 This was calculated by normalizing each participants data to the highest vertical point of their COM within a given trial and resulted in a net vertical displacement in cm.

STATISTICAL ANALYSIS

A 2x3 repeated measures ANOVA was used to assess differences of TMR® scores between the preferred and non-preferred legs at Baseline, post-treatment (Post1), and 10-minutes post-treatment (Post2) in R (The R Foundation for Statistical Computing Platform, 2021). The significance level for statistical analyses of TMR® scores was set a priori to \( \alpha = 0.05 \). Significant main effects were followed up with post hoc t-tests and Bonferroni alpha corrections. Interactions were followed up with separate one-way ANOVAs for time on each leg and followed up with t-tests and Bonferroni corrections when the ANOVA indicated a difference. Additionally, the effect of leg at each time point was assessed with follow up paired t-tests and alpha corrections. Effect sizes were calculated for TMR® scores using partial eta squared values that were interpreted as small \( (\eta^2_p = 0.01) \), medium \( (\eta^2_p = 0.06) \), and large \( (\eta^2_p = 0.14) \), and Cohen’s \( d \) values were calculated for pairwise comparisons and interpreted as small \( (d = 0.2) \), medium \( (d = 0.5) \), and large \( (d = 0.8) \).18

Separate 2x3 repeated measures ANOVAs were also used to compare kinetic and kinematic waveforms for the preferred and non-preferred limbs at each of the three time points using an open-source software package spm1D 0.4.19 Significant results from the repeated measures ANOVAs were followed up with post hoc t-tests as well as with single subject (SS) analyses. The significance level for all SPM tests was set a priori to \( \alpha = 0.05 \). For the SPM analyses, an alpha correction was not deemed appropriate because the procedure requires independence across the tests which is not the case with time-series data.20 Additionally, SPM analyses have been shown to reduce type I error as-

International Journal of Sports Physical Therapy
sociated with kinematic data. For group data, the participant’s mean values of the eight trials, for both the preferred and non-preferred legs, were calculated for each task and used for analysis. For the SS analyses, the eight trials were compared between the two legs for each task. When the participant’s statistical difference between legs crossed the critical threshold, the timing of this cross from 0-100% of the movement was recorded. If a cumulative 10% or more of the task reached statistical difference, the participant was classified as containing an asymmetry and reported as a percentage of the population. As some participants were found to have significant differences only during the first or last five percent of the trial, and these findings may lack clinical implications, the cutoff percentage of 10% was used to limit inflation for number of participants with significant differences between legs.

RESULTS

Of the 27 participants who were screened, 20 qualified for the study (10 female, 10 male; age = 24.1 ± 3.5 years; height = 173.8 ± 10.8 cm; mass = 72.0 ± 14.4 kg) with TMR® score imbalances > 10 (non-preferred side scores = 50.2 ± 15.6, preferred side scores = 29.5 ± 17.2) during the SLS. When examining the frequency of self-reported symptoms and locations, 50% identified stability deficits, 40% of participants reported reduced ROM, 35% described tightness, 15% reported pain as an issue, and 10% noted weakness. In terms of location, the ankle was indicated as problematic by 45% of participants, the hip by 40%, the knee by 35%, and the thigh by 25%. Importantly, these percentages reflect the frequency of each symptom and region reported, but do not total 100% given that individual participants often reported multiple problematic symptoms across various regions (Table 1).

An interaction of leg and time (p < 0.01, ηp² = 0.05) was found for TMR® scores. The one-way ANOVA for the preferred leg found no effect of time on score (p = 0.91, ηp² = 0.00). A significant effect of time was found for the non-preferred leg (p < 0.01, ηp² = 0.19). Post hoc t-tests indicated that bilateral differences were present at baseline and Post1 for TMR® scores but not at Post2 (Table 2). Scores on the non-preferred leg were reduced after treatment and remained below baseline levels at Post2 (Table 2, Figure 3).

Significant main effects from the SPM analyses for kinematic and kinetic variables are reported in Table 3. Post hoc tests for time and leg are displayed in Table 4, and Table 5. The SPM statistical package does not report p-values that do not reach statistical significance. Increased knee flexion moments were found after the treatment at the group level as well as in 40% of individual participants (Figure 4). Bilateral differences were found for knee and ankle flexion, as well as knee flexion moments before and after the treatment at both the group and single subjects level (Figure 5).

DISCUSSION

This study included participants with bilateral TMR® score differences between preferred and non-preferred legs (Δ 20.7). Increased values were observed on the preferred leg for knee flexion, ankle flexion, and knee flexion moments (Figure 5). Overall, 75% of the sample had an asymmetry for at least one of the aforementioned variables. On the preferred leg, 83% percent of participants with a bilateral difference had increased knee flexion and 90% had increased ankle flexion and knee flexion moments. The current findings provide initial evidence that self-identified asymmetries with the TMR® scale for a SLS are related to deficits in knee flexion, ankle flexion, and knee flexion moments during a SLS. This is an important finding as bilateral differences can often be masked at the group level due to intraparticipant variability or defining limb dominance based on the leg used to kick a ball. Thus, the TMR® scale could be used as an effective instrument for identifying preferred and non-preferred legs during movement screen scenarios, or when assessing single leg weightbearing movement prior to developing return to sport protocols.

Following the intervention, the group analysis demonstrated statistically greater internal knee flexion moments on the non-preferred leg. However, this finding was largely driven by only 40% of participants who demonstrated increased knee flexion moments between Baseline and Post1 (Figure 4). Of those eight responders, seven also had reduced perceptions of dysfunction (average Δ Baseline-Post1 = 16.5), suggesting that improved TMR® scores are sensitive to changes in loading the knee during the SLS. Participants maintained this gain after the 10-minute rest period as there was no effect of time between Post1 and Post2 for internal knee flexion moments, and only 10% of participants were found to have a difference after the rest period (Figure 4). Clinicians should be cognizant of the potential for patients to not respond in this manner as less than half of the current sample demonstrated increased moments at the knee. However, as this protocol requires limited contribution from the non-preferred leg, mitigating the risk of exacerbating symptoms, TMR® could still be considered during rehabilitation protocols where patients are reluctant to perform SLSs on one side due to factors such as pain, tightness, limited ROM, etc.

The current findings are the first to indicate that performing one of the primary TMR® motions on the preferred leg can improve TMR® scores on the non-preferred leg (Figure 3). Prior studies have not reported these measures but have demonstrated the potential effectiveness of a TMR® intervention to increase ROM. The current study also found a statistically significant change in hip flexion following the SLS intervention (p = 0.05, 7-17% of SLS). However, this finding may not be clinically significant as there was only a 0.2° average increase in hip flexion. Additionally, of the six participants who had a bilateral difference (30% of the population), three increased hip flexion, and three had decreased hip flexion on the non-preferred leg immediately after the intervention. Although increased knee moments were observed and 55% of the participants
had resolved TMR® scores following the intervention, squat depth did not increase, and bilateral differences were still present (Figure 4). Thus, improvements in TMR® scores may coincide with biomechanical changes at the knee but do not necessarily result in visually observable changes for clinical measures of movement.

The current findings are partially corroborated by a case-series that found a TMR® intervention resulted in clinically important differences in pain scores for patients experiencing AKP. The case-series also found that the functional measures of single leg weightbearing were unchanged after a TMR® intervention. A reduction in self-identified factors of dysfunction with no visually observable changes for SLS mechanics has not been limited to the TMR® paradigm. For example, investigations into different taping techniques intended to improve AKP have found that symptoms were reduced following the tape application but did not impact SLS kinematics. A reduction of pain during the SLS has been attributed to changes in quadriceps muscle activation; however, pain effects beyond biomechanical explanations (i.e., placebos) should also be considered as an explanation. The potential of interventions such as TMR® or taping to improve symptoms during a SLS could be useful during rehabilitation but clinicians may want to supplement these interventions with longer-term training protocols that have been found to improve kinematic variables. For example, Hale et al. found four weeks of balance training performed solely on the uninjured ankle improved motor control in the injured ankle of those with chronic ankle instability.

Although bilateral differences were identified by using the TMR® scale, the importance of the biomechanical bilateral differences during a SLS is disputed. A longitudinal study found that practitioner rated bilateral differences

Table 1. Description of symptoms and their locations for each participant.

<table>
<thead>
<tr>
<th>Participant ID</th>
<th>Symptom</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ROM, Instability</td>
<td>Ankle</td>
</tr>
<tr>
<td>2</td>
<td>Weakness, ROM</td>
<td>Thigh</td>
</tr>
<tr>
<td>3</td>
<td>Pain, Instability</td>
<td>Knee</td>
</tr>
<tr>
<td>4</td>
<td>Tightness, ROM, Instability</td>
<td>Ankle, Hip, Knee</td>
</tr>
<tr>
<td>5</td>
<td>Tightness, Instability</td>
<td>Thigh</td>
</tr>
<tr>
<td>6</td>
<td>Tightness, Instability</td>
<td>Knee</td>
</tr>
<tr>
<td>7</td>
<td>Pain</td>
<td>Knee</td>
</tr>
<tr>
<td>8</td>
<td>ROM</td>
<td>Ankle, Hip, Knee</td>
</tr>
<tr>
<td>9</td>
<td>Pain</td>
<td>Knee</td>
</tr>
<tr>
<td>10</td>
<td>Instability</td>
<td>Ankle</td>
</tr>
<tr>
<td>11</td>
<td>ROM</td>
<td>Hip</td>
</tr>
<tr>
<td>12</td>
<td>Instability</td>
<td>Hip, Knee</td>
</tr>
<tr>
<td>13</td>
<td>Instability</td>
<td>Ankle, Hip</td>
</tr>
<tr>
<td>14</td>
<td>ROM, Instability</td>
<td>Ankle</td>
</tr>
<tr>
<td>15</td>
<td>Tightness</td>
<td>Ankle, Knee</td>
</tr>
<tr>
<td>16</td>
<td>Tightness</td>
<td>Thigh</td>
</tr>
<tr>
<td>17</td>
<td>Weakness, ROM, Instability</td>
<td>Thigh, Hip</td>
</tr>
<tr>
<td>18</td>
<td>Tightness</td>
<td>Thigh</td>
</tr>
<tr>
<td>19</td>
<td>ROM</td>
<td>Ankle, Knee, Hip</td>
</tr>
<tr>
<td>20</td>
<td>Pain, Tightness</td>
<td>Ankle, Knee, Hip</td>
</tr>
</tbody>
</table>

ROM indicates that the participant felt they had limited range of motion.

Table 2. Results of pairwise comparisons for TMR® scores.

<table>
<thead>
<tr>
<th></th>
<th>Comparison</th>
<th>Mean Diff.</th>
<th>p-value</th>
<th>Cohen's d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-hoc tests for Non-Pref. leg between time points</td>
<td>Baseline - Post1</td>
<td>-15.0</td>
<td>&lt;0.01</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Baseline - Post2</td>
<td>-19.4</td>
<td>&lt;0.01</td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td>Post1 - Post2</td>
<td>-4.4</td>
<td>0.06</td>
<td>0.23</td>
</tr>
<tr>
<td>Post-hoc tests between legs at each time point</td>
<td>Baseline</td>
<td>20.7</td>
<td>&lt;0.01</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>Post1</td>
<td>5.9</td>
<td>0.04</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>Post2</td>
<td>3.4</td>
<td>0.26</td>
<td>0.20</td>
</tr>
</tbody>
</table>
Figure 3. Boxplots comparing TMR® scores between Preferred and NonPreferred legs at Baseline, immediately after the intervention (Post1), and 10 minutes after Post1 (Post2).

in the frontal plane at 90° of knee flexion did not predict future non-contact anterior cruciate ligament injury. However, by not including potential differences for sagittal plane asymmetries of the lower extremity, longitudinal studies may limit potential findings as it relates to injury risk. Longitudinal studies for bilateral differences have also neglected to include a SS approach for the identification of asymmetries or focused on the leg used to kick a ball. As leg dominance has been found to be task specific and bilateral kinematic differences can be masked at the group level, the inclusion of a SS approach is necessary to fully understand the importance of injury risk as it relates to movement symmetry. Additionally, investigators should consider the potential of the bilateral movement imbalances found in the current study to coincide with more functional movements such as walking and running, subsequently identifying whether these potential imbalances elicit chronic lower extremity injuries due to a decreased ability to load the non-preferred leg. As the TMR® screen for the SLS can be performed in a few minutes, its use as an instrument to track injury risk from bilateral asymmetries may be warranted.

The current study has limitations. First, the current study assessed participants with a heterogeneous symptom profile (i.e., stability, tightness, pain, etc.) at various points of the lower extremity (i.e., ankle, knee, thigh, and hip) that could have produced distinct compensatory movement strategies during the SLS. However, the inclusion of a single subject analysis provides more detailed insight into individual responses that helps compensate for the lack of a homogeneous sample. Next, only one movement from the six primary TMR® motions for movement assessment was included. As TMR® is often thought to identify regional imbalances throughout the body that may be connected, only assessing one of these movements may have missed the root cause of the dysfunction and limited the effectiveness of the treatment. However, as the core foundation of the treatment is to use movement on one side of the body to improve movement on the other, it is essential to establish the efficacy of this fundamental concept for the paradigm. The current study’s protocol also differed from the TMR® protocol in the number of sets and repetitions (2x15-20) that are typically performed prior to reassessing the TMR® score. Per the TMR® protocol, if an observed improvement (score decreased by 10) is not found after the first reassessment, a change is made to the treatment that could increase the intensity (e.g., performing the repetitions faster). Thus, a lack of treatment dosage and omitting changes to the treatment protocol may have influenced the outcomes of this study, and is a factor that could be considered in future studies examining the effects of TMR®. Self-reported scores are also a potential source of bias that could have influenced the results for perceived asymmetry. Specifically, a response bias could have led participants to unconsciously minimize or downplay dysfunction in order to appear more symmetrical, which they may have believed was more desirable or expected by the researchers. The methods were designed to limit this bias by not informing participants about the proposed mechanism of the treatment until after the completion of the study. Lastly, the observed decrease in TMR® scores is less than what has been reported as a minimal detectable change (MDC) of 26.1 pints using the TMR® scale for the SLS. This may not directly translate to the current results though, as the reliability study that established the MDC did not assess scores before and after a TMR® treatment.

Table 3. Results of main effects from repeated measures ANOVAs.

<table>
<thead>
<tr>
<th>Variable</th>
<th>p-value</th>
<th>% of Task</th>
<th>p-value</th>
<th>% of Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip Flexion</td>
<td>0.02, &lt;0.01</td>
<td>3-23, 55-83</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Knee Flexion</td>
<td>&lt;0.01</td>
<td>48-67</td>
<td>&lt;0.01</td>
<td>7-45</td>
</tr>
<tr>
<td>Ankle Flexion</td>
<td>-</td>
<td>-</td>
<td>&lt;0.01</td>
<td>11-36</td>
</tr>
<tr>
<td>Hip Moment</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Knee Moment</td>
<td>0.03</td>
<td>46-53</td>
<td>&lt;0.01</td>
<td>7-50</td>
</tr>
<tr>
<td>Ankle Moment</td>
<td>0.02, 0.03</td>
<td>41-55, 88-100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>COM Displacement</td>
<td>&lt;0.01</td>
<td>53-66</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

% of Task indicates timing of the significant difference, a dash indicates a lack of significant difference.
Table 4. Results of post hoc tests for significant main effect of time.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Comparisons</th>
<th>Non-Preferred Leg</th>
<th>Preferred Leg</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>p-value</td>
<td>% of Task</td>
<td>% of SSs</td>
<td>p-value</td>
<td>% of Task</td>
</tr>
<tr>
<td>Hip Flexion</td>
<td>Baseline vs. Post 1</td>
<td>0.04</td>
<td>8-15</td>
<td>30</td>
<td>0.03</td>
<td>7-17</td>
</tr>
<tr>
<td></td>
<td>Post 1 vs. Post 2</td>
<td>&lt;0.01</td>
<td>32-66</td>
<td>30</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Baseline vs. Post 2</td>
<td>&lt;0.01</td>
<td>7-23</td>
<td>60</td>
<td>0.03</td>
<td>62-70</td>
</tr>
<tr>
<td>Knee Flexion</td>
<td>Baseline vs. Post 1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Post 1 vs. Post 2</td>
<td>&lt;0.01</td>
<td>48-63</td>
<td>30</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Baseline vs. Post 2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Knee Moment</td>
<td>Baseline vs. Post 1</td>
<td>&lt;0.01</td>
<td>45-59</td>
<td>45</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Post 1 vs. Post 2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Baseline vs. Post 2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ankle Moment</td>
<td>Baseline vs. Post 1</td>
<td>0.02</td>
<td>85-99</td>
<td>15</td>
<td>0.02</td>
<td>44-51</td>
</tr>
<tr>
<td></td>
<td>Post 1 vs. Post 2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Baseline vs. Post 2</td>
<td>0.04</td>
<td>89-92</td>
<td>30</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>COM Displacement</td>
<td>Baseline vs. Post 1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Post 1 vs. Post 2</td>
<td>p&lt;0.01</td>
<td>27-65</td>
<td>55</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Baseline vs. Post 2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

COM = center of mass, % of Task indicates timing of the significant difference, % of SSs indicates the percentage of Single Subjects with a significant difference, a dash indicates a lack of a significant difference.

Table 5. Results of post hoc tests comparing legs at each time point.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Time</th>
<th>p-value</th>
<th>% of Task</th>
<th>% of SSs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee Flexion</td>
<td>Baseline</td>
<td>&lt;0.01</td>
<td>4-43</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Post 1</td>
<td>&lt;0.01</td>
<td>11-42</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>Post 2</td>
<td>&lt;0.01</td>
<td>13-44</td>
<td>70</td>
</tr>
<tr>
<td>Ankle Flexion</td>
<td>Baseline</td>
<td>&lt;0.01</td>
<td>5-27</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Post 1</td>
<td>0.04</td>
<td>18-21</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>Post 2</td>
<td>&lt;0.01</td>
<td>18-40</td>
<td>60</td>
</tr>
<tr>
<td>Knee Moment</td>
<td>Baseline</td>
<td>&lt;0.01</td>
<td>8-27</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Post 1</td>
<td>&lt;0.01, &lt;0.01</td>
<td>12-39, 90-97</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>Post 2</td>
<td>&lt;0.01, 0.03</td>
<td>12-34, 35-39</td>
<td>60</td>
</tr>
</tbody>
</table>

% of Task indicates timing of the significant difference, % of SSs indicates the percentage of Single Subjects with a significant difference.

CONCLUSION

The results of this study indicate that participants with bilateral differences of 10 points or greater per the TMR® assessment for the SLS were also found to have biomechanical asymmetries at the knee and ankle. Performing sets of the SLS on the preferred leg was found to reduce perceptions of symptoms related to pain, tightness, and stability on the contralateral leg and enable small but statistically increased knee flexion moments. However, reducing the perception of symptoms did not resolve movement symmetry. Clinicians should be cautious about relying solely on improvements in patient perception when applying TMR® and consider supplementing this method with targeted interventions to address observable movement deficits.

International Journal of Sports Physical Therapy
Figure 4. SPM paired t-tests comparing Baseline and Post1 analysis (left) and Post1 and Post2 analysis (right). Shaded gray areas indicate where the group waveforms were statistically different. Vertical blue bars indicate the percentage of participants with a significant difference at each percentage of the task. Horizontal blue line indicates the total percentage of participants with a significant difference.

Figure 5. SPM t-tests comparing preferred and non-preferred legs at Baseline and Post1. Shaded gray regions indicate where the group waveforms were statistically different. Vertical blue bars indicate the percentage of participants with a significant difference at each percentage of the task. Horizontal blue line indicates the total percentage of participants with a significant difference.

Submitted: April 12, 2023 CST, Accepted: October 30, 2023 CST
© The Author(s)
REFERENCES


Reliability of the EasyAngle® for Assessing Hip Range of Motion in Healthy Children

Elana Duffy, PT, DPT¹, Maria Wells, PT, DPT¹, Alan Miller, PT, DPT¹, Megan Tondra, PT, DPT¹, Antonette Doty, PT, PhD, Board Certified Clinical Specialist in Pediatric Physical Therapy¹²

¹ Physical Therapy, Walsh University

Keywords: digital goniometer, normative values, range of motion, reliability

https://doi.org/10.26603/001c.90865

International Journal of Sports Physical Therapy

Background

The use of digital goniometry has emerged as a viable alternative to universal goniometry for assessing hip range of motion (ROM). However, few studies have assessed the use of digital goniometry in pediatric populations and there are a limited number of studies that investigate any one device. The EasyAngle® is a digital goniometer that may be beneficial for use in pediatric settings as it requires only one hand to operate the device.

Purpose

The purposes of this study were 1) to establish the intrarater and interrater reliability of the EasyAngle® digital goniometer in measuring hip joint ROM in healthy elementary school-aged children, and 2) to establish preliminary normative reference values for each year of age using the EasyAngle® for hip joint ROM in healthy elementary school-aged children.

Study Design

Descriptive Laboratory Study

Methods

Passive hip ROM (flexion, abduction, extension, internal rotation, external rotation) was measured on each leg of healthy participants using the EasyAngle®. A total of 40 hip joints were measured. Two blinded raters conducted three trials of each hip motion on both legs. Intrarater and interrater reliability of the recorded hip range of motion were calculated using intra-class correlation coefficients (ICC) (3,1).

Results

Twenty healthy children were measured (age 5-10, mean = 7.40 years old, SD = 1.37, 9 males, 11 females). Mean hip ROM was reported by age. Intrarater and interrater reliability were good to excellent for all hip ROM measurements (0.81-0.97 intra rater; 0.77- 0.91 interrater). Hip flexion had the strongest intrarater (0.96, 0.97) and interrater reliability (0.91). Intrarater reliability was lowest for hip abduction for Rater 1 and hip extension for Rater 2. Interrater reliability was lowest for hip external rotation (0.78).

Conclusion

The EasyAngle® is a reliable tool for assessing hip range of motion in healthy children ages 5-10. Normative hip ROM values using the EasyAngle® are available to clinicians.

Level of Evidence

Level 3- Reliability study

a Corresponding Author:
Antonette Doty, PT, PhD, Board Certified Clinical Specialist in Pediatric Physical Therapy
2020 E Maple St, North Canton, OH 44720
Email: adoty@walsh.edu, Phone: 330-490-7370
INTRODUCTION

Participation in team sports is an increasingly popular activity for children in the United States. Data from 2020 shows that over half of US children between the ages 6-17 participate in at least one sport throughout the year. While participation in youth sports provides numerous benefits, such as improvements in grades and physical activity levels, it is also associated with an increased risk of injury. More than 3.5 million children ages 5-14 have visited the emergency room for a sports-related injury, and the majority of these injuries involve the lower extremity. The preparticipation examination was developed as a preventative tool against sports-related injury, and it is recommended that a musculoskeletal examination is conducted as part of this assessment. Range of motion (ROM) is an important component of a musculoskeletal examination, for children with and without impairments. Decreased ROM may be indicative of muscular shortening, joint stiffness, spasticity, bony torsion, and many other neuromusculoskeletal impairments and injuries. Improvements in ROM are often one of the many desired outcomes of physical therapy interventions, as improved ROM leads to improvements in activity and participation (including participation in youth sports). Therefore, it is important for clinicians to have accurate and reliable methods to measure and track changes in ROM.

The universal goniometer (UG) is the preferred method for quantifying joint mobility in clinical practice. The device’s relatively low cost and versatility make it a staple in most clinics today, and it has been shown to be both reliable and valid. Despite its versatility, its use in particular pediatric populations is questionable. One study suggests that the UG has poor reliability for the measurement of hip ROM in pediatric femoral fractures owing partially to the child’s small physical size and lack of cooperation. Utilization of the UG is further complicated by its protocol for use. Two hands are needed to operate the goniometer, and the participant is required to maintain a static position or may require external stabilization (which may be difficult for pediatric participants). Furthermore, there is limited information on a standardized protocol for positioning the participant to measure ROM in pediatric populations as there is for adults.

Alternative approaches to measuring joint ROM have begun to emerge, which include (but are not limited to) smartphone applications, digital photography, digital inclinometers, and digital goniometers. There is a growing body of literature surrounding the clinical applicability of these new methods, and overall they are reliable and valid for use on various body segments in adult populations. Longoni et al. appraised 15 different smartphone applications and reported mostly good intrarater and interrater reliability, with an ICC value of 0.80 for extremities (reliability was lower for measurements of the spine). Concluded that the digital inclinometer has high intrarater reliability with an ICC value of 0.90 and is valid for measuring passive ROM of the hip. However, they also determined that the digital inclinometer does not have concurrent validity against a universal goniometer and as such, these two devices should not be used interchangeably. While studies with adult populations have reported high degrees of intrarater and interrater reliability (ICC > 0.85), they also report limitations in sample size or clinical generalizability. Additionally, despite ongoing research regarding alternative methods of goniometry, very few studies investigate clinical applicability in the pediatric population.

The EasyAngle®, developed by Meloq (Stockholm, Sweden), is a digital goniometer that can be used in place of UGs, inclinometers, scoliometers, cervical range of motion (CROM) devices, and back range of motion devices. The manufacturer reports the device measures ROM in all three planes of movement of any given joint and is convenient for measuring ROM in the pediatric population due to its portability, clear alignment guide, and single-handed use. Current studies using the EasyAngle® in adults, while limited, have demonstrated good intrarater and interrater reliability for measuring knee, scapular, and cervical ROM. Intrarater reliability was found to be as high as an ICC value of 0.998 depending on the joint measured, while ICC values for interrater reliability were reported to be as high as 0.994. Measurements of knee ROM were consistently the highest, and scapular ROM consistently yielded the least reliable results. Svensson et al. identified no difference between novice and experienced clinicians when using the EasyAngle®. Furthermore, the EasyAngle® has been found to be comparable to or more reliable than traditional methods of measuring ROM such as inclinometry, digital photography, and CROM device use across multiple populations (either individuals with a pathology of interest or healthy individuals). Currently, no published studies assess the use of the EasyAngle® in pediatric populations. Furthermore, there are a limited number of studies that assess the reliability of the EasyAngle® in measuring hip ROM, and none of the studies that specifically investigate the hip joint are available in English. The hip joint is of particular interest in the pediatric population as it is involved in 10-24% of youth sports-related injuries. In addition to a reliable tool to measure and track ROM, a clinician must also have access to ROM values gathered from a healthy population so that atypical values can be distinguished from reference, or “normed,” values. In pediatric populations, it is important to establish age- and sex-matched norms to accurately identify deviations from typical development so that therapeutic interventions can be implemented to increase function and participation.

The purposes of this study were 1) to establish the intrarater and interrater reliability of the EasyAngle® digital goniometer in measuring hip joint ROM in healthy elementary school-aged children, and 2) to establish preliminary normative reference values for each year of age using the EasyAngle® for hip joint ROM in healthy elementary school-aged children. To the authors’ knowledge, no known studies exist that explore the reliability of hip measurements using the EasyAngle® in the pediatric population. The research question was: Is the EasyAngle® a reliable tool to measure hip range of motion in elementary school-aged children?
METHODS

After Institutional Review Board approval, participants whose parents understood, signed, and returned both the consent and assent forms to investigators were included. Local guidelines regarding COVID-19 were followed and efforts were made to maintain social distancing when possible.

This study included 20 healthy participants - 9 male and 11 female students from a local elementary school. The right and left legs of each participant were counted separately to reach a sample size of N = 40 hip joints. Inclusion criteria included both males and females who were of elementary school age (kindergarten through 4th grade) from a convenience sample. Participants were excluded if they had a diagnosed musculoskeletal condition such as a bone fracture in the leg, Osgood-Schlatter, Legg-Calvé-Perthes disease, slipped capital femoral epiphysis, or muscle strain. Participants were also excluded if they had been diagnosed with a neuromuscular condition such as cerebral palsy, muscular dystrophy, or spina bifida. The school administration was aware of the exclusion criteria and assisted in the screening process. Demographic data, including age, sex, and ethnicity were collected from each participant prior to measurement.

The EasyAngle® device was used for all data collection. A team of four student physical therapists divided into two measurement teams to conduct the data collection. On each team, one researcher served as the data recorder while the other served as the rater. Teams and roles were determined prior to testing and remained consistent throughout the study. Both raters had experience with goniometric measurements. Prior to data collection at the school, all researchers underwent EasyAngle® device training with a Meloq representative. The researchers conducted two practice sessions, each lasting two hours, to familiarize themselves with the device. Members of the research team acted as "participants" during these practice sessions. Prior to initiating the study at the school, a practice session with one elementary school-aged participant was conducted to determine proper positioning and stabilization of the participant as well as placement and use of the EasyAngle®. No data was recorded from this session and therefore the measurements obtained from this participant were not included in the final data analysis. Raters were blinded to the measurements from the EasyAngle® by placing opaque tape over the device's screen. Blinding was done to prevent bias that may have occurred had the rater known each measurement after obtaining the data. Each data recorder ensured all measurements were properly collected and recorded on the EasyAngle® device.

Data were collected at the local elementary school over a period of four nonconsecutive days in June of 2022. Participants were brought into the examination room two at a time and assigned to a measurement team. Participants were informed of all measurement procedures and verbal as well as written assent was obtained. Participants were dressed in their school uniforms, which consisted of a t-shirt and either shorts or skirts and leggings. A licensed physical therapist was present to oversee the student research teams, and parents were notified via the cover letter that they were permitted to be present in the room during their child's testing session (however, no parents elected to attend data collection sessions).

TESTING PROTOCOL

The rater conducted four trials of passive range of motion of each of the five hip motions – flexion, abduction, extension, internal rotation, and external rotation, respectively. The participant was positioned in supine for flexion and abduction, and prone for extension, internal rotation, and external rotation. Measurement for each motion was obtained first on the right lower extremity and then the left. The first trial served as a demonstration and was not recorded. For each trial in which data was recorded, the EasyAngle® was first aligned with standardized anatomic landmarks (as described in Appendix 1), and the turquoise button was pressed to indicate the start of the measurement. The limb was then passively moved into the standardized measurement position as described in Appendix 1, and the device was moved along with the limb. The turquoise button was pressed for a second time to indicate the end of the measurement. The turquoise button was pressed for a third time to save the measurement and then pressed a fourth and final time to begin the next trial. Figure 1 depicts how the device can be used to measure hip flexion.

After the rater completed the three recorded trials of any particular hip motion, the data recorder documented the three measurements obtained, then cleared the device's history and returned the recalibrated device to the rater. Once measurements had been obtained for all five hip motions on both the right and left legs, each participant repeated the procedure with the other measurement team. Total testing time was approximately 30 minutes per participant (15 minutes per rater). Refer to Appendix 1 for a complete testing protocol that was developed for this research study.

STATISTICAL METHODS

A preliminary power analysis was conducted based on calculations developed by Bujang and Baharum using the Power Analysis and Sample Size (PASS) software. An $\alpha = 0.05$ and $\beta = 0.2$ (power = 80%) were used to determine that a minimum sample size of 36 was required for an expected ICC of 0.95. Both the intrarater and interrater reliability of the recorded hip range of motion were calculated using intra-class correlation coefficient (ICC) (3,1) using an average of three trials per hip motion and a confidence interval of 95%. The ICC values were interpreted as poor ($<0.5$), moderate (0.5-0.75), good (0.76-0.90), or excellent (>0.90) reliability. An independent samples t-test was performed to determine if gender-based differences in hip ROM existed. The significance level was set to $p < 0.05$. Statistical assumptions were met to proceed with parametric testing. All data were analyzed using SPSS version 27 (IBM SPSS Inc, Armonk, NY, USA).
RESULTS

DESCRIPTIVE STATISTICS FOR HIP RANGE OF MOTION

Data were collected on 40 hip joints from 20 participants between the ages of 5-10 (mean = 7.40 years old, SD = 1.37) including nine male participants (18 hip joints) and 11 female participants (22 hip joints). There were 15 Black or African American participants, three White participants, and two Hispanic or Latino participants. Table 1 provides the mean range of motion measurements for five hip motions by age. Most of the hip joints assessed in this study were from participants who were 8 years old (N = 14 hip joints).

COMPARISON OF HIP MEASUREMENTS BY RATER

A total of five hip range of motion measurements were recorded three times each by both raters. Table 2 illustrates the mean range of motion measurements for each rater. Overall, Rater 1 appeared to measure greater range of motion compared to Rater 2. Higher standard error values were noted for both raters with external rotation and lower standard error values were seen for both raters with hip extension.

INTRARATER RELIABILITY OF HIP MEASUREMENTS USING THE EASYANGLE®

Intrarater reliability for all five hip range of motion measurements is presented in Table 3. The results showed good
Table 2. Comparison of Hip Measurements by Rater. All results are reported in degrees.

<table>
<thead>
<tr>
<th></th>
<th>Rater 1</th>
<th></th>
<th></th>
<th>Rater 2</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>SE</td>
<td>Mean</td>
<td>SD</td>
<td>SE</td>
</tr>
<tr>
<td>Flexion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 1</td>
<td>113.35</td>
<td>10.22</td>
<td>1.62</td>
<td>101.23</td>
<td>20.56</td>
<td>3.25</td>
</tr>
<tr>
<td>Trial 2</td>
<td>113.05</td>
<td>10.59</td>
<td>1.67</td>
<td>99.83</td>
<td>21.15</td>
<td>3.34</td>
</tr>
<tr>
<td>Trial 3</td>
<td>114.45</td>
<td>10.97</td>
<td>1.73</td>
<td>99.83</td>
<td>19.63</td>
<td>3.10</td>
</tr>
<tr>
<td>Mean</td>
<td>113.62</td>
<td></td>
<td></td>
<td>100.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 1</td>
<td>23.82</td>
<td>4.41</td>
<td>.70</td>
<td>18.78</td>
<td>5.51</td>
<td>.87</td>
</tr>
<tr>
<td>Trial 2</td>
<td>23.85</td>
<td>4.49</td>
<td>.71</td>
<td>17.80</td>
<td>5.87</td>
<td>.93</td>
</tr>
<tr>
<td>Trial 3</td>
<td>23.20</td>
<td>4.32</td>
<td>.68</td>
<td>16.55</td>
<td>4.98</td>
<td>.79</td>
</tr>
<tr>
<td>Mean</td>
<td>23.63</td>
<td></td>
<td></td>
<td>17.71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 1</td>
<td>55.25</td>
<td>8.04</td>
<td>1.27</td>
<td>37.32</td>
<td>7.40</td>
<td>1.17</td>
</tr>
<tr>
<td>Trial 2</td>
<td>56.32</td>
<td>6.62</td>
<td>1.05</td>
<td>36.77</td>
<td>7.81</td>
<td>1.24</td>
</tr>
<tr>
<td>Trial 3</td>
<td>54.20</td>
<td>7.10</td>
<td>1.12</td>
<td>38.27</td>
<td>7.74</td>
<td>1.22</td>
</tr>
<tr>
<td>Mean</td>
<td>55.25</td>
<td></td>
<td></td>
<td>37.46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Rotation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 1</td>
<td>43.00</td>
<td>7.40</td>
<td>1.17</td>
<td>34.38</td>
<td>9.28</td>
<td>1.47</td>
</tr>
<tr>
<td>Trial 2</td>
<td>44.07</td>
<td>6.26</td>
<td>.99</td>
<td>34.55</td>
<td>8.88</td>
<td>1.40</td>
</tr>
<tr>
<td>Trial 3</td>
<td>45.75</td>
<td>6.61</td>
<td>1.05</td>
<td>35.30</td>
<td>10.40</td>
<td>1.64</td>
</tr>
<tr>
<td>Mean</td>
<td>44.27</td>
<td></td>
<td></td>
<td>34.74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>External Rotation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 1</td>
<td>46.90</td>
<td>1.25</td>
<td>7.88</td>
<td>27.65</td>
<td>1.11</td>
<td>7.05</td>
</tr>
<tr>
<td>Trial 2</td>
<td>46.13</td>
<td>1.33</td>
<td>8.43</td>
<td>26.78</td>
<td>1.08</td>
<td>6.80</td>
</tr>
<tr>
<td>Trial 3</td>
<td>46.78</td>
<td>1.51</td>
<td>9.53</td>
<td>28.40</td>
<td>1.16</td>
<td>7.33</td>
</tr>
<tr>
<td>Mean</td>
<td>46.60</td>
<td></td>
<td></td>
<td>27.61</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SD = Standard Deviation  
SE = Standard Error

to excellent intrarater reliability for both raters [ICC (3,1) = 0.888 - 0.961, Rater 1] [ICC (3,1) = 0.807 - 0.971, Rater 2] for all hip range of motion measurements. Hip flexion had the highest ICC value for intrarater reliability [ICC (3,1) = 0.961, Rater 1 and 0.971, Rater 2]. Hip abduction had the lowest intrarater reliability for Rater 1 [ICC (3,1) = 0.888], and hip extension had the lowest intrarater reliability for Rater 2 [ICC (3,1) = 0.807].

INTERRATER RELIABILITY OF HIP MEASUREMENTS USING THE EASY ANGLE

Interrater reliability for all five hip range of motion measurements is provided in Table 3. Both Rater 1 and Rater 2 had ICC values for interrater reliability that were considered good to excellent for all five hip range of motion values. Hip flexion had the highest ICC value [ICC (3,1) = 0.911] and hip external rotation demonstrated the lowest ICC value [ICC (3,1) = 0.778].

INDEPENDENT SAMPLES T-TEST

An Independent Samples T-Test compared mean hip range of motion measurements between measures obtained from male and female participants as shown in Table 4. Hip flexion (p = 0.002) and abduction (p < 0.001) were statistically significantly different. The other three measures were not significantly different, but overall females demonstrated greater range of motion measurements compared to males.

DISCUSSION

The results of this study suggest that the EasyAngle® is a reliable tool for assessing hip joint ROM in healthy children ages 5-10. Intrarater and interrater reliability were good to excellent for all motions assessed. Intrarater reliability is clinically relevant in order to determine whether or not a device consistently measures data across multiple trials for a participant while one clinician is performing the measurements. Interrater reliability is clinically relevant in order to determine whether or not a device consistently measures data between multiple raters. These findings suggest
Table 3. Interclass Correlation Coefficients for Both Raters and Between Raters

<table>
<thead>
<tr>
<th></th>
<th>ICC</th>
<th>95% Confidence</th>
<th>F</th>
<th>Df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower</td>
<td>Upper</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intrarater Reliability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rater 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>.961</td>
<td>.934</td>
<td>.978</td>
<td>25.708</td>
<td>39</td>
</tr>
<tr>
<td>Extension</td>
<td>.907</td>
<td>.843</td>
<td>.948</td>
<td>10.730</td>
<td>39</td>
</tr>
<tr>
<td>Abduction</td>
<td>.888</td>
<td>.811</td>
<td>.937</td>
<td>8.943</td>
<td>39</td>
</tr>
<tr>
<td>Internal Rotation</td>
<td>.904</td>
<td>.839</td>
<td>.946</td>
<td>10.467</td>
<td>39</td>
</tr>
<tr>
<td>External Rotation</td>
<td>.910</td>
<td>.847</td>
<td>.949</td>
<td>11.054</td>
<td>39</td>
</tr>
<tr>
<td>Rater 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>.971</td>
<td>.950</td>
<td>.984</td>
<td>34.113</td>
<td>39</td>
</tr>
<tr>
<td>Extension</td>
<td>.807</td>
<td>.674</td>
<td>.891</td>
<td>5.178</td>
<td>39</td>
</tr>
<tr>
<td>Abduction</td>
<td>.895</td>
<td>.822</td>
<td>.941</td>
<td>9.503</td>
<td>39</td>
</tr>
<tr>
<td>Internal Rotation</td>
<td>.855</td>
<td>.755</td>
<td>.918</td>
<td>6.897</td>
<td>39</td>
</tr>
<tr>
<td>External Rotation</td>
<td>.872</td>
<td>.783</td>
<td>.928</td>
<td>7.791</td>
<td>39</td>
</tr>
<tr>
<td>Interrater Reliability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>.911</td>
<td>.861</td>
<td>.948</td>
<td>11.266</td>
<td>39</td>
</tr>
<tr>
<td>Extension</td>
<td>.792</td>
<td>.674</td>
<td>.878</td>
<td>4.815</td>
<td>39</td>
</tr>
<tr>
<td>Abduction</td>
<td>.792</td>
<td>.673</td>
<td>.878</td>
<td>4.803</td>
<td>39</td>
</tr>
<tr>
<td>Internal Rotation</td>
<td>.819</td>
<td>.716</td>
<td>.894</td>
<td>5.523</td>
<td>39</td>
</tr>
<tr>
<td>External Rotation</td>
<td>.778</td>
<td>.651</td>
<td>.870</td>
<td>4.501</td>
<td>39</td>
</tr>
</tbody>
</table>

ICC = Intra-class coefficient, F = Frequency, Df = Degrees of Freedom, p-value = Probability value

Table 4. Independent Samples T-test for Gender and Hip ROM Measurements. Average ROM reported in degrees.

<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th>Female</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>18</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>100.06</td>
<td>112.59</td>
<td>.002</td>
</tr>
<tr>
<td>Extension</td>
<td>19.76</td>
<td>21.40</td>
<td>.142</td>
</tr>
<tr>
<td>Abduction</td>
<td>42.56</td>
<td>49.45</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Internal Rotation</td>
<td>38.58</td>
<td>40.26</td>
<td>.387</td>
</tr>
<tr>
<td>External Rotation</td>
<td>35.58</td>
<td>38.35</td>
<td>.110</td>
</tr>
</tbody>
</table>

N = number of hip joints measured, p-value = Probability value.

that this tool is reliable for use between therapy sessions and between clinicians, so long as standardized protocols related to positioning are established.

Based on a review of existing literature, the researchers hypothesized before initiating data collection that the EasyAngle® should be a reliable tool to measure hip ROM in the pediatric population.12,13 While this is the first known study to evaluate the EasyAngle®’s use for assessing hip ROM in a pediatric population, previous authors who studied various adult populations suggest that the EasyAngle® is a reliable device for joints such as the knee, shoulder, and cervical spine. In this current study, both intrarater and interrater reliability were good to excellent for each motion assessed. Hip flexion had the highest intrarater reliability [ICC (3,1) = 0.961, Rater 1 and 0.971, Rater 2] and interrater reliability [ICC (3,1) = 0.911]. This may be due to the relative ease of passively performing this movement compared to others. A challenge to each motion (aside from flexion) was ensuring that measurements were taken in a straight plane without compensatory movements such as pelvic rotation. This may account for the lower intrarater reliabilities seen with abduction for Rater 1 [ICC (3,1) = 0.888] and extension for Rater 2 [ICC (3,1) = 0.807], as each rater may have determined the threshold of compensatory motion differently. Another explanation for the high ICC values seen for hip flexion is that it was the first measurement taken on each participant, so the participant may have been more engaged and better able to relax during this measurement.

In general, intrarater reliability was greater than interrater reliability, which is consistent with previous studies.5,8 A challenge that may have contributed to lower ICC values for interrater reliability could be fatigue on the part of both the participant and the rater. External rotation had the lowest intrarater reliability [ICC (3,1) = 0.778]. However, this was the last measurement taken for each participant, so at

International Journal of Sports Physical Therapy
Table 5. Comparison of Range of Motion Normative Values in Pediatric Populations (Age Measured in Years).

<table>
<thead>
<tr>
<th></th>
<th>Soucie et al., 2011</th>
<th>Mudge et al., 2014</th>
<th>Sankar et al., 2012</th>
<th>Lowes &amp; Hay, 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td><strong>Flexion</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-8 yrs:</td>
<td>2-8 yrs:</td>
<td>131.1°</td>
<td>2-8 yrs:</td>
<td>140.8°</td>
</tr>
<tr>
<td>9-19 yrs:</td>
<td>9-19 yrs:</td>
<td>135.2°</td>
<td>9-19 yrs:</td>
<td>134.9°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Extension</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-8 yrs:</td>
<td>2-8 yrs:</td>
<td>28.3°</td>
<td>2-8 yrs:</td>
<td>26.6°</td>
</tr>
<tr>
<td>9-19 yrs:</td>
<td>9-19 yrs:</td>
<td>18.2°</td>
<td>9-19 yrs:</td>
<td>20.5°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Abduction</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-8 yrs:</td>
<td>4-7 yrs:</td>
<td>4.7°</td>
<td>2-8 yrs:</td>
<td>42.1°</td>
</tr>
<tr>
<td>9-19 yrs:</td>
<td>8-11 yrs:</td>
<td>36.4°</td>
<td>8-11 yrs:</td>
<td>34°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Internal Rotation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-8 yrs:</td>
<td>4-7 yrs:</td>
<td>61.3°</td>
<td>2-8 yrs:</td>
<td>45°</td>
</tr>
<tr>
<td>9-19 yrs:</td>
<td>8-11 yrs:</td>
<td>61.2°</td>
<td>8-11 yrs:</td>
<td>40°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>External Rotation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-8 yrs:</td>
<td>4-7 yrs:</td>
<td>49.5°</td>
<td>2-8 yrs:</td>
<td>51°</td>
</tr>
<tr>
<td>9-19 yrs:</td>
<td>8-11 yrs:</td>
<td>44.1°</td>
<td>8-11 yrs:</td>
<td>44°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Yrs = years old

At least 12 measurements had been taken previously. At this point, participants may have been fatigued from the number of measurements obtained and may not have been as relaxed to allow for full passive range to be assessed. Conversely, there may have been fatigue on the part of the raters. Having taken a large number of measurements, each rater may have unintentionally performed less precise measurements for external rotation or may have determined that compensatory movement was occurring at an earlier point than for previous measurements. The lower interrater reliability for hip external rotation may be due to differences in determining compensatory movements or may be due to fatigue from an extensive measurement protocol.

Previous studies have compiled normative data regarding hip joint range of motion in pediatric populations based on age and sex; however, these norms were derived from early studies that utilized universal goniometry.\(^4\) Table 5 illustrates mean ROM values for children obtained via universal goniometry from multiple studies using a variety of methods.\(^3,4,14,17\)

The data from the current study suggest that gender was a significant factor for hip flexion and abduction. In a study by Sankar et al. researchers found that older males (ages 11-17) had less ROM than older females in all directions aside from internal rotation (combined with hip flexion); however, they found no significant difference for gender with any motion in their youngest age group (ages 2-5), and no findings regarding gender differences were discussed for ages 6-10.\(^17\) The current study produced similar findings where ROM was greater in females compared to males; however, these findings were seen in a younger age range (5-10 years old) than identified by Sankar et al.

Statistical analysis regarding the relationship between age and ROM was omitted from this study due to a relatively small number of hip joints present in each individual age group from ages 5-10. However, the descriptive data that was obtained suggests little to no change with age across all five joint motions. This is in contrast to previous studies, which suggest that range of motion tends to decline with increasing age.\(^4,14,17\) An important note is that the age range in this study (5-10 years old) is narrower than in previous studies, which may explain this difference in findings. A gross comparison to the norms established in previous studies (Table 5) reveals that this study produced relatively similar averages across the age group studied here. While flexion and external rotation...
were slightly higher in previous studies, this present study found measures of extension, abduction, and internal rotation to be fairly consistent with previously established normative data.

LIMITATIONS

One limitation of this study is that a relatively homogenous sample was obtained. 75% of the hip joints measured were from Black or African American participants, while 15% of hip joints were from White participants and 10% were from Hispanic or Latino participants. Because of the limited diversity of participants, the findings of this study may not be applicable to children of various ethnic backgrounds. Another limitation may have been related to differences between raters in determining the endpoint of ROM. Efforts were made to minimize any discrepancy between raters through multiple practice sessions with members of the research team to gain familiarity with the device, as well as a practice session with a child not included in the study. An established protocol was followed, and feedback was provided by members of the research team during all practice sessions to promote consistency with measurements. Despite this, it is possible that each rater may have had different criteria for determining end-feel and for determining when any compensatory movements (such as pelvic rotation during hip IR/ER) began. For instance, if one rater stopped the measurement at the first point of resistance (R1) rather than moving their participant through the full available range (R2), this would result in lower range of motion measurements obtained by that rater. This may explain the differences seen in ICC values between intrarater and interrater reliability as explained previously. Another limitation of this study may have been related to participant behavior. As the number of measurements obtained required each participant to remain still for an extended period of time, there were some instances where the participant had difficulty relaxing and allowing full passive movement. Additionally, there were several times when the participant had to be asked to return to the testing position. Thus, the first rater to assess a participant may have obtained more accurate findings compared to the second rater based on behavior experienced throughout the testing session.

FUTURE RESEARCH

As this is the first known study to date to assess the use of the EasyAngle® for measuring hip ROM in pediatric populations, it is recommended that future studies replicate this one to verify and expand upon the reliability of the results in this study, as well as to refine this original testing protocol. While this study obtained a sufficient sample size based on a preliminary power analysis, future studies with larger national sample sizes across a variety of geographic areas would help to strengthen the results. Finally, future studies are needed to investigate the reliability of the EasyAngle® in children who participate in youth sports or in children with diagnosed conditions.

CONCLUSIONS

The results of this study suggest that the EasyAngle® is a reliable tool to use for assessing hip ROM in healthy children ages 5-10. The EasyAngle® demonstrated good to excellent intrarater and interrater reliability when used to measure five motions of the hip joint in this population. The findings of this study suggest that clinicians can reliably use this novel digital goniometer to measure hip ROM in pediatric clinical settings, or in preparticipation examinations for children who will be participating in youth sports. This study also established preliminary normative values by year of age using the EasyAngle® for measures of hip flexion, extension, abduction, internal rotation, and external rotation in a healthy population of children aged 5-10 that can be used in clinical practice to assess for impairments in body structure or function.

Submitted: August 15, 2023 CST, Accepted: November 17, 2023 CST
© The Author(s)

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


SUPPLEMENTARY MATERIALS

Appendix 1
Original Research

A One Session Gait Retraining Protocol with Metronome Augmentation Increases Cadence in Novice and Recreational Runners

Angie Huber, Dave Verhoff

1 Doctor of Physical Therapy, University of Findlay

Keywords: Cadence, Gait Retraining, Metronome, Step Rate, running related injuries

https://doi.org/10.26603/001c.90909

International Journal of Sports Physical Therapy

Background

Running is a common leisure physical activity that carries a risk for running related injury (RRI). Non-experienced runners are more likely to sustain RRIs. One form of gait retraining focuses on increasing cadence to improve running biomechanics related to RRI. Protocols for increasing cadence must be pragmatic to be implemented into clinical practice.

Hypothesis/Purpose

The purpose of this study was to determine if a pragmatic protocol including one instructional session, followed by independent gait retraining with metronome augmentation resulted in increased cadence and altered biomechanics in novice and recreational runners.

Study Design

Randomized Controlled Trial

Methods

Thirty-three novice or recreational adult runners completed a 12 Minute Cooper Run on an indoor track. Variables measured during the 12 Minute Cooper Run included distance, rate of perceived exertion (RPE), heart rate (HR), and 3-D biomechanics using inertial measurement units (IMUs). After baseline testing, the intervention group received instruction and five minutes of gait retraining at a cadence set 5-10% higher than baseline with metronome augmentation (Pro Metronome- Tempo, Beat; by Xiao Yixiang). They then ran two to three times a week for two weeks up to 30 minutes per session with the metronome set at the new cadence. After two weeks, repeat testing using the same protocol was completed. A Mann-Whitney U test analyzed differences between groups.

Results

Cadence at one minute (p = 0.037) and average cadence over the entire run (p=0.002) increased in the intervention group only with a large effect size (Cohens d = 0.837). No other group differences were found.
Conclusion
A pragmatic gait retraining protocol with metronome augmentation including one instructional and four to six independent sessions over a two-week duration increased cadence without negative effects on HR, RPE, distance. Biomechanics did not change with this intervention. Further research with pragmatic gait retraining protocols that increase cadence are needed with larger sample sizes, repeated measures over time, across runners of various abilities and experience levels.

Level of Evidence
Level 2

INTRODUCTION
Running requires continuous lower extremity loading, predisposing runners to injury. Running related injuries (RRI) incidence varies from 10.9-84.8%, with a mean of 40.2%.\(^1\) Running is a top leisure activity globally\(^2\) and physical activity has been associated with a reduction in noncommunicable disease (NCD). Multiple researchers have reported greater incidence of RRI in runners with less running experience.\(^3\)–\(^5\) Linton et al. found runners with six months or less of running experience were 1.98 times more likely to get injured compared to runners with 5-10 years of experience.\(^5\) In a meta-analysis, Videbaek et al. reported that novice runners incur 17.8 RRI per 1000 hours and recreational runners incur 7.7 RRI per 1000 hours of running.\(^4\) Gomez-Molina et al.\(^6\) found that experienced runners used a higher step rate and shorter step length than untrained runners, and concluded that adopting a higher step rate and shorter step length may be an adaptive response to decrease the risk of RRI. Therefore, gait retraining intervention that aims to reduce RRI, particularly in runners with novice or recreational experience, is a clinical pursuit that may have long lasting effects on physical activity participation in the form of leisure running and therefore, NCD.

Gait retraining – including a feedback phase and a period of unsupervised practice of running retraining principles – is one proposed intervention to address prevention and treatment of RRIs. Doyle et al. reported on modes of gait retraining including: cadence manipulation, changing a runner’s foot strike from rearfoot to forefoot, reducing impact forces, reducing ground contact time, and multiparameter programs.\(^7\) Gait retraining in the form of cadence manipulation has been shown to be a safe retraining method resulting in improved biomechanics. For example, an increased cadence resulted in a decrease in vertical loading rate, vertical impact peak, and peak patellofemoral joint reaction force.\(^7\) Heiderscheit et al. reported subtle changes in cadence reduced the energy absorption required for lower extremity joints\(^8\) while Adams reported increasing cadence in persons with RRI’s decreased vertical oscillation resulting in lower loading rates and ground reaction forces.\(^9\) Hafer et al. investigated coordination variability and found increased cadence resulted in decreased knee flexion. Also, knee flexion, knee internal rotation, and shank internal rotation occurred later in mid-stance.\(^10\) Runners who increased their running cadence had reduced tibiofemoral contact forces,\(^11\) reduced peak knee extensor moments, reduced negative hip work, peak hip adduction, peak hip flexion, and reduced foot strike angle.\(^12\) In a mixed methods study examining experts opinions, Barton et al.\(^13\) found that experts recommended increasing step rate to manage running related injuries and suggested gait retraining as a method for injury prevention while Schubert et al.\(^14\) concluded increasing step rate may help reduce running related injury rate. Therefore, gait retraining via altering cadence appears to improve biomechanics related to RRI\(^14\) and is a worthwhile clinical intervention to investigate.

Gait retraining protocols aimed to increase cadence that are high in duration and intervention frequency, or that have time intensive feedback structures limit the pragmatic use of gait retraining in clinical settings. Variability in feedback methods and minimum increases for prescribing cadence complicate intervention decision making. Cadence retraining may include audio feedback or visual feedback from the provider or from external devices such as a metronome.\(^15\) A systematic review by Schubert, Kempf, and Heiderscheit concluded the minimum increase in step frequency required to observe a biomechanical change was as little as 5%, however, optimal change was 10%.\(^14\) Doyle et al. reported gait retraining protocols ranged from one to 36 sessions over an average of two to eight weeks.\(^7\)

The purpose of this study was to determine if a pragmatic protocol using audio metronome feedback set at 5-10% above a runners self-selected cadence would result in a change in cadence. The researchers hypothesized that a pragmatic gait retraining protocol focused on increasing cadence would improve biomechanics of running gait, without effecting physiologic markers including heart rate, rate of perceived exertion, or distance.

METHODS
STUDY DESIGN
This randomized controlled trial compared an augmented metronome cadence retraining intervention to a control group over a two-week period. Microsoft Excel Version 16.76.1 was used to create a random allocation sequence, with no stratification by co-variates, which resulted in an intervention group (n=17) and a control group (n=18). All but one researcher, was blinded to the group assignment until intervention began. The researcher who enrolled participants was blinded to the participant’s allocation. Researchers were unable to be blinded during intervention due to the nature of treatment.
Figure 1. Flow of participants through study

Participants were assessed during a Cooper 12-Minute Run at two instances: pre-retraining (Pre1), and post-retraining (Post2; after 2 weeks of independent retraining). The independent variable was gait retraining through increasing cadence. Pre1 and Post2 dependent variables were measured during Cooper 12-Minute Runs of both participant groups. Dependent variables consisted of average cadence over the entire run, cadence after 1 minute of running, heart rate (HR) at 5 and 11 minutes, Rate of Perceived Exertion (RPE) at 5 and 11 minutes, and distance ran. The stance duration, vertical excursion, knee flexion, and lumbar flexion were measured throughout the run using inertial measurement units (IMU). The study protocol was approved by the University of Findlay Institutional Review Board.

PARTICIPANTS

A total of 35 participant (14 male, 21 female) runners—recreational defined as running consistently for the last twelve months with a minimum of 10 km per week\(^4\) or novice—defined as running inconsistently for the last twelve months\(^4\) — provided consent to participate in the study. Inclusion criteria included participants who were adults (\(>18\) years old) with no injuries at the time of the study, cardiovascular disease, cardiovascular signs and symptoms during exercise, diabetes, cancer, metabolic, renal disease, or cognitive impairments that would limit their safety during high intensity physical activity. Participants were excluded if they were experienced runners defined as running a minimum average of 24 km per week\(^4\) or who had trained for a half marathon or marathon.

G*Power (Version 3.1.9.4.3) was used to determine the sample size. The calculation was based on an alpha level of 0.05. The Type II error rate was set at 80% and the effect size at a medium level (0.5) of the primary outcome variables. The appropriate sample size for this study was determined to be 34 participants. The participant flow chart as per the CONSORT statement is shown in Figure 1.

INSTRUMENTS

Kinematic and spatiotemporal variables were collected using IMUs (Noraxon Myorsearch MR 3.14, Scottsdale AZ, USA). IMUs have been found to be a valid method to collect this data during distance runs\(^16\) with only a joint range of motion mean error of 1.17 degrees compared to gold standard optical systems.\(^17\) HR was collected using Polar M450 GPS running watch (Polar Electro Oy, Kempele, Finland) and Polar FT1 chest strap heart rate monitor (Polar Electro Oy, Kempele, Finland). Data were transmitted wirelessly to a laptop computer and analyzed using the software associated with the Polar M450 watch. The Rate of Perceived Exertion (RPE) Scale\(^18\) was used to collect perception of physical exertion on a scale of 0-10. The RPE scale had strong correlation (r = 0.80-0.90) with HR during exercise and was valid in most conditions.\(^18,19\) Cooper’s 12-Minute Run distance was used to measure performance. Penny et al reported excellent reliability (0.96) and high validity coefficients (r = 0.90) for Cooper’s 12-Minute Run.\(^20\) A metronome app was used on the participants personal smartphone devices to provide auditory cueing.
PROCEDURES

After inclusion/exclusion screening, nine IMU motion sensors were attached to the subjects with elastic and Velcro strapping at the top of both feet, bilateral mid-shins, bilateral mid-thighs, above the tailbone, and mid-low back. A Polar FTI chest strap HR monitor, and Polar M430 Watch were fitted to the participant. (Figure 2)

The participant was given five minutes to perform a self-selected warm up routine, which at minimum included acclimating to the equipment when walking around the indoor running track. IMU motion sensors were then calibrated using Noraxon Myoresearch MR3.14 protocol. Participants completed two-separate Cooper 12 Minute Runs (Pre1 and Post2) approximately two weeks apart on an indoor track (129 meters around and 30 meters straightaways). For the Pre1 Cooper 12-Minute run and the Post2 Cooper 12-Minute run the participant was asked to run at a self-selected pace that they could maintain for 12 consecutive minutes until they were asked to stop. Additionally, a script was used, “At 5 minutes and 11 minutes of running, you will tell one of the researchers how difficult your run currently is on a scale of 0-10 with 0 being no effort at all and 10 being absolute maximum effort. At the end of your 12-minute run, you will cool down by walking or jogging another lap.” Each participant was shown the RPE Scale. HR from the Polar Watch application and RPE was recorded at six and 12 minutes into the runs. The distance run at completion of the Cooper 12-Minute runs were recorded. The Cooper 12-Minute Run was chosen because it is a reliable field test, and an inside track was chosen to control for the external environment yet allow the participant to self-select their pace throughout each run to increase external validity. Distance was measured to determine if pace was significantly altered. Cadence, stance duration, vertical excursion, knee flexion, and lumbar flexion was collected throughout the run with IMUs and wirelessly transmitted to Noraxon Myometrics software program. Consistent with Reenald, data were analyzed for five seconds (10 stride lengths) of straightaway running after 60 seconds into the run.

INTERVENTION

Average cadence was determined from baseline IMU measurements during the entire initial Cooper 12-minute run. Only the participants in the cadence retraining group were instructed to download the Pro Metronome-Tempo metronome application on their smartphone devices, and the participants’ metronome beat was set to a 10% increase in average cadence. These participants practiced this cadence for one lap and were permitted to adjust the cadence, if the retraining cadence was at minimum 5% greater than their average cadence. This allowance was made to enhance participant autonomy and compliance without compromising performance; in addition, beneficial changes have been found with a change as little as 5% increase in cadence. Once the participant reported comfort with a cadence between 5-10% above their average for one lap they were done with the session. They were asked to run or complete a combination of running and walking at least three times for 30 minutes for two weeks, running at their new increased self-selected cadence. The cadence retraining participants were required to complete a minimum of four sessions to remain included in post testing over the two-week period. The control group participants were instructed to maintain their current exercise routine. To mitigate suspicions of being in the control group, both groups were asked to document their exercise regimen on an activity log until their two-week Post2 testing. At their Post2 test, both groups completed the Cooper 12-minute run without the metronome. After the two-week Post2 testing the control group was offered the same metronome retraining as the intervention group, however, with no scheduled follow up.

DATA MANAGEMENT AND ANALYSIS

Biomechanical variables – cadence, stance duration, vertical excursion, stance duration, knee flexion at midstance, and lumbar flexion, RPE (at 5 and 11 minutes), HR (at 5 and 11 minutes), and distance run were analyzed in Jefrey’s Amazing Statistics Program (JASP). To examine descriptive differences (age, height, weight, BMI, days run per week, average miles run per week, average miles per run, and years’ experience running) between groups independent t-tests were completed. Outliers were identified via box plot analysis. The box plot analysis was determined to keep variables in analysis due to natural variation reflecting the target population. The Shapiro Wilk Test demonstrated an abnormal distribution, therefore, nonparametric testing – Mann Whitney U test was used. Separate and independent Mann-Whitney U tests were completed to analyze differences in cadence, HR, RPE, stance duration, center of vertical excursion, right and left knee stance duration, right and left knee flexion, and lumbar flexion. Effect size of in-
Table 1. Descriptive characteristics of the Control and Intervention groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control</th>
<th>Intervention</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>18</td>
<td>15</td>
<td>-</td>
</tr>
<tr>
<td>Gender</td>
<td>10F 8M</td>
<td>9F 6M</td>
<td>-</td>
</tr>
<tr>
<td>Age (year)</td>
<td>23.8±4.46</td>
<td>25.3±5.62</td>
<td>0.75</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.2±3.47</td>
<td>24.6±4.05</td>
<td>0.87</td>
</tr>
<tr>
<td>Days Run/Week</td>
<td>2.1±1.23</td>
<td>2.4±1.54</td>
<td>0.66</td>
</tr>
<tr>
<td>Miles/Run (avg)</td>
<td>2.00±1.32</td>
<td>1.86±1.06</td>
<td>0.85</td>
</tr>
<tr>
<td>Miles/Week (avg)</td>
<td>4.77±3.79</td>
<td>4.80±4.05</td>
<td>0.98</td>
</tr>
</tbody>
</table>

F, female; M, male; BMI, body mass index; kg/m², kilograms per meters squared; avg, average.

Table 2. Cadence at 1 minute and Averaged over Coopers 12-Minute Run

<table>
<thead>
<tr>
<th>Cadence</th>
<th>Control (n=18) mean±SD</th>
<th>Intervention (n=15) mean±SD</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre1</td>
<td>Post1</td>
<td>Pre1</td>
</tr>
<tr>
<td>Entire Run</td>
<td>160±10.06</td>
<td>160±10.28</td>
<td>161±7.11</td>
</tr>
<tr>
<td>At 1 Minute</td>
<td>162±10.99</td>
<td>163±10.82</td>
<td>165±8.62</td>
</tr>
</tbody>
</table>

SD, standard deviation; *, statistical significance < 0.05

Intervention cadence change was calculated via Cohens d₂ in Microsoft Excel (V16.76.1).

RESULTS

DESCRIPTIVE

Descriptive characteristics of the participants randomization into control or intervention groups, are provided in Table 1. Independent t-tests indicated no statistical differences in anthropometric and training characteristics between groups.

CADENCE

Results for cadence are presented in Table 2. There was a significant increase in cadence average over the entire run (p=0.002) and after 1 minute (p=0.037) in the intervention group compared to the control group. The effect size of the difference between Pre1 and Post2 cadence over the entire run in the intervention group was Cohen’s d₂, 0.837, indicating a large effect size.²¹

HR AND RPE

Results for HR and RPE at five and 11 minutes of the run are presented in Table 3. Group differences (p>0.05) and Pre1 and Post2 differences was not observed for HR or RPE.

DISTANCE

Results for performance, measured by distance completed in the Cooper 12-minute Run is presented in Table 4. Group differences (p>0.05) in Pre1 and Post2 running distance was not observed.

BIOMECHANICS

Biomechanical variables are presented in Table 5. Group differences (p>0.05) in Pre1 and Post2 stance duration, vertical oscillation, left and right knee flexion and lumbar flexion were not observed.

DISCUSSION

The primary finding of this study was that two weeks of gait retraining altering cadence with augmented feedback via a metronome increased self-selected cadence during a performance run in recreational and novice runners. Overall, these results indicate that one instructional session of gait retraining with an independent component including four to six visits over two weeks duration resulted in a change in self-selected cadence. Furthermore, the cadence change effect size from Pre1 and Post2 testing was large, indicating a meaningful increase in cadence.

Participants in this study completed a pragmatic gait retraining protocol. The intervention included one face-to-face instructional session, followed by four to six independent practice sessions using auditory external feedback via a metronome application on a smartphone device over two weeks. Doyle et al. reported gait retraining interventions varying between one and 36 sessions over a two to eight week phase.²⁷ Wang et al.²² reported a similar protocol using a metronome application for auditory feedback over a 12-week time with weekly group runs for compliance checks. Baumgartner et al.²⁵ initiated a six-week gait retraining protocol using an alert system to maintain cadence zones that increased cadence, however, lost seven of 38 subjects to follow up. Unlike previous research studies²²,²²,²¹ the protocol in this study required limited instruc-
Table 3. Fatigue Factors (HR and RPE)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control (n=18) mean±SD</th>
<th>Intervention (n=15) mean±SD</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre1</td>
<td>Post1</td>
<td>Pre1</td>
</tr>
<tr>
<td>HR at 5 min</td>
<td>157±25.37</td>
<td>150±23.11</td>
<td>154±19.81</td>
</tr>
<tr>
<td>HR at 11 min</td>
<td>179±10.02</td>
<td>167±29.02</td>
<td>177±16.62</td>
</tr>
<tr>
<td>RPE at 5 min</td>
<td>4.4±1.09</td>
<td>4.6±1.19</td>
<td>4.4±0.73</td>
</tr>
<tr>
<td>RPE at 11 min</td>
<td>6.2±1.26</td>
<td>6.5±1.38</td>
<td>6.4±1.18</td>
</tr>
</tbody>
</table>

HR, heart rate; RPE, rate of perceived exertion; min, minutes; SD, standard deviation

Table 4. Distance Ran

<table>
<thead>
<tr>
<th></th>
<th>Control (n=18) mean±SD</th>
<th>Intervention (n=15) mean±SD</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre1</td>
<td>Post1</td>
<td>Pre1</td>
</tr>
<tr>
<td>Distance (feet)</td>
<td>6844±1080</td>
<td>6653±1139</td>
<td>7008±668</td>
</tr>
</tbody>
</table>

SD, standard deviation

Table 5. Kinematic and Spatiotemporal measurements during Cooper's 12-Minute Run

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control (n=18) mean±SD</th>
<th>Intervention (n=15) mean±SD</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre1</td>
<td>Post1</td>
<td>Pre1</td>
</tr>
<tr>
<td>Lumbar Flexion (deg)</td>
<td>16±6.50</td>
<td>14±7.37</td>
<td>12±4.37</td>
</tr>
<tr>
<td>Knee Flexion L (deg)</td>
<td>49±9.61</td>
<td>49±9.31</td>
<td>46±7.34</td>
</tr>
<tr>
<td>Knee Flexion R (deg)</td>
<td>47±9.94</td>
<td>45±7.65</td>
<td>46±10.81</td>
</tr>
<tr>
<td>Vert Exc Max (cm)</td>
<td>10.2±0.70</td>
<td>10.1±0.72</td>
<td>10.0±0.74</td>
</tr>
<tr>
<td>Vert Exc Range (cm)</td>
<td>12.1±3.89</td>
<td>9.0±3.56</td>
<td>9.8±2.65</td>
</tr>
<tr>
<td>Stance Dur L (ms)</td>
<td>275±36.98</td>
<td>268±44.67</td>
<td>267±30.10</td>
</tr>
<tr>
<td>Stance Dur R (ms)</td>
<td>279±41.33</td>
<td>273±45.98</td>
<td>278±36.62</td>
</tr>
</tbody>
</table>

deg, degrees; cm, centimeters; ms, microseconds; Vert Exc, vertical excursion; Dur, duration; SD, standard deviation; L, left; R, right.

...tional time, was employed in a short duration, and resulted in a low attrition rate.

Secondary findings indicated this protocol did not change recreational and novice runners' biomechanical variables including stance duration, vertical excursion, knee flexion at midstance, and maximal lumbar flexion (p-value=0.05). Data collection with IMU's can be a valid method to collect real-time in-field data, however, can have a mean estimation of error of 1.17 degrees when compared to an optical movement system (Vicon). Anderson et al. report moderate to strong evidence that increasing cadence resulted in biomechanical factors including decreased step length and strong evidence for a reduced knee flexion angle. In the current study, cadence parameters were set to a 5-10% increase, Post2 testing did not result in a mean of > 5% difference in cadence, despite the large effect size and statistical differences found Pre1 and Post2. The mean difference in cadence over the entire run was 6.67 steps, resulting in a 4.14% change. Heiderscheit et al. and Schubert et al. report the minimum change in step frequency required to observe biomechanical change is a 10% increase in cadence, although some changes are seen with a 5% increase. Therefore, the low percentage of overall change in cadence along with in field data measuring error may have limited the detection of changes in biomechanical variables.

The results demonstrated in this study indicate an increase in cadence does not impact HR and RPE. Study on the effect of cadence change on HR and RPE is limited. A weak positive correlation of vertical displacement coupled with step rate and RPE has been reported in experienced male runners. This study highlights the lack of effect of cadence on HR and RPE in a participant group of novice and recreational runners, whose running technique is likely less optimal compared to experienced runners. Even so, the results HR and RPE in this study may be limited by the possibility of a Type II error.

Measuring overground data with IMUs allowed in field testing which enhanced external validity versus lab-constrained optical systems and additionally allowed running at a self-selected speed rather than at a constrained speed typically encountered on a treadmill. Given reported biomechanical differences between overground and treadmill running, direct biomechanical comparisons to treadmill...
studies may be difficult. In addition, Lacaille et al\textsuperscript{26} reported lower levels of RPE during overground running versus treadmill running.

LIMITATIONS

Future research should include repeated testing on cadence and biomechanical variables using gait retraining protocols with limited frequency of face-to-face instruction and emphasize independent retraining with audio feedback to reduce barriers to clinical implementation. Randomized studies of cadence retraining intervention that continue to be pragmatic yet have larger sample sizes and longitudinal post testing are needed to improve the understanding of the effect and retention of increased cadence. Future research should consider standardizing definition of types of runners to enhance the external validity of findings. In addition, investigations should look at interventions over a longer period and assess injury risk in those who received or did not receive intervention.

CONCLUSION

Notwithstanding the limitations, this is a unique study because of the limited face to face instruction required of the protocol which enhances applicability to clinical settings. The results of this study indicate a pragmatic protocol including short duration, low frequency feedback in a primarily independent manner with external auditory metronome feedback can be applied clinically. The large effect size of the average cadence between Pre1 and Post2 testing indicates this protocol creates meaningful short-term change in recreational and novice runners’ cadence, however, not greater than a 5% increase. Biomechanical changes and differences in distance, RPE, and HR were not detected. These findings encourage future investigation of clinically reasonable gait retraining protocols in larger sample sizes, with repeated measures over time, across varying types of runners (including experienced runners) who are pre-determined as having low cadence.

CONFLICTS OF INTEREST

The authors have no competing or conflicts of interests to disclose.

FUNDING

No funding was received in relation to the project.

ACKNOWLEDGEMENTS

The authors thank all who participated in this research.

Submitted: September 27, 2023 CST, Accepted: November 20, 2023 CST
© The Author(s)
REFERENCES


Effect of a Novel Training Program in Patients With Chronic Shoulder Pain Based on Implicit Motor Learning: Pilot and Feasibility Study.

Annelies Maenhout, Wieg Heijenk, Peter Glashouwer, Lore Quatacker, Luna Praet, Dorien Borms

Keywords: motor control, chronic shoulder pain, rehabilitation, exercise, telerehabilitation

https://doi.org/10.26603/001c.90284

Original Research

Background
Implicit motor learning has been shown to be effective for learning sports-related motor skills. It facilitates automaticity of movements and thereby improves performance in multitasking and high-pressure environments. Motor learning to develop motor skills and neuroplastic capacities is not sufficiently incorporated in musculoskeletal rehabilitation. Especially in patients with chronic pain conditions like shoulder pain this approach might benefit over traditional exercise programs.

Purpose/hypothesis
The aim of this study was to investigate the feasibility and clinical outcome of a new implicit motor learning exercise program in a group of patients with chronic shoulder pain.

Study design
Pilot and feasibility cohort study

Methods
Twenty-six patients with chronic shoulder pain performed a 6-week home exercise program with weekly remote follow up by a physiotherapist. The program comprised five exercises designed to challenge overall body balance, simultaneously engaging the upper limbs in a range of reaching tasks. The tasks included reaching above the head, at and below waist level, in various directions. No instructions on correct performance were provided to foster external focus. Feasibility was assessed by (1) recruitment rate, (2) follow up rate, (3) subjective experience, (4) self-reported adverse events and (5) self-reported adherence of subjects. Clinical effects of the program were assessed with (1) the Shoulder Pain and Disability Index (SPADI), (2) the Auto-Constant score, (3) the numeric rating scale (NRS) at rest and at night, (4) the patient specific functional scale (PSFS), (5) the avoidance endurance questionnaire (AEQ), (6) patient acceptable symptom state (PASS) and (7) a global rating of change (GROC).

Results
The study protocol was feasible in terms of follow up rate (16w for 28 patients), exercise adherence (77.1%± 29.41), and adverse events (no serious, 5 light adverse events). Statistically significant improvements were observed for SPADI (p<0.001), NRS at rest (p=0.033), at night (p=0.29), PSFS (p<0.001) and PASS (p<0.001) after only six weeks training.

a Corresponding author:
Annelies Maenhout, PhD, PT
Department of Rehabilitation Sciences
Ghent University
De Pintelaan 185, 9000 Ghent, Belgium
Phone number: 0032 3320268
Email: annelies.maenhout@ugent.be
Conclusion

This study reveals promising results of another way of looking at exercise for patients with chronic shoulder pain. Both feasibility and clinical effects of the program on pain and function was acceptable. Future studies should incorporate a control group, provide longer follow up and include objective measurements.

Level of evidence

INTRODUCTION

Shoulder disorders are the third most common musculoskeletal disorder after low back and neck pain. When shoulder pain becomes chronic, it may seriously impair work and leisure participation, disturb sleep, and decrease health-related quality of life. A conservative approach including exercise is the mainstay in the treatment of chronic shoulder complaints. Although exercise therapy has proven its effectiveness in chronic musculoskeletal pain there is still a lot unknown about which approach is best for conditions of the shoulder. Exercise programs mainly focus on scapular posture, scapular/rotator cuff strengthening, and anterior/posterior shoulder stretching.

Besides improving posture and increasing strength and range of motion, it might be important to prescribe exercises to optimize movement behavior in patients with chronic shoulder pain. Hodges and Tucker reported changes at multiple levels of the motor system in patients with chronic pain resulting in altered movement behavior with the objective to "protect" the tissues from further pain or injury, or threatened pain or injury. These long-lasting neuromuscular adaptations in response to pain may offer short-term benefit, but have potential long-term consequences due to factors such as increased load, decreased movement, and decreased variability and are advised to address in patients with chronic musculoskeletal pain.

In the majority of clinical practice, patients are provided with explicit guidance for proper movement when retraining motor control. This guidance commonly pertains to coordinating the movements of the patient’s body, including instructions on scapular posture and muscle recruitment. A small alteration in the wording of instructions can result in a substantial influence on both performance and motor learning outcomes. When patients are directed to focus their attention on how their movements affect the environment—an external focus of attention—it leads to more effective and efficient movements. A movement pattern is considered more efficient or economical if the same movement outcome is achieved with less energy expended. In contrast, directing attention internally towards one’s own movements results in a more conscious form of control that limits the motor system and disrupts automatic control processes.

The aim of implicit motor learning methods is to minimize the amount of explicit knowledge about movement execution and/or muscle recruitment during learning (internal focus), reduce the reliance on the working memory, and promote a more automatic control process.

Implicit learning is an approach in which self-organization is key. The principle of self-organization emphasizes that coordinated movements emerge naturally from the interactions among the components of the motor system. Instead of being rigidly controlled from outside, the body adapts and organizes itself to achieve task goals while exploring different movement patterns. This concept highlights the importance of allowing learners to explore and discover their own movement solutions, promoting adaptability and skill development. In sports science, there is increasing evidence that implicit motor learning is superior to explicit learning when it comes to learning new skills and improving performance. There are a number of disciplines in which implicit learning has been successfully applied, including pediatric physiotherapy, gait training for stroke patients, and ACL rehabilitation, but implicit learning is rarely used in the context of shoulder rehabilitation.

Considering the expected duration of rehabilitation within chronic shoulder pain patients, telerehabilitation seems a suitable medium for this population. During the COVID-19 pandemic physiotherapists widely used telerehabilitation to coach patients in their home exercise programs. In systematic reviews, both Seron et al. and Gava et al. concluded that telerehabilitation could be comparable to in-person rehabilitation to reduce pain and improve physical function in musculoskeletal conditions generally and shoulder pain specifically, but more high quality research is needed. The main advantage of telerehabilitation is that both the healthcare professional and the patient can carry out the treatment in their own environment without travel time or necessary transport.

The promising results of implicit motor learning in other conditions and the possibility of implicit learning to change motor control deficits evidenced in chronic pain conditions gave rise to this study. The aim of this study was to investigate the feasibility and clinical outcome of a new implicit motor learning exercise program in a group of patients with chronic shoulder pain.

MATERIALS AND METHODS

STUDY DESIGN

The feasibility study was a single group pre-post intervention design. The Institutional Review Board of Ghent University Hospital (B.U.N.: B6702020000611) approved the study.

PARTICIPANTS

Adults with chronic shoulder pain were recruited on social media and via flyers in public buildings and physiotherapy
practices. Potential candidates were first screened through an online questionnaire to check whether they met inclusion criteria (questions on duration of shoulder pain, the experience of an unstable feeling in the shoulder, dislocations/subluxations, mobility restrictions of the shoulder, results of medical imaging, medical diagnosis). To be included patients had to have had shoulder pain for at least six months for which they consulted a medical doctor (MD). Participants were excluded if they were currently in therapy or had undergone shoulder surgery or sustained a shoulder fracture. Moreover, patients that were expected not to benefit the intervention were excluded namely patients with an unstable shoulder (shoulder dislocation/instability, labral lesion), capsular stiffness (frozen shoulder, severe osteoarthrosis) or with inflammatory nociceptive pain mechanisms (bursitis, calcific tendinopathy, rheumatic disorders), as diagnosed by the MD, were excluded. All participants signed an informed consent prior to participation.

OUTCOMES

Feasibility outcomes consisted of recruitment rate, follow up rate (%) of participants who successfully completed the program and were reevaluated on six weeks, subjective reports regarding experience with the content of the program (custom-crafted statements on the content of this program scored with Likert scale eg. "I understood what was expected", "I thought the exercises were easy to do"), self-reported adverse events, and self-reported adherence. Adherence was scored weekly as 0 (did not meet minimal exercise adherence of 15', 5x/week) or 1 (meets minimal exercise adherence of 15', 5x/week). A score of six out of six (100%) was defined as perfect adherence. Based on this outcome the feasibility of a future RCT and the need for protocol modification were assessed.

At baseline and after the six-week home exercise program patients were requested to complete an online questionnaire package that consisted of demographic variables and several patient reported outcome measures (PROMs). Pain and function were evaluated with the Shoulder Pain and Disability Index (SPADI) and Auto-Constant score. The SPADI was chosen due to excellent reported reliability (ICC>0.90) in most studies, with reported minimal detectable change (MDC) of 18 points and minimal clinically important difference (MCID) between 8 and 15 points. 

The Auto-Constant score (patient self-report based) and the Constant score (clinician-based) have been shown to correlate well but no information on test-retest reliability of the Auto-Constant score is available. This alternative to the Constant score allows remote assessment which was necessary at the time of the study due to COVID precautions. Self-perceived active mobility and strength was measured with the Auto-Constant score. In this questionnaire patients have to select the pictures of a person lifting a weight or performing a specific movement that correspond with the level of lifting or moving they estimated themselves to be capable of. To assess patterns of fear-avoidance and endurance-related responses to pain the Avoidance Endurance Questionnaire (AEQ) was used. According to Hasenbring et al., inactive, avoidance behavior would drive disuse-related muscle weakness, deconditioning, and metabolic changes in the musculoskeletal structures and the central nervous system, potentially leading to peripheral and central sensitization and increased pain perception. In contrast, in overactive behavior, inappropriate muscle forces might expose mainly passive structures (vertebral joints, ligaments, connective tissue) to increased stress and repetitive strain, causing microdamage, laxity, and inflammation. The AEQ was developed to assess emotional, cognitive, and behavioral fear-avoidance and endurance responses to pain, and has been validated and repeatedly applied in different chronic pain populations. This self report questionnaire consists of three parts (pain affective, cognitive and behavioural responses). More detailed information on the subscales of the AEQ can be found in Appendix 2.

Each item was scored on a 7 point-Likert scale (0: never, 1: almost never, 2: seldom, 3: sometimes, 4: often, 5: most of the time, and 6: always). Higher scores represent more thoughts that correspond with avoidance or endurance of pain. All subscales Cronbach's alpha were in range from 0.76 to 0.91, which showed acceptable internal consistency. The participants were asked to fill out the questionnaire considering the pain they experienced in the past 14 days.

Overall satisfaction with the shoulder condition was evaluated before and after the 6-week program with the Patient Acceptable Symptom State (PASS). After the program patients were asked to score the rate of change between -5 and 5 (Global rating of change (GROC)). A score of -5 corresponds with shoulder complaints being a lot worse than before the program, 0 with no change, and 5 with full recovery of shoulder complaints. A systematic review and meta-analysis on measurement properties concluded that GROC shows excellent test-retest reliability (ICC = 0.84) but as recall bias might influence validity it is advised to combine with other outcomes to track changes in symptoms.

During weekly follow up, patients were asked to rate their pain at rest and at night on a numeric rating scale (NRS) as well as their ability to perform three important functional activities, using the Patient Specific Function Scale (PSFS). For NRS MCID was found to be 2.17 points in a population with shoulder pain. The PSFS shows moderate to good test-retest reliability (ICC 0.71) and MCID was shown to be 1.2 points. The advantage of the PSFS is that each patient can rate functional ability during daily life tasks that are relevant for them.

INTERVENTION

For specific content reporting of the home based exercise program the Consensus on Exercise Reporting Template was followed. A general instruction video and videos with exercise instructions (Appendix 1) were accessible online.

The program consisted of five exercises (Figure 1 and Appendix 1 detailed instructions). The exercise program was based on the principles of implicit motor learning.
Figure 1. Home exercise program

SELF ORGANIZATION

To elicit unconscious automatic bottom-up organization of motor control of the upper extremities, overall balance was challenged during the exercises. Each exercise had ten levels of difficulty to maintain total body balance (Appendix 1). To determine the level at the start, the 70–30% rule was used. Participants were instructed to select the level at which they could execute the exercise approximately seven out of ten times without losing balance.

To encourage participants to expand their range of motor control possibilities and engage their shoulder muscles beyond their comfort zone, they were consistently prompted to reach their maximum extent during all exercises. While performing the exercise, individuals should exert additional effort to reach the target and fully utilize their shoulder mobility. To achieve this, subjects were directed to position themselves in a manner where the target was placed just beyond their normal reach.

EXTERNAL FOCUS INSTRUCTIONS

During all exercises the focus was on the target (sliding objects over the floor, reaching towards the wall, touching toes) and no instructions were provided on how to perform the exercise. To correct performance in case of discomfort or low back pain for example analogies were used to elicit the desired movement behavior implicitly throughout the program such as for example: “imagine your legs both in a cast as you perform the exercises, now imagine that your legs are out of the casts” or “imagine your legs stuck in concrete, now the concrete is broken and you are free again”.

SELF-CONTROLLED LEARNING AND ENHANCED EXPECTATIONS

In the majority of rehabilitation scenarios, clinicians typically dictate the specifics of the training session. This includes decisions about the sequencing of tasks, the duration of practice, and when or whether instructions or demonstrations are provided. Consequently, patients often play a relatively passive role, with clinicians maintaining general control over most practice aspects. However, self-controlled learning, such as allowing patients to have some influence, requesting feedback, or selecting exercises, emerges as a potent instrument in the realm of motor learning. From a motivational perspective, patients were encouraged by the therapists (two last year master physiotherapy students that were specifically trained and under the supervision of two experienced senior shoulder physiotherapists) to take maximal responsibility in their training program and received the autonomy to make choices. During the six weeks participants were asked to practice with a minimum of three times a week. The therapists suggested that there may be superior outcome if the patients practiced more than three times per week. Duration of one exercise session was instructed to be 15 to 20 minutes but participants were allowed to perform shorter sessions multiple times a day. The sequence and duration of each exercise was not set. Participants could choose when and how much a specific exercise was done as long as a total of 15-20 minutes was reached. To control the pain (during and immediately after exercise, day to day, and week to week), participants were instructed to follow the pain monitoring model (Appendix 1). When pain increased or fatigue began, participants were instructed to switch to another exercise.

Follow-up with the participants was provided by the therapists during a weekly video or phone call according to individual preference. During these calls, patients, PSFS, the level of difficulty achieved for each exercise (and whether this was challenging enough), adverse events, and the frequency and duration of training sessions were discussed.

STATISTICAL ANALYSIS

Data were analyzed with SPSS statistical software (IBM SPSS Statistics, Version 27.0). Descriptive statistics were
used to assess the feasibility outcomes. A Shapiro-Wilk test was combined with a histogram to check normal distribution. Paired sample t-tests and Wilcoxon signed-rank tests were used to compare SPADI, AEQ, Auto-Constant scores and NRS at rest, at night, and during patient specific activities (PSFS) pre to post. Differences in the PASS were analyzed with a McNemar test. Statistically significant differences were considered at p<0.05. Post hoc power analysis was conducted based on the SPADI.

RESULTS

A group of 28 participants (Mean age= 34.9 years ±13.59; male/female= 10/17) was recruited. Baseline characteristics are summarized in Table 2. Medical diagnoses of their shoulder pain differed among the group most of which were related to the rotator cuff (shoulder impingement, subacromial impingement, rotator cuff related shoulder pain, subacromial pain syndrome, rotator cuff tendinopathy, rotator cuff muscle "sprain") however, some patients did not have clear medical diagnoses (such as "functional shoulder pain"). Twenty-six patients completed the study and two were lost to follow-up (one spontaneous improvement of pain before start of the study and one decided to consult an orthopedic surgeon for second opinion).

FEASIBILITY OUTCOME

- **Recruitment rate**: A total of 16 weeks was required to screen 96 patients of which 28 patients met the inclusion criteria and were eligible for participation in this study.
- **Follow up rate**: 92.9% of participants successfully completed follow up assessment after 6 weeks.
- **Subjective experience with the content of the program**: The outcome of the questions regarding the personal experience of the exercise program is visualized in Figure 2. Majority of participants (66.6%) indicated their expectations regarding the exercise program were fulfilled. Therapist guidance, follow up and content of the exercise program received positive feedback from all participants. Moreover, 62.9% of participants felt the exercise program had positive effects on their shoulder pain.
- **Self-reported adverse events**: Five patients reported adverse events during performance of exercises: low back pain (n=3), groin pain (n=1) and knee pain (n=1). All could be resolved by providing information on correct performance of the exercises or adapting the exercises. No patients reported adverse events after completion of the study.
- **Self-reported adherence**: The mean adherence to the exercise program was 77.1 ± 29.41%. It can be observed in Figure 3 that the adherence was higher during the first two weeks, decreased after that, and increased again towards the end of the program.

EFFECT OF THE PROGRAM ON PROMS

An overview of the pre- and post-intervention scores for the PROMs and the corresponding p-values are presented in Table 1. Post hoc power analysis based on the SPADI resulted in a power of 0.94.

SPADI pain scores were significantly lower after six weeks of training (median difference [95%CI] = -14.0 [-22.0; -7.0]; p<0.001). SPADI function scores were significantly improved after the exercise program (median difference [95%CI] = -10.0 [-15.0; - 5.6]; p<0.001). Total SPADI scores improved significantly (mean difference [95%CI] = - 13.6 [-19.8; -7.4]; p<0.001).

In the Auto-Constant questionnaire, significant improvement was attained for pain, self-perceived strength, and ROM. The pain scores decreased significantly (median difference [95%CI]= -3.0 [-4.5; -1.5]; p<0.001), strength scores increased significantly (median difference [95%CI]= 2.5 [0.0; 5.0]; p=0.008) and ROM scores improved significantly (median difference [95%CI]= 2.0 [1.0; 3.5]; p=0.001). Activity scores did not change significantly (mean difference [95%CI]= 0.5 [-0.2; 1.2]; p=0.168) and the total Auto-Constant score was not significantly different after intervention (mean difference [95%CI]= 3.0 [-0.1; 6.1]; p= 0.060).

Before the program, 23.1% of the participants was satisfied with their shoulder condition, whereas after the study 69.3% were satisfied as measured with the PASS. This proportional change was significant (p<0.001).

The mean NRS pain score at rest improved significantly through the research (median difference [95%CI]= -0.5 [-1.5; 0.0]; p=0.053) as did the pain scores at night (median difference [95%CI]= -0.8 [-1.5; 0.0]; p= 0.029). For the PSFS the participants reported a significantly lower score reflecting improved ability to perform functional activities after the program (mean difference [95%CI]= -2.4 [-3.4; -1.5]; p<0.001).

Regarding the AEQ, the Pain Emotional Reactions score improved significantly after the intervention. The Anxiety Depression Scale (ADS) showed a significant mean difference [95%CI] of -0.6 [-0.8; -0.3] (p<0.001). Additionally, the Positive Mood Scale (PMS) significantly improved after training with a median difference [95%CI] of 0.5 [0.2; 1.0] (p=0.007). For the subscale Pain Cognitive Reactions, only the Help Hopelessness Scale (HHS) reached a significant difference (mean difference [95%CI]= -0.7 [-1.0; -0.3]; p= 0.002).

The self-perceived change in the condition of the shoulder after six weeks of exercising as measured with the GROC showed a mean change of 1.9 points (+1.89). The distribution of the scores are presented in Figure 4.

DISCUSSION

The aim of this research was to determine whether a novel home exercise program conducted via telerehabilitation based on implicit motor learning was effective for patients with chronic shoulder pain and whether the study protocol was feasible. The results showed that the study protocol was feasible in terms of follow up rate, exercise adherence,
and adverse events. Statistically significant improvements were observed for the SPADI, NRS at rest and at night, and PASS after only six weeks training.

Twenty-six participants completed the six-week exercise program at home with weekly remote follow-up. The results showed that the study protocol was feasible with respect to follow-up rate and acceptable in terms of personal experience with the program, exercise adherence and adverse events. Majority of participants (66.6%) indicated their expectations regarding the exercise program to be fulfilled. Therapist guidance, follow up, and content of the exercise program received positive feedback from all participants. Moreover, 62.9% of participants felt the exercise program had positive effects on their shoulder pain. This is an important finding, since perception of participants about the exercise program is crucial for adherence to the treatment and thus successful rehabilitation.42,43 Although patient and therapist never met in person due to COVID-19 measures, participants indicated that they understood the instructions on the phone or video-calls, when combined with the YouTube videos.

Frequency of follow-up also appeared important in view of adverse events. Providing instructions on how to adapt the exercises was key in preventing pain in other joints such as low back and knee to persist. Hence, the communication used in this study appeared suitable for telerehabilitation.

Figure 2. Personal experience regarding the exercise program (expressed as the percentage of participants in each answer category)
Figure 3. Mean adherence (percentage) over 6 weeks (100% equals exercising as prescribed at least 3 days a week, at least 15 minutes)

The clinical outcome results are very promising after only six weeks of training. There was a 13.6 point decrease in the primary outcome (SPADI score). This result is higher than the MCID of 8-15 points but lower than the MDC of the SPADI of 18 points. The magnitude of this difference is comparable to other studies investigating the effect of more traditional exercise programs with strength and mobility exercises. Littlewood et al. for example showed improvement of SPADI scores after three months with 12.4 points in the self-managed group and 16.7 points in the usual physiotherapy group in patients with subacromial pain syndrome. Especially considering the study population (>6 months shoulder pain) a longer duration is recommended given that earlier research indicated longer lasting complaints may require a prolonged rehabilitation. The improvement in pain was significant for pain at rest and at night. The amount of change was smaller than the MCID of 2.17 points but comparable to changes seen in other intervention studies in this population. It is important to note that the small improvement might also be related to the rather low pain scores at baseline (1.8-1.9) which is most likely the result of exclusion of serious shoulder pathology such as frozen shoulder in the current study. A mean change in shoulder complaints of 1.9 points on the GROC represents that participants consider the change valuable regarding their health status.

After the program it was shown that pain emotional reactions, as measured with the AEQ, significantly improved, meaning that patients had fewer depressive thoughts and anxiety and were in a better mood. This may relate to a happier lifestyle and thus a higher quality of life. In contrast, no significant changes were seen in participant’s coping reactions. Pain cognitive reactions also did not change significantly except for the HHS. The HHS represents the lack of hope and the feeling of impossibility to become pain-free. In other words, participants believed in the advantages of exercising and had a more optimistic point of view on the future after study completion. Combining the exercise program with behavioral change techniques could be an interesting direction for future research.

The current study attained a high percentage of compliance of 77%. Compared to other studies this adherence rate with home-based training was rather high. For example, Burns et al. reported an adherence of 41% with a home exercise program for patients with rotator cuff pathology. Possible reasons for this strong adherence might be the weekly follow-up calls, the dynamic nature of the exercises and the freedom of planning practice. Freedom of planning their own practice was perceived as an advantage by 96% of participants. Rehabilitation outcome strongly depends on treatment adherence. Interestingly, in this study it was observed that adherence decreased to the lowest value at week four and then started improving again towards the end of the program. A potential cause for the motivational dip could be that the novelty of the exercises was gone, and the end of the training period still seemed a long way off. NRS scores at rest and at night increased between week four and five probably causing the participants to see the benefit of the exercise program which in turn increased the adherence. After six weeks of training 70.4% of participants indicated they planned to continue to perform the exercises after study completion. The setup of this study with a home-based program and maximal responsibility for patients might be advantageous for patients’ self-efficacy, autonomy, and active coping behavior.
The training program only consisted of exercises based on implicit motor learning with external focus, no manual therapy or strength training was included. The underlying mechanism that could explain the clinical improvements might be related to motor learning resulting in more efficient and less rigid movement patterns. Studies investigating EMG muscle recruitment during a variety of exercises comparing external focus of attention to internal focus of attention showed lower muscle recruitment in the first. In these studies, where the executed movement remains constant and only the focus of attention is shifted, a decrease in muscle recruitment could indicate enhanced efficiency in performing the exercise. This could be beneficial during functional movements in daily activities. During follow up, some participants spontaneously reported that they noticed starting to use their affected shoulder more during daily activities and a significant improvement was found in their ability to perform individually reported activities as measured with the PSFS. A future study might include objective measurements of arm use in daily life. The placebo effect due to being included in a study and receiving attention from the therapist cannot be out ruled as there was no control group.

LIMITATIONS

A first limitation of this study is the lack of a control group. In addition to ruling out the influence of natural recovery, incorporating a control group would provide clarity on how the outcomes of this novel exercise program compare to a conventional function-based program. The latter typically includes a range of isolated shoulder strengthening and mobility exercises.

The second limitation is that no objective data on strength and mobility could be collected due to COVID measures at the time of the study. To evaluate exercise adherence objective data would also be desirable. Since the

Table 1. Patient reported outcome measurements before and after the intervention.

<table>
<thead>
<tr>
<th></th>
<th>Pre (mean ± SD)</th>
<th>Post (mean ± SD)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SPADI</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pain</td>
<td>36.0 ± 21.50</td>
<td>20.8 ± 19.21</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Function</td>
<td>26.6 ± 20.81</td>
<td>14.6 ± 16.81</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Total</td>
<td>31.3 ± 20.25</td>
<td>17.7 ± 17.75</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td><strong>Auto-Constant</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pain</td>
<td>6.7 ± 3.07</td>
<td>3.8 ± 2.98</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Strength</td>
<td>14.4 ± 4.97</td>
<td>17.1 ± 5.32</td>
<td>0.008*</td>
</tr>
<tr>
<td>ROM</td>
<td>16.5 ± 4.81</td>
<td>19.3 ± 3.46</td>
<td>0.001*</td>
</tr>
<tr>
<td>Activity</td>
<td>12.8 ± 2.06</td>
<td>13.3 ± 1.76</td>
<td>0.168</td>
</tr>
<tr>
<td>Total</td>
<td>50.5 ± 8.52</td>
<td>53.4 ± 5.43</td>
<td>0.060</td>
</tr>
<tr>
<td><strong>PASS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADS</td>
<td>1.5 ± 1.02</td>
<td>0.9 ± 0.82</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>PMS</td>
<td>4.2 ± 1.52</td>
<td>4.7 ± 0.82</td>
<td>0.007*</td>
</tr>
<tr>
<td><strong>AEQ: pain emotional reactions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HHS</td>
<td>2.1 ± 1.31</td>
<td>1.4 ± 1.12</td>
<td>0.002*</td>
</tr>
<tr>
<td>CTS</td>
<td>0.5 ± 0.89</td>
<td>0.4 ± 0.69</td>
<td>0.471</td>
</tr>
<tr>
<td>TSS</td>
<td>2.7 ± 1.37</td>
<td>2.8 ± 1.44</td>
<td>0.737</td>
</tr>
<tr>
<td><strong>AEQ: pain cognitive reactions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>APAS</td>
<td>1.3 ± 0.98</td>
<td>1.3 ± 0.87</td>
<td>0.951</td>
</tr>
<tr>
<td>ASAS</td>
<td>1.5 ± 0.55</td>
<td>1.4 ± 0.42</td>
<td>0.169</td>
</tr>
<tr>
<td>PPS</td>
<td>2.5 ± 0.75</td>
<td>2.6 ± 0.74</td>
<td>0.340</td>
</tr>
<tr>
<td>HDS</td>
<td>2.9 ± 0.98</td>
<td>2.8 ± 0.75</td>
<td>0.700</td>
</tr>
<tr>
<td>BES (PPS + HDS)</td>
<td>5.4 ± 1.55</td>
<td>5.4 ± 1.32</td>
<td>0.859</td>
</tr>
<tr>
<td><strong>AEQ: pain coping reactions (severe pain)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>APAS</td>
<td>1.7 ± 0.57</td>
<td>1.4 ± 0.81</td>
<td>0.089</td>
</tr>
<tr>
<td>ASAS</td>
<td>2.1 ± 0.48</td>
<td>2.0 ± 0.46</td>
<td>0.146</td>
</tr>
<tr>
<td>PPS</td>
<td>3.0 ± 0.90</td>
<td>2.9 ± 1.02</td>
<td>0.615</td>
</tr>
<tr>
<td>HDS</td>
<td>3.0 ± 1.26</td>
<td>3.2 ± 1.25</td>
<td>0.475</td>
</tr>
<tr>
<td>BES (PPS + HDS)</td>
<td>6.1 ± 1.93</td>
<td>6.1 ± 2.00</td>
<td>0.895</td>
</tr>
<tr>
<td><strong>NRS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pain @ rest</td>
<td>1.8 ± 1.68</td>
<td>1.2 ± 1.91</td>
<td>0.033*</td>
</tr>
<tr>
<td>Pain @ night</td>
<td>1.9 ± 2.05</td>
<td>1.1 ± 1.94</td>
<td>0.029*</td>
</tr>
<tr>
<td>PSFS</td>
<td>4.6 ± 1.73</td>
<td>2.3 ± 2.00</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

* indicates a statistically significant change at p<0.05; SD = Standard Deviation; SPADI= Shoulder Pain and Disability Index; ROM= Range of Motion; PASS= Patient Acceptable Symptom State; AEQ= Avoidance-Endurance Questionnaire; ADS = Anxiety Depression Scale; PMS= Positive Mood Scale; HHS= Help Hopelessness Scale; CTS= Catastrophizing Thoughts Scale; TSS= Thought Suppression Scale; APAS= Avoidance of Physical Activities Scale; ASAS= Avoidance of Social Activities Scale; PPS= Pain Persistence Scale; HDS= Humor Distraction Scale; BES= Behavioral Endurance Scale; NRS= Numeric Rating Scale; PSFS= Patient Specific Function Scale.
Figure 4. Global rating of change
A score of -5: shoulder complaints a lot worse than before the program, 0: no change, 5: full recovery of shoulder complaints

Follow-up calls were not anonymous, socially desirable responses might unconsciously have been encouraged.

Finally, study duration can be considered a limitation. A future trial should have a longer training program of at least 12 weeks and include long term follow-up after six months up to one year.

CONCLUSION

The results of the current study provide promising results of a novel way designing shoulder exercises for patients with chronic shoulder pain. The home-based, six-week exercise program based on implicit motor learning produced significant improvements in pain and function in patients with chronic shoulder pain. The study protocol was feasible in terms of follow up rate, exercise adherence and adverse events. Participants especially appreciated the freedom to plan their exercise sessions and instructions and follow up provided by the therapists. Recruitment rate was rather low. Future studies should incorporate a control group, provide longer follow up, and include objective measurements to analyze changes in strength, range of motion, and use of the affected upper limb during daily life.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

Submitted: February 02, 2023 CST, Accepted: October 30, 2023 CST © The Author(s)
REFERENCES


SUPPLEMENTARY MATERIALS

Appendix 1

Appendix 2
Abstract
The acromioclavicular joint (ACJ), a key element in shoulder movement and stability, is prone to various injuries such as sprains, dislocations, and osteoarthritis, typically resulting from physical trauma or wear and tear. Accurate and timely diagnosis is paramount for effective treatment and rehabilitation. Musculoskeletal (MSK) ultrasound has emerged as a pivotal diagnostic tool due to its ability to visualize soft tissues and provide real-time imaging. This non-invasive tool is also invaluable for monitoring healing progress and the evolution of osteoarthritic changes. This article reviews the application of MSK ultrasound in the evaluation of ACJ injuries, highlighting its advantages, specific applications, and recent technological advancements that enhance its diagnostic capabilities.

Keywords: Acromioclavicular Joint, Musculoskeletal Ultrasound, Diagnostic Imaging, Rehabilitation, Shoulder Injuries, Soft Tissue Visualization, Non-Invasive Assessment, Technology Advancements.

Introduction
Sports physical therapists often deal with a range of musculoskeletal (MSK) issues, where accurate diagnosis and effective treatment are crucial for an athlete's recovery and performance. The acromioclavicular joint (ACJ) plays a pivotal role in shoulder stability and movement, being the junction between the acromion process of the scapula and the clavicle. Given its importance, injuries to this joint, commonly resulting from falls, car accidents, or sports activities, can have significant repercussions. These injuries range from mild sprains, where ligaments are partially torn but the joint remains aligned, to severe dislocations with complete ligament tears and joint misalignment. Furthermore, repetitive use or wear and tear can lead to osteoarthritis of the ACJ, characterized by joint pain, stiffness, and swelling. Timely and accurate diagnosis is crucial for effective management. Traditional imaging techniques like radiographs often fall short in adequately assessing these injuries, particularly in visualizing soft tissues and dynamic joint function. MSK ultrasound has become increasingly popular for evaluating ACJ injuries, offering real-time, detailed imaging of soft tissue structures.

Benefits of MSK Ultrasound in ACJ Injury Assessment
MSK ultrasound offers a non-invasive, cost-effective, and dynamic assessment of the ACJ. Its superiority in visualizing soft tissue structures, such as ligaments, articular cartilage, and the joint capsule, allows for a more nuanced diagnosis than what is achievable with radiographs. Its non-invasive nature also allows for repeated assessments, essential in monitoring the healing process or the progression of degenerative changes. This imaging modality is also beneficial for monitoring the healing process and guiding interventions such as injections.

Specific Applications in ACJ Assessment
In acute injury scenarios, MSK ultrasound effectively assesses the extent of ligament and soft tissue damage, aiding in the accurate classification or grading of the injury and facilitating appropriate treatment planning. In chronic conditions, MSK ultrasound aids in identifying degenerative joint changes due to repetitive use or aging. The ability to perform dynamic assessments with MSK ultrasound is particularly useful in evaluating joint stability and function. It also detects concomitant injuries like rotator cuff tears or fractures, often missed by radiographs. In chronic conditions, it helps identify structural changes within the joint due to repetitive stress or aging.

Advantages of MSK Ultrasound for ACJ Visualization
1. **Real-Time Imaging**: Unlike static images provided by radiographs or magnetic resonance imaging (MRI), MSK ultrasound offers dynamic, real-time imaging. This allows therapists to assess the ACJ under movement, providing a more comprehensive understanding of the injury.
2. **High Resolution**: Ultrasound provides high-resolution images of soft tissues, making it ideal for detecting subtle changes or injuries in the ligaments and tendons surrounding the ACJ.
3. **Patient Comfort and Safety**: Being a non-invasive procedure, ultrasound is more comfortable for patients. It also avoids the exposure to radiation that comes with radiographs.
4. **Cost-Effectiveness and Accessibility:** Ultrasound equipment is generally more affordable and portable compared to other imaging modalities, making it a practical tool in various settings, including clinics and sports fields.

**Clinical Applications in ACJ Injuries**

1. **Diagnosis:** MSK ultrasound can quickly and accurately diagnose ACJ injuries, such as sprains, separations, or arthritis. It can differentiate between types of injuries based on the appearance of soft tissues.

2. **Guided Interventions:** In some cases, therapeutic interventions like injections are needed. Ultrasound can guide these procedures with precision, ensuring that the treatment is delivered to the exact location.

3. **Non-Invasive Monitoring Progress:** The non-invasive nature of MSK ultrasound allows for repeated assessments, making it ideal for monitoring injury progression and healing, especially in chronic conditions like osteoarthritis. Rehabilitation providers can use ultrasound to monitor the healing process of ACJ injuries, adjusting treatment plans as needed based on real-time feedback.

**Advancements in MSK Ultrasound Technology**

Recent advancements have significantly enhanced the utility of MSK ultrasound in ACJ evaluation. High-frequency transducers now offer detailed images of smaller structures like ACJ ligaments with greater resolution and clarity. Additionally, 3D and 4D imaging provide comprehensive evaluations of joint dynamics and movement. The use of contrast agents has also become a game-changer, aiding in distinguishing between active inflammation and structural changes, particularly in diagnosing osteoarthritis.

**Conclusion**

With advancements in ultrasound technology, there's potential for even greater use in sports physical therapy. Innovations like 3D imaging and enhanced Doppler capabilities could provide deeper insights into joint health and injury mechanisms. As such, rehabilitation providers should incorporate MSK ultrasound into their diagnostic protocols for ACJ injuries as this represents a significant advancement in the evaluation of ACJ injuries. Its ability to visualize soft tissues, combined with its non-invasive nature, makes it a superior choice for accurate diagnosis and treatment monitoring. Additionally, the ability for repeated assessments makes it a valuable tool in both acute and chronic injury management. Advancements in technology have further improved its capabilities, making it an essential tool for clinicians in the management of ACJ injuries. Early and precise diagnosis is key to successful recovery and preventing complications. Healthcare professionals should actively consider MSK ultrasound in their diagnostic arsenal for ACJ concerns, ensuring proactive and comprehensive care for joint health.

Incorporating MSK ultrasound into their practice requires training and proficiency in ultrasound technology. Understanding the anatomy and common injury patterns of the ACJ is crucial for accurate interpretation of ultrasound images. Continuous education and practice are essential to maintain a high level of skill in ultrasound application.
**ACROMIOCLAVICULAR (AC) JOINT**

**Figure 1A: Patient Position and Transducer Placement**
The patient is seated with their arm resting by their side and hand in their lap. The transducer is placed in a short axis view (SAX) perpendicular to the spine directly over top the AC joint. Palpating this superficial joint prior to placement of the transducer can help with aligning it with the long shaft of the clavicle. This helps visualize the bony margins more efficiently.

**Figure 1B: Dynamic Imaging with Patient Position and Transducer Placement**
Dynamic imaging can be performed by having the patient slowly bring their hand out with shoulder external rotation showing an AC joint separation determining joint instability.

**NORMAL VIEW IN SHORT AXIS (SAX)**

**Figures 2A and 2B Short Axis View:** AC joint is a simple synovial joint with fibrocartilage lining on both the acromion and clavicle. At times the hyperechoic “fibrocartilage disc” is present deep within the joint to maintain joint space/gap. The AC ligament is a flat, band-like ligament contributing to joint stability. The acromial bony margin is shorter in length by comparison to the linear, hyperechoic cortical reflection of the clavicle.
AC JOINT SPRAIN

Figure 3A & 3B: Assessed with dynamic imaging performed by having the patient slowly bring their hand out with shoulder external rotation showing an AC joint separation determining joint instability.

Figure 3A: Type 1 AC Joint Sprain. A sprain or incomplete tear of the joint capsule and its reinforcing AC ligament. May note some mild effusion in the joint space.

Figure 3B: Type 2 AC Joint Sprain. A complete tear of the joint capsule and its reinforcing AC ligament. Intact coraco-clavicular ligaments remain. The joint space is widened, and clavicle is elevated above acromion.

AC JOINT OSTEOARTHRITIS:

Figure 4: Osteoarthritis is a common non-traumatic disorder in the AC joint and noted here with chondral wearing and cortical irregularities. Note the capsular hypertrophy and the joint space narrowing.

AC JOINT SYNOVITIS WITH NEOVASCULARIZATION

Figures 5A & 5B: The AC joint capsule appears to be more hypoechoic due to swelling. The capsule shows signs of a proliferating capsule with more hyperechoic parts that can be seen within the anechoic joint fluid. This proliferation is usually due to neovascularization and can be visualized with a Doppler US setting.
Implementing a Hybrid Model of Therapy is a Win for Therapists, Patients and Payers

Ben Galin, DPT

1 Vice President of Strategy, Genie Health

Keywords: digital healthcare, hybrid PT, remote therapy

Having the mindset of a veteran practicing physical therapist (PT), a clinic owner, and a PT consultant, I see a perfect storm brewing between reimbursement rates, care delivery costs, and vacancy of PT positions that could mean a serious doomsday vision – if I did not know a solution already existed.

Current physical therapy stats shown by WebPT said that only 30% of patients finish their course of care. Other previously published statistics have shown that only 19% to 30% of patients perform their HEP (Home Exercise Plan). My anecdotal ‘n of 1’ tells me post-surgical patients are compliant with their HEP for a few weeks, but non-operative patients are “dabbling” in it at best.

The current physical therapy machine is broken. It worked when patients came into the clinic three times a week for 12 weeks. It does not work today when competing for a patient’s 2-4 hours per week is difficult to say the least; let alone competing for their time between appointments.

The lack of follow through between sessions and attrition from the prescribed program causes a perceived "failure of conservative care" to the payer, referral source, and the patient. It results in a loss of momentum between sessions. When I started practicing 20 years ago, the three-time-per-week diligent patient could overcome some of the fall off between sessions. Today, forward progress is difficult to attain with patients coming in-clinic only one to two times per week at best, with the typical eight sessions over seven or so weeks. The constant in-clinic reassessments and program adjustments cause lost progress and time. Clinically, we know that motor learning, neuroplasticity, and pain theories require repetition of non-noxious and prescribed motion, and the average patient is not getting that between sessions or in clinic enough to make PT work.

BILLING SCENARIOS

A traditional clinic, seeing one patient per hour, and scheduling for 2.25 times per week on average per FTE could feasibly carry a caseload of 18 active patients per week. With the national 20-25% cancellation rate, this brings visits down to 1.88 per week (data across various states). Using CMS rates, this means a FTE is billing $5,900 per week. The available physical space, desired scheduling times of day, staffing availability, all factor into how much you can maximize the total number of patients seen per day in a clinic. The same traditional clinic that had three FTEs, and patients open to scheduling, could max out at a 54 active patient caseload and bill $11,700 weekly.

But the reality is all patients want to be seen at clustered times and many staff members will not work past 6 p.m. Another reality is that there are more patients who want to come in that front door than can be scheduled, but "squeezing them in" just means other patients are not getting their visits, or it is getting over-crowded, and it must give somewhere. That "somewhere" is provider burnout or in patient’s not being seen regularly enough to see the value.

So, we know the problem. But what is the answer? Luckily, hybrid care is also an operational reality.

- Virtual Care
- Remote Monitoring
- Telehealth

Individualizing the amount, timing, and frequency of in-clinic patient care (per their unique needs and abilities) allows some patients to be seen all in-clinic, some all virtual but MOST benefiting from hybrid care based on their recovery life cycle. For example, someone in a phase of pure AROM and AAROM for the shoulder after surgery, may do very well at home for a period of a few weeks. Someone who has progressed in plyometrics, and randomization of tasks would do much better in the clinic.

SCENARIOS OF A HYBRID PATIENT JOURNEY

A two-unit patient in-clinic visit is the standard of hybrid care (and why does a patient need to be in the office for an hour anyway?). Knowing we have another two-unit virtual and telehealth program backing the in-person sessions ensures progression, attention, and compliance between visits. Evenly dosing patients with virtual and in-clinic and
Implementing a Hybrid Model of Therapy is a Win for Therapists, Patients and Payers

one weekly session of telehealth, the case load capacity at LEAST doubles.

This now means with the same three FTE plus a telehealth PT, can carry 110 patients, and there is room for evaluations, more patients, and cancellations are easily rescheduled (and are not as painful when they happen). The billing per week max for the three FTE and PT tele position goes up to $22K a week. It doubles with the same in-office staff, with just one telehealth position and monitoring team added. There is more NET revenue in this model and the billing per hour per therapist is higher due to less MPPR infliction. Other benefits:

- Patients get their hand held and receive concierge care both at home and in-clinic throughout their journey in a virtual remote monitored program.
- Concerns can be escalated into telehealth as needed.
- Patients are not inconvenienced by having to come to the clinic.
- The clinic is open for more capacity.
- Evals can happen on the same day.
- No stress about scheduling the new and already active patients.

There is no downside.

The catch? Mindset changes. Therapists need to embrace the hybrid model and step away from the three-time-per-week–four-unit mantra that has been followed for decades. They need to understand the power of the home program when it is fully deployed, monitored, and followed. They need to see patient’s acceptance and approval and improved outcomes when a fully hybrid model is deployed.

According to Genie Health patient surveys, when using the Genie Health platform, patients recovered 60 percent faster, their pain was reduced by 50 percent, and they reported a 90 percent increase in satisfaction with their traditional PT program.*

Hybrid care addresses:

- the consumption of healthcare
- the vacancy of PT positions
- staffing issues of current staff
- declining reimbursements
- cancelations
- therapists who want to work from home
- patient outcomes

Hybrid care is here, it is in its infancy for sure, but those who conquer it the soonest will be reaping the rewards and the patients will surely be steering themselves to these models.

To contact the author, please email: bgalin@genie.health

Sources: Webpt: https://www.webpt.com/blog/7-thought-provoking-facts-about-physical-therapy-you-cant-ignore

Neuroplasticity Source: Dr. Schmidt’s 1991 book Motor Learning, “it takes 300–500 repetitions to develop a new motor pattern. To correct a bad motor pattern, it takes 3,000–5,000 repetitions.”

*As presented at both the American Physical Therapy Association and American Association of Orthopedic Surgeons annual meetings in 2023.

© The Author(s)

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