Boost 2

EFFORTLESS OFF-WEIGHTING

The Boost microgravity treadmill enables you to de-load up to 80% of your body weight to reduce pain, rehabilitate lower body injuries, and train longer and harder without the impact on your body.

- Precision Motorized Height Adjustment
- Whisper Quiet
- Simplified User Controls
- Expanded Gait Viewing Windows
- Pre-Programmed Workouts
- Easy Access to Service & Clean

Contact us at 800-WOODWAY or info@woodway.com to experience the Boost difference.
CHATTANOOGA® INTELECT® RPW 2

NEXT GENERATION SHOCKWAVE THERAPY

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 Tendinopathy
- Disorders of Tendon Insertions
- Myofascial Trigger Points
- Plantar Fasciitis

Scan the QR code to request a quote, or visit learn.chattanoogarehab.com/ijspt-dec-23-journal-quote.
Dear Reader…

It's hard to believe we are now wrapping up our eighteenth year at IJSPT. We've made a lot of changes over these years!

The first was the move to a digital publication in 2009. The second was a change of name from the North American Journal of Sports Physical Therapy (NAJSPT) to the International Journal of Sports Physical Therapy (IJSPT) in 2011, to emphasize with our alliance with the International Federation of Sports Physical Therapy. During this time, the journal also grew from 5 to 10 and then to 15 articles per issue.

In 2020, the American Academy of Sports Physical Therapy (AASPT) decided to cease publication of the IJSPT, beginning in 2021. As the sitting Editor in Chief and NAJSPT/IJSPT Board Member since its inception, I did not want to see this stellar journal die. So a business I am a partner in, North American Sports Medicine Institute, took over the publication of the IJSPT.

This effort was brought to fruition quickly with the help of former Senior Editor Barb Hoogenboom, who moved into the Editor-in-Chief position; Ashley Campbell, former board member, became our Managing Editor; and Mary Wilkinson, our former Managing Editor moved into the Executive Director position. Casey Lewis is our Manuscript Editor, and many of our long time board members, such as Phil Page, Kevin Wilk, Terry Grindstaff, and Rob Manske, pledged to continue their support of the IJSPT.

Since the first February 2021 issue, the IJSPT has continued to grow, featuring as many as thirty articles in a single issue. The journal is indexed in PubMed / Library of Congress and is also an Official Publication of the International Federation of Sports Physical Therapy (which has 40 member countries around the world), ICCUS, and AASPT. We presently have a circulation of about 28,000 PT’s – but this is growing monthly, and we have expanded into the Sports MD (AOSSM), ATC and Chiropractic professions. Our goal is to grow the subscription list to over 50,000 within the next couple of years. Having said that, we are a “Gold open access” journal and can track our users through the Library of Congress. This past year (2022), we had over 1.8 million different unique user IP addresses visit the journal and had over 3.2 million article downloads. While that data comes directly from NLM, we also have seen roughly another 250,000 downloads from our own website, the Scholastica portal, Crossref, and Portico, which is our archiving portal for article/manuscript retention. Our manuscript submissions continue to climb each year. So, we know that we are making a difference worldwide.

Internally, IJSPT is committed to the highest publication ethics and subscribed to the best practice and guidelines of the Committee on Publication Ethics (COPE). COPE is committed to educating and supporting editors, publishers, universities, research institutes, and all those involved in publication ethics to move the culture of publishing towards one where ethical practice become a normal part of the culture itself. We also subscribe to the best practice guidelines from the International committee of Medical Journal Editors (IJCME).

Additionally, IJSPT is a member of the Directory of Open Access Journals (DOAJ). In 2022, IJSPT completed a comprehensive process with the Directory of Open Access Journals, and we were not only approved by DOAJ – but also given the “Gold Medal” seal for our processes. This recognition is a good external validation of our internal processing and policies. The DOAJ Gold Seal is awarded to journals that demonstrate best practice in open access publishing. Around 10% of journals indexed in DOAJ have been awarded the Seal. While already

EDITORIAL
WE ARE READY FOR 2024!

Michael L. Voight, PT, DHSc, OCS, SCS, ATC, CSCS
Belmont University
Executive Editor/Publisher
indexed with PubMed and the National Library of Medicine, in the fall of 2022, IJSPT was added to both the SCOPUS and SCIMAGO indexing for journals.

We've been able to offer Journal Club, Grand Rounds and webinars in cooperation with our sponsors. These free events are open to anyone who participate...just register in advance.

We've packed a lot into three years (during which we experienced a pandemic, at that!) and now we are ready to take the next step up: beginning on January 1, 2024, the IJSPT will become a monthly publication!

This is an exciting change, one we've worked for over many years. This means more open access articles, delivered straight to your inbox, every month.

This also means we want your best work! Submit today...our portal is open 24/7 at https://ijspt.scholasticahq.com/for-authors. Should you have any questions or concerns, please email Ashley Campbell at acampbell@ijspt.org.

We also have space for sponsors and advertisers at many levels. Meet your market in the IJSPT! Contact Mary Wilkinson at mwilkinson@ijspt.org. You may also view costs and our publication calendar at https://ijspt.org/advertising/.

Thank you for your readership in 2023, and we look forward to sharing everything new with you each month in 2024!

All the Best,

Michael Voight
Editor in Chief
IJSPT
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!

**Title Sponsor**

**Marketing Partner**

**Supported by**
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 an official journal of the International Federation of Sports Physical Therapy (IFSP). Countries with access to IJSPT as a member benefit. Reach us at www.ifsp.org.

IJSPT is an official journal of the ICCUS Society for Sports Rehabilitation. www.iccus.org

ISSN 2159-2896
Introducing PiezoWave²T

FASTER. SMARTER. LIGHTER.
The Best Rehab Technology Just Got Better

Controlling Pain. Restoring Motion.
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.

Learn more about our Sports Medicine Solutions
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.

DOWNLOAD:
How TRAZER Works

Aligned at the point where biology, technology, and data intersect.

WATCH:
TRAZER in Action

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, Tennesse, USA

Turner A. "Tab" Blackburn, APTA Life Member,
ATC-Ret, AOSSM-Ret
NASM
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
Bellarmine University
Louisville, KY, USA

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

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

Duane Button, PhD
Memorial University
St. 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
Zurich, Switzerland

Todd Ellenbecker
Rehab Plus
Phoenix, AZ, USA

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

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

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

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

Maggie Gebhardt, PT
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

Martin Hagglund, PT PhD
Linkoping University
Linkoping, Sweden

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

Richard Hawkins, MD
Professor of surgery, University of South Carolina
Adjunct Professor, Clemson University
Principal, Steadman Hawkins, Greenville and Denver (CU)

John D. Heick, PT, PhD, DPT, OCS, NCS, SCS
Northern Arizona University
Flagstaff, AZ, USA

Tim Hewett, PhD
Hewett Consulting
Minneapolis, Minnesota, USA

Per Holmich, MD
Copenhagen University Hospital
Copenhagen, Denmark

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

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

Jon Karlsson, MD
Sahlgrenska University
Goteborg, Sweden

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

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

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

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

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

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

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

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

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

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

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

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

Mal McHugh, PhD
NISMAT
New York, NY, USA

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

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

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

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

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

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

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

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

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

Kevin Plancher, MD, MPH, FAAOS
Plancher Orthopedics and Sports Medicine
New York, NY USA

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

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

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

## VOLUME 18, NUMBER 6

<table>
<thead>
<tr>
<th>PAGE</th>
<th>TITLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>92</td>
<td><strong>EDITORIAL</strong></td>
</tr>
<tr>
<td></td>
<td>We are Ready for 2024!</td>
</tr>
<tr>
<td>Voight M.</td>
<td></td>
</tr>
<tr>
<td>1257</td>
<td><strong>INTERNATIONAL PERSPECTIVE</strong></td>
</tr>
<tr>
<td></td>
<td>Do the International Competencies of the Sports Physical Therapist need Updating?</td>
</tr>
<tr>
<td>Verschueren J, Constantinou M.</td>
<td></td>
</tr>
<tr>
<td>1260</td>
<td><strong>ORIGINAL RESEARCH</strong></td>
</tr>
<tr>
<td></td>
<td>Which Tests Predict 6-Month Isokinetic Quadriceps Strength After ACL Reconstruction? An Examination of Isometric Quadriceps Strength and Functional Tests at 3 Months.</td>
</tr>
<tr>
<td>Giampetruzzi N, Weaver A, Roman DP, et al.</td>
<td></td>
</tr>
<tr>
<td>1271</td>
<td></td>
</tr>
<tr>
<td>1283</td>
<td></td>
</tr>
<tr>
<td>Mylonas V, Chalitsios C, Nikodēs T.</td>
<td></td>
</tr>
<tr>
<td>1290</td>
<td></td>
</tr>
<tr>
<td>Soga T, Yamaguchi S, Inami T, et al.</td>
<td></td>
</tr>
<tr>
<td>1299</td>
<td></td>
</tr>
<tr>
<td>1306</td>
<td></td>
</tr>
<tr>
<td>Yousufy U, Chimera NJ.</td>
<td></td>
</tr>
<tr>
<td>1315</td>
<td></td>
</tr>
<tr>
<td>1321</td>
<td></td>
</tr>
<tr>
<td>1356</td>
<td></td>
</tr>
<tr>
<td>Williams CL, Falyar CR, McConnell RC et al.</td>
<td></td>
</tr>
<tr>
<td>1364</td>
<td><strong>CLINICAL COMMENTARY</strong></td>
</tr>
<tr>
<td></td>
<td>Neurocognitive and Reactive Return to Play Testing Protocol in Overhead Athletes Following Upper Extremity Injury.</td>
</tr>
<tr>
<td>1364</td>
<td><strong>MSK ULTRASOUND BITES: TIPS &amp; TRICKS</strong></td>
</tr>
<tr>
<td></td>
<td>Utilizing MSK Ultrasound for Comprehensive Assessment of the Femoral Trochlea: A Game Changer in Sports Medicine.</td>
</tr>
<tr>
<td>Manske RC, Voight M, Page P, Wolfe C.</td>
<td></td>
</tr>
<tr>
<td>1366</td>
<td><strong>DIGITAL HEALTH CORNER</strong></td>
</tr>
<tr>
<td></td>
<td>Utilizing MSK Ultrasound for Comprehensive Assessment of the Femoral Trochlea: A Game Changer in Sports Medicine.</td>
</tr>
<tr>
<td>Gobezie, R.</td>
<td></td>
</tr>
</tbody>
</table>
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

Drive revenue through remote monitoring
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
- 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

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
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

**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

**EDUCATIONAL PARTNER**

IJSPT

INTERNATIONAL JOURNAL OF SPORTS PHYSICAL THERAPY
Dear Reader...

It's hard to believe we are now wrapping up our eighteenth year at *IJSPT*. We've made a lot of changes over these years!

The first was the move to a digital publication in 2009. The second was a change of name from the *North American Journal of Sports Physical Therapy* (NAJSPT) to the *International Journal of Sports Physical Therapy* (IJSPT) in 2011, to emphasize with our alliance with the International Federation of Sports Physical Therapy. During this time, the journal also grew from 5 to 10 and then to 15 articles per issue.

In 2020, the American Academy of Sports Physical Therapy (AASPT) decided to cease publication of the *IJSPT*, beginning in 2021. As the sitting Editor in Chief and NAJSPT/IJSPT Board Member since its inception, I did not want to see this stellar journal die. So a business I am a partner in, North American Sports Medicine Institute, took over the publication of the IJSPT.

This effort was brought to fruition quickly with the help of former Senior Editor Barb Hoogenboom, who moved into the Editor-in-Chief position; Ashley Campbell, former board member, became our Managing Editor; and Mary Wilkinson, our former Managing Editor moved into the Executive Director position. Casey Lewis is our Manuscript Editor, and many of our long time board members, such as Phil Page, Kevin Wilk, Terry Grindstaff, and Rob Manske, pledged to continue their support of the IJSPT.

Since the first February 2021 issue, the IJSPT has continued to grow, featuring as many as thirty articles in a single issue. The journal is indexed in PubMed / Library of Congress and is also an Official Publication of the International Federation of Sports Physical Therapy (which has 40 member countries around the world), ICCUS, and AASPT. We presently have a circulation of about 28,000 PT’s – but this is growing monthly, and we have expanded into the Sports MD (AOSSM), ATC and Chiropractic professions. Our goal is to grow the subscription list to over 50,000 within the next couple of years. Having said that, we are a “Gold open access” journal and can track our users through the Library of Congress. This past year (2022), we had over 1.8 million different unique user IP addresses visit the journal and had over 3.2 million article downloads. While that data comes directly from NLM, we also have seen roughly another 250,000 downloads from our own website, the Scholastica portal, Crossref, and Portico, which is our archiving portal for article/manuscript retention. Our manuscript submissions continue to climb each year. So, we know that we are making a difference worldwide.

Internally, *IJSPT* is committed to the highest publication ethics and subscribed to the best practice and guidelines of the Committee on Publication Ethics (COPE). COPE is committed to educating and supporting editors, publishers, universities, research institutes, and all those involved in publication ethics to move the culture of publishing towards one where ethical practice become a normal part of the culture itself. We also subscribe to the best practice guidelines from the International committee of Medical Journal Editors (IJCME)

Additionally, *IJSPT* is a member of the Directory of Open Access Journals (DOAJ). In 2022, IJSPT completed a comprehensive process with the Directory of Open Access Journals, and we were not only approved by DOAJ – but also given the “Gold Medal” seal for our processes. This recognition is a good external validation of our internal processing and policies. The DOAJ Gold Seal is awarded to journals that demonstrate best practice in open access publishing. Around 10% of journals indexed in DOAJ have been awarded the Seal. While already
indexed with PubMed and the National Library of Medicine, in the fall of 2022, *IJSPT* was added to both the SCOPUS and SCIMAGO indexing for journals.

We’ve been able to offer Journal Club, Grand Rounds and webinars in cooperation with our sponsors. These free events are open to anyone who participate...just register in advance.

We’ve packed a lot into three years (during which we experienced a pandemic, at that!) and now we are ready to take the next step up: **beginning on January 1, 2024, the *IJSPT* will become a monthly publication!**

This is an exciting change, one we’ve worked for over many years. This means more open access articles, delivered straight to your inbox, every month.

This also means we want your best work! Submit today...our portal is open 24/7 at https://ijspt.scholasticahq.com/for-authors. Should you have any questions or concerns, please email Ashley Campbell at acampbell@ijspt.org.

We also have space for sponsors and advertisers at many levels. Meet your market in the *IJSPT*! Contact Mary Wilkinson at mwilkinson@ijspt.org. You may also view costs and our publication calendar at https://ijspt.org/advertising/.

Thank you for your readership in 2023, and we look forward to sharing everything new with you each month in 2024!

All the Best,

Michael Voight
Editor in Chief
*IJSPT*
Can you remember what you were doing on your birthday in 2005?

A simple question can take you a long way back. A lot can change since then.

In 2005, the International Federation of Sports Physical Therapy (IFSPT) published the Sports Physiotherapy for All project (SPA) which defined four key roles and eleven competencies a sports physical therapist should have, setting the standards for international education ever since. The aim of this international perspective is to reflect on the IFSPT competencies of a sports physical therapist and explore the need for an update.

The SPA project defined a sports physical therapist as a health care expert practicing at a Master’s level and having “extensive knowledge and skills that demonstrate critical reasoning, flexibility, creativity, independence and leadership” as described by the Scottish Credit and Qualifications Framework Level 11. The SPA project identified the eleven competencies of a sports physical therapist as injury prevention, acute intervention, rehabilitation, performance enhancement, promotion of safe active lifestyle, lifelong learning, professionalism and management, research involvement, dissemination of best practice, extending practice through innovation and promotion of fair play and anti-doping practices. Across all identified competencies, the sports physical therapist uses an evidence-based approach and embodies the values of professionalism and ethical practice in caring for “athletes of all ages and abilities, while ensuring a high standard of professional and ethical practice.”

This international competency profile was implemented in many national health care systems, has inspired many professional, academic and life-long learning educational programmes and guided international sporting organizations in defining the roles and responsibilities of sports physical therapists in high performance environments.

So let’s hope a lot of good things have happened to you since 2005.

However, like most good things, they do not come without challenges. We would like to take the opportunity to share some of the existing challenges for the global sports physical therapist community and see how we might turn these into good things together.

As a healthcare specialist, sports physical therapists should be aware of international perspectives on health care and reflect on how these affect their specific role. However, there is diversity in different education and health services globally. The CANMEDS framework, an internationally referenced competency-based model, describes the roles and competencies of healthcare professionals, specifying seven roles that should align with sports physical therapists’ roles. The International Olympic Committee Medical Commission provides guidelines for the roles and responsibilities of sports medicine professionals, including sports physical therapists. Similarly, the World Physiotherapy Education Framework provides a comprehensive and flexible approach to physiotherapy education, including an important focus on the global perspective, technology and life-long learning. While the World Health Organization (WHO) describes the importance of physical activity and health inequities, with wide disparities in the health status of different social groups. The WHO is also counting on all sports physical therapists and healthcare professionals.
professionals to tackle the most important health challenges ahead and to continue to promote physical activity as an important part of a safe and active lifestyle. All together, these international perspectives urge us to reflect on our current sports physical therapy competency profile accepted in 2005 and consider how this should evolve to meet contemporary needs.

From the clinical perspective, sports physical therapists are faced with the challenge of staying up to date with the latest evidence and developments in their field in order to provide the best quality care to their patients. This includes staying current on injury-specific rehabilitation, injury prevention and return-to-sport protocols, as well as advancements in movement analysis, motor control, and performance. With new research being published regularly, sports physical therapists must continuously review and critically evaluate the latest evidence to apply in their clinical practice. In addition, they must be willing to reflect and adapt their approach based on new findings. While evidence is growing, exposing the end-user to new perspectives on load, performance, health and well-being, we remain challenged, as health professionals, to design tailored strategies for monitoring and protecting the health of our athletes and patients. A growing body of evidence highlights the importance of the cultural component in patient-centered care, whereas pain science provokes us to discuss “cure versus care,” all the while respecting a growing complexity in ethics in sports. Within this growing complexity, should we differentiate between the sports physical therapist in a clinical environment and the sports physical therapist on the field of play? In their role as managers and communicators, sports physical therapists should show leadership skills, towards patients and athletes, individually and in a team.

So, which competencies still define a sports physical therapist, and how can these competencies protect both the athlete and the physical therapist?

We all share the passion for sports physical therapy. We are all proud to be part of the global sports physical therapy community and the IFSPT, which continues to engage its member organizations in developing the sports physical therapy competencies together.

It is now time to update the competencies of a sports physical therapist to ensure contemporary practice. The IFSPT will be organising a new Delphi study and focus groups or interviews with stakeholders to facilitate an updated set of competencies for the sports physical therapist. Having an updated standard of competence to aspire to, physical therapists, globally, will have a possible career pathway to aim for.

References:


Original Research

Which Tests Predict 6-Month Isokinetic Quadriceps Strength After ACL Reconstruction? An Examination of Isometric Quadriceps Strength and Functional Tests at 3 Months

Nicholas Giampetruzzi1, Adam P Weaver1, Dylan P Roman1, Joshua A Cleland2, Brandon M Ness2
1 Sports Physical Therapy, Connecticut Children’s Medical Center, 2 Doctor of Physical Therapy Program, Tufts University

Keywords: anterior cruciate ligament, anterior cruciate ligament reconstruction, adolescent, quadriceps strength, rehabilitation

https://doi.org/10.26603/001c.89263

International Journal of Sports Physical Therapy

Background
Restoration of quadriceps strength after anterior ligament reconstruction (ACLR) is a persistent challenge for patients and clinicians. Inadequate recovery of quadriceps strength has been linked to increase risk of re-injury. Developing methods of early identification of strength deficits is essential to allow clinicians to provide more individualized interventions early in the rehabilitation process.

Purpose
To determine whether 3-month isometric quadriceps strength, the Y-Balance Test (YBT), and the anterior step-down test are predictive of isokinetic quadriceps strength at six months in adolescents after ACLR.

Design
Retrospective cohort

Methods
Thirty-six adolescent patients with primary ACLR (58% female, 36% with concomitant meniscal repair, age: 15.7 ± 1.6 years). At three months post-operative, isometric quadriceps strength via isokinetic dynamometer, YBT-Lower Quarter, and anterior step-down tests were completed. At six months post-operative, an isokinetic knee strength assessment was completed. Regression analysis was used to evaluate the predictive relationship between 3-month isometric tests and 6-month isokinetic knee extension tests.

Results
Three-month post operative isometric quadriceps peak torque predicted isokinetic quadriceps peak torque at 6 months, F(1,34) = 19.61, p <0.001. Three-month isometric quadriceps peak torque accounted for 36.6% of the variance in normalized isokinetic quadriceps peak torque at 6 months with adjusted R² = 34.7%. Including YBT anterior reach (β = 0.157, p = 0.318) in regression added 1.9% of variance when predicting 6-month isokinetic quadriceps peak torque, F (2,33) = 10.32, p <0.001, R² = 0.385, ΔR² = 0.019.
Conclusion
At three months post-ACLR, isometric strength testing appears more optimal than other functional tests in predicting isokinetic quadriceps peak torque in later stages of rehabilitation for adolescents. Clinicians should use tests at three months that measure quadriceps strength if aiming to predict isokinetic quadriceps peak torque at six months post-ACLR, rather than using functional tests such as the YBT-LQ or anterior step-down.

Level of Evidence
Level 3

INTRODUCTION
One of the primary rehabilitation goals after anterior cruciate ligament reconstruction (ACLR) is to restore quadriceps strength. Quadriceps strength after ACLR typically improves over time, yet strength deficits can exceed 20% at six months post-ACLR and these deficits may last even longer. This is crucial, as limitations in quadriceps strength after ACLR have been linked to anterior cruciate ligament (ACL) re-injury, altered running and landing biomechanics, poor self-reported outcomes and post-traumatic osteoarthritis. Functionally, quadriceps strength plays an important role in running and hopping tasks and persistent quadriceps weakness can lead to alterations in movement patterns up to two years after ACLR.

Obtaining valid, reliable strength measurements during ACLR rehabilitation provides valuable feedback on patient progress and is used in clinical decision making for return to activity/sport. Several options exist for objective strength assessment after ACLR including isometric dynamometry or handheld dynamometry, repetition-maximum testing, or isokinetic dynamometry. The current gold standard device for quadriceps strength testing is an isokinetic dynamometer. In instances where access to an isokinetic dynamometer is limited, isometric dynamometry can be performed using devices that are offer increased clinical accessibility (i.e., cost, space) while maintaining acceptable levels of validity and reliability. Gaining further insight into isometric quadriceps strength in adolescents would be valuable, given the wide reaching impact of quadriceps strength on patient outcomes after ACLR.

The timing of clinical measures, including knee strength testing, can vary after ACLR due to factors such as graft type, however, early strength measures appear to be an indicator of late strength outcomes (i.e., time of return to play). Hannon et al. reported isokinetic quadriceps peak torque 12 weeks postoperatively was a strong predictor (47% of the variance) of isokinetic quadriceps peak torque at time of return to play in adolescent athletes following primary bone-patellar tendon-bone autograft ACLR. Similarly, the isokinetic quadriceps peak torque limb symmetry index at three months postoperatively predicted nearly 55% of the variance for the same measure at six months in young adults following primary ACLR with hamstring autograft. It is currently unknown whether early isometric quadriceps strength is associated with isokinetic late-stage quadriceps strength in adolescents after ACLR.

It would be incorrect to assume that most clinicians are using a handheld or isokinetic dynamometer to evaluate knee strength after ACLR. Recent trends in knee strength assessment after ACLR among physical therapists have been somewhat concerning. In a survey of those making return to sport decisions, 80.6% of respondents indicated using manual muscle testing results to make decisions to initiate jogging and modified sports activity. Further, 56.1% of respondents reported using manual muscle testing as the only method of strength assessment. In the absence of using a device to objectively assess isolated quadriceps strength after ACLR, clinicians will at times utilize other functional tests as a proxy for strength assessment. However, it must be recognized that such tests may not accurately measure maximum strength of a specific muscle or group, but rather reflect a different construct or require contributions from other muscle groups. Two such tests include the Y-Balance Test (YBT) and the anterior step-down test, which can often be performed at three months post-ACLR. The YBT is used to measure single limb dynamic balance, where asymmetries of greater than four centimeters have been shown to identify those individuals after ACLR that were unable to achieve 90% or greater limb symmetry on hop tests, as well as correlate to higher scores on patient-reported outcomes. Finally, the anterior step-down test has been linked to patient reported outcomes and running, and has a stronger relationship to knee mechanics and patient-reported knee function than the YBT. It has yet to be determined whether early performance on the YBT and/or anterior step-down test have an association with late-stage quadriceps strength after ACLR.

It appears that early isokinetic quadriceps strength measures have predictive value for determining late-stage isokinetic quadriceps strength. However, it is unknown if early isometric strength and other functional measures are predictive of late-stage isokinetic quadriceps strength in adolescents. Therefore, the purpose of this study was to determine whether 3-month isometric quadriceps strength, YBT, and the anterior step-down test are predictive of isokinetic quadriceps strength at six months in adolescents after ACLR. It was hypothesized that isometric quadriceps strength at 3-months would be a better predictor of isokinetic strength at six months when compared to the YBT and the anterior step-down test.

METHODS

DESIGN
This study was approved by the Institutional Review Board at Connecticut Children’s. A retrospective chart review of
patients undergoing ACLR at the organization between January 2015 and November 2021 was performed. Information pertaining to demographics, surgical procedure, and clinical outcome measures were collected. Only those patients with a full data set were included in the study.

**PATIENTS**

To be eligible for this study, patients had to satisfy the following inclusion criteria: 1) were 12-18 years of age when surgery was performed, 2) had undergone primary ACLR using hamstring autograft, with or without meniscal injury, and 3) had completed the organization’s standard testing procedures in full at both "early-stage" testing as well as "late-stage" testing post-operatively. "Early-stage" was defined as two to four months (60-122 days) while "late-stage" was defined as 5.6-9.6 months (171-294 days) post-operatively. The gap of nearly two months between early- and late-stage testing was chosen with the aim to create more distinct testing timeframes, as it was reported that it may take upwards of two months to observe clinically meaningful quadriceps strength gains after ACLR.¹

Patients undergoing concurrent meniscus repair, chondroplasty, or anterolateral ligament reconstruction were eligible. Patients were included if they completed strength testing at both rehabilitation time points and complete data was available for all outcomes of interest. Patients were excluded if they underwent bony deformity correction surgery, multi-ligament reconstruction, ACL revision, posterolateral corner reconstruction, or experienced post-operative complications (re-injury, arthrofibrosis or nerve injury). Demographic data including age, height, mass, and sex, at time of surgery were extracted. Surgical procedure information including ACLR surgical technique, and concomitant pathology were also recorded.

Patients treated by five different orthopedic sports medicine surgeons at Connecticut Children’s and patients completing physical therapy at Connecticut Children’s were included in this sample. All patients were provided with a standardized postoperative rehabilitation protocol (Appendix A) with recommendations for attaining supervised rehabilitation. Patients attended physical therapy at a variety of locations, both within and independent of the host organization. All clinical tests were completed at Connecticut Children’s.

**EARLY-STAGE 3-MONTH TESTING**

All patients undergoing ACLR at Connecticut Children’s were scheduled for a follow up examination with the orthopedic surgeon at approximately three months following ACLR. At this time, a battery of tests and measures were completed to assess the patient’s progress. This included range of motion (hip, knee, and ankle), isometric strength (knee extension, knee flexion, hip extension), dynamic balance (YBT Lower Quarter), functional testing (anterior step down and single-leg bridge), and patient reported outcome measures (Pedi International Knee Documentation Committee Subjective Knee Evaluation Form and Anterior Cruciate Ligament Return to Sport after Injury). All testing was performed and evaluated by a Connecticut Children’s sports physical therapist.

The YBT Lower Quarter (YBT-LQ) (Functional Movement System, Chatham, VA) has shown to be reliable when measuring dynamic balance in adolescent athletes.²³ Patients were instructed to stand on the center footplate barefoot with the distal tip of the tested foot at the marked starting line. Patients maintained single leg stance while reaching with the free limb in the anterior, posteromedial, and posterolateral directions by pushing the indicator box as far as possible. Three practice trials were performed prior to administration of three test trials on each limb. Three successful test trials were recorded in each direction. A trial was deemed unsuccessful if the patient did one or more of the following: kicking the indicator box, not returning to the starting position under control, touching down with upper or lower extremities during reach, or placing their foot on top of the indicator box. The uninjured limb was tested first, followed by the involved lower limb. The mean distance of the three recorded trials in each direction, normalized to height, were used for analysis.

Patients began the anterior step-down test ²² by standing on a firm 12-inch step without shoes. They were instructed to attain single leg stance on the test limb and descend with their free limb lowering towards a 1.5-inch scale on top of a 1.5-inch box positioned anterior to the step. A successful trial was tallied if the patient contacted the scale with their heel without transferring more than 10% of their body mass onto the scale. Patients completed as many repetitions as possible in 60 seconds. Repetitions were excluded if the patient did not contact the scale, exceeded 10% of body mass transfer, or failed to return to the starting position. The uninjured limb was tested prior to the involved limb.

Isometric quadriceps peak torque was evaluated using an isokinetic dynamometer (Humac CSMI USA, Stoughton, MA, USA). Patients were positioned in sitting with 90 degrees of hip flexion, their trunk and thigh supported with straps, and dynamometer arm secured proximal to the ankle joint. Isometric peak torque was measured with the knee joint positioned at 60 degrees of knee flexion. After one practice trial, patients performed three maximal effort test trials lasting five seconds each with five seconds of rest between each trial. Verbal encouragement was provided throughout the test to encourage maximal effort. The highest peak torque measurement was recorded in newton-meters (Nm) and normalized to the patient’s body mass (Nm/kg). The uninjured limb’s quadriceps and hamstring strength were tested first, followed by the involved limb. Patients were given verbal encouragement throughout the test to provide maximal effort. Using an isokinetic dynamometer in this manner has been shown to be a reliable method to quantify quadriceps and hamstring torque in adults²⁴,²⁵ and children.²⁶

**LATE-STAGE 6-MONTH TESTING**

The organizational standard for a late-stage testing battery included knee range of motion, KT1000 arthrometer, isometric and isokinetic knee strength, single-leg hop tests, drop vertical jump assessment, and other functional metrics.

*International Journal of Sports Physical Therapy*
strength measures. Of these late-stage tests, only the isokinetic knee strength measurements were included for analysis in this study.

Isokinetic knee strength testing replicated the initial set up as previously described for early-stage isometric knee strength testing. Isokinetic quadriiceps and hamstring torque was assessed through a knee range of motion from 0–90 degrees with gravity correction applied.27 A practice trial of two repetitions and a testing trial of five repetitions were completed at 60°/sec, with 10 seconds of rest between trials. Patients were provided with verbal encouragement to provide maximal effort through the full knee range of motion. The highest peak torque measurement of the testing trial was recorded in newton-meters (Nm) and normalized to the patient's body mass (Nm/kg). The uninjured limb's quadriiceps and hamstring strength were measured first, followed by the involved limb. Patients were given verbal encouragement throughout the test to provide maximal effort.

STATISTICAL ANALYSIS

Descriptive statistics were calculated for demographic and all outcome data for the involved lower limb including normalized quadriiceps peak torque, normalized YBT-LQ reach distance, and the number of anterior step-down repetitions. Pearson-product-moment correlation coefficients were calculated between outcomes. Of the 3-month clinical measures that were shown to be significantly correlated with 6-month isokinetic quadriiceps peak torque, a regression analysis was used to evaluate their predictive value. Hence, a hierarchical regression analysis was used to evaluate the predictive relationship between 3-month isometric quadriiceps peak torque and 6-month isokinetic quadriiceps peak torque (step 1). Then, normalized YBT-LQ anterior reach was added in step two of the regression. Data were assessed for violations of the assumptions for regression analysis at each step including independence of residuals, linearity, homoscedasticity, and multicollinearity. Visual inspection of histograms and normal predicted probability (P–P) plots revealed normal distribution of the standardized residuals. Alpha level was set to 0.05. SPSS version 26.0 (IBM Corp, Armonk, NY, USA) was used to conduct the statistical analyses.

RESULTS

Thirty-six patients were included in the study (58% female, 36% with concomitant medial and/or lateral meniscal repair, age: 15.7 ± 1.6 years, height: 168.2 ± 9.6 cm, mass: 65.1 ± 15.6 kg). Descriptive statistics are presented in Table 1.

A significant positive correlation was identified between 3-month isometric quadriiceps peak torque and 6-month isokinetic quadriiceps peak torque (r = 0.605, p < 0.01), in addition to YBT-LQ anterior reach and 6-month isokinetic quadriiceps peak torque (r = 0.405, p < 0.05) (Table 2). No other clinical measures had significant correlation with 6-month isokinetic quadriiceps peak torque, thus were not included in the regression.

The regression analysis (Table 3) revealed 3-month isometric quadriiceps peak torque significantly predicted isokinetic quadriiceps peak torque at 6 months, F(1,54) = 19.61, p <0.001. Three-month isometric quadriiceps peak torque accounted for 36.6% of the variance in normalized isokinetic quadriiceps peak torque at 6 months with adjusted R² = 34.7%. In the second step when YBT-LQ anterior reach (β = 0.157, p = 0.318) was included in the regression, this added only 1.9% of variance when predicting 6-month isokinetic quadriiceps peak torque, F(2,53) = 10.32, p <0.001, R² = 0.385, ΔR² = 0.019.

DISCUSSION

The purpose of this study was to determine whether 3-month isometric quadriiceps strength, YBT, and the anterior step-down test were predictive of isokinetic quadriiceps strength in adolescents six months after ACLR. Normalized isometric quadriiceps peak torque and YBT-LQ anterior reach during early-stage testing were significantly associated with normalized isokinetic quadriiceps peak torque during late-stage testing. Early-stage isometric quadriiceps peak torque accounted for 36.6% of the variance in isokinetic quadriiceps peak torque during late-stage testing, while YBT-LQ anterior reach only added an additional 1.9% of variance. No significant correlations were observed between YBT-LQ posterolateral reach, posteromedicalial, or anterior step-down relative to 6-month isokinetic quadriiceps peak torque.

In comparison to the current findings, Hannon et al17 reported isokinetic quadriiceps peak torque at 12 weeks post-ACLR accounted for greater variance (47%) in the same measure at time of return to sport. Although their study population was similar in age (16.1 ± 1.4 years) and gender distribution (54% female), a bone–patellar tendon–bone autograft was used and return to sport testing occurred later (7.3 ± 1.3 months). Additionally, Mitomo et al18 examined the three- and six-month limb symmetry index of isokinetic quadriiceps peak torque in young adults following primary ACLR with hamstring autograft. Despite the current study's examination of normalized quadriiceps peak torque, three-month isokinetic quadriiceps limb symmetry index accounted for a similar level of variance (34.9%) in limb symmetry index at six months, comparatively.18 While limb symmetry indices are commonly used to establish desired performance thresholds after ACLR, the uninjured limb may experience deterioration in function leading to an overestimation of strength and function for the injured limb.28–30 It has also been reported that isometric quadriiceps strength, when normalized to body mass, was a better predictor of high self-reported function (subjective International Knee Documentation Committee index > 90%) after ACLR when compared to the quadriiceps strength limb symmetry index.31 Hence, it would seem plausible to advocate for reporting torque measurements normalized to body mass in future investigations.

The three-month functional tests included in the study were the YBT-LQ and anterior step-down test. The only functional test that had significant correlation with six-
Table 1. Descriptive Statistics for 3- and 6-Month Testing after ACL Reconstruction

<table>
<thead>
<tr>
<th></th>
<th>3-month testing timeframe (days since surgery)</th>
<th>6-month testing timeframe (days since surgery)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>92.8 ± 10.7 (89.2, 96.4)</td>
<td>197.6 ± 26.5 (188.6, 206.6)</td>
</tr>
<tr>
<td>Isometric quadriceps peak torque – Involved (Nm)</td>
<td>109.5 ± 31.8 (98.8, 120.3)</td>
<td>116.3 ± 33.8 (104.9, 127.7)</td>
</tr>
<tr>
<td>Normalized to body mass (Nm/kg)</td>
<td>1.71 ± 0.43 (1.56, 1.85)</td>
<td>1.80 ± 0.45 (1.65, 1.96)</td>
</tr>
<tr>
<td>Y-Balance Test Lower Quarter – normalized to height</td>
<td>36.5 ± 4.2 (35.1, 38.0)</td>
<td>22.5 ± 9.9 (19.2, 25.9)</td>
</tr>
<tr>
<td>Anterior reach (cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posteromedial reach (cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterolateral reach (cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior step down (repetitions completed)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Values are expressed as mean ± SD, (95% confidence interval)*

Table 2. Pearson correlations between 3-month clinical measures and 6-month isokinetic quadriceps peak torque

<table>
<thead>
<tr>
<th></th>
<th>6-month normalized isokinetic quadriceps peak torque</th>
<th>3-month normalized isometric quadriceps peak torque</th>
<th>YBT-LQ anterior reach</th>
<th>YBT-LQ posteromedial reach</th>
<th>YBT-LQ posterolateral reach</th>
<th>Anterior step down</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-month normalized isokinetic quadriceps peak torque</td>
<td>--</td>
<td>.605*</td>
<td>.405*</td>
<td>.155</td>
<td>.173</td>
<td>.187</td>
</tr>
<tr>
<td>3-month normalized isometric quadriceps peak torque</td>
<td>.605*</td>
<td>--</td>
<td>.468*</td>
<td>.211</td>
<td>.239</td>
<td>.217</td>
</tr>
<tr>
<td>YBT-LQ anterior reach</td>
<td>.405*</td>
<td>.468*</td>
<td>--</td>
<td>.688*</td>
<td>.571*</td>
<td>.506*</td>
</tr>
<tr>
<td>YBT-LQ posteromedial reach</td>
<td>.155</td>
<td>.211</td>
<td>.688*</td>
<td>--</td>
<td>.831*</td>
<td>.349*</td>
</tr>
<tr>
<td>YBT-LQ posterolateral reach</td>
<td>.173</td>
<td>.239</td>
<td>.571*</td>
<td>.831*</td>
<td>--</td>
<td>.288</td>
</tr>
<tr>
<td>Anterior step down</td>
<td>.187</td>
<td>.217</td>
<td>.506*</td>
<td>.349*</td>
<td>.288</td>
<td>--</td>
</tr>
</tbody>
</table>

YBT-LQ, Y Balance Test Lower Quarter, * with bolded text indicates significant correlation (p < 0.05)

3-month isokinetic quadriceps peak torque was the YBT-LQ anterior reach. The anterior reach task generally requires increased contributions from the quadriceps relative to other reach directions in healthy individuals, but is not always the case. In those recovering from ACL-R, isokinetic quadriceps peak torque on the involved ACL-R limb had the greatest correlation with anterior reach performance (r = 0.591) compared to the posteromedial (r = 0.498) and posterolateral (r = 0.294) reach directions. Moderate correlations of YBT-LQ reach distance and quadriceps peak
Table 3. Hierarchical regression analysis results of 3-month clinical measures relative to 6-month normalized isokinetic quadriceps peak torque

<table>
<thead>
<tr>
<th>Step 1</th>
<th>B (constant)</th>
<th>R²</th>
<th>ΔR²</th>
<th>B</th>
<th>β</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-month normalized isometric quadriceps peak torque</td>
<td>.366</td>
<td>.624</td>
<td>.605</td>
<td>&lt;0.001*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2</td>
<td>.385</td>
<td>0.019</td>
<td>.548</td>
<td>.532</td>
<td>0.002*</td>
<td></td>
</tr>
<tr>
<td>3-month normalized isometric quadriceps peak torque</td>
<td>.017</td>
<td>.157</td>
<td>.318</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

YBT-LQ, Y Balance Test Lower Quarter

Torque may be partially explained by the electromyographic activity of the vastus medialis only reaching 69-79% maximum voluntary isometric contraction (MVIC) in healthy participants during the YBT-LQ during various reach directions. By comparison, although examining the rectus femoris and using a shorter step height (mean of 8.6-9.3 inches), an anterior step-down task required only 12-13% MVIC. Given that the YBT-LQ does not appear to require maximum muscle activation to complete the reaching task, it may partly explain the relatively low amount of variance (1.9%) when YBT-LQ anterior reach was added to the regression to predict 6-month isokinetic quadriceps peak torque. Additionally, both the YBT-LQ and anterior step-down are multi-joint tasks, which may allow for compensations or offloading during these closed chain movements. The study findings suggest the YBT-LQ and anterior step-down are weak predictors of isokinetic quadriceps strength at six months postoperatively.

LIMITATIONS

The retrospective design limits the strength and applicability of the results of this study. The study did not include participant activity/sport level, rates of return to sport after surgery, or secondary injuries. Also, the testing methods used in the study may have impacted isometric quadriceps strength and anterior step-down test outcomes and limit the generalizability of the findings. During maximal strength testing, the limited rest period may not have allowed for full recovery between trials. Further, the knee joint angle for isometric testing was set at 60° using an isokinetic dynamometer, which differs from 90° of knee flexion when using more clinically available devices such as a handheld dynamometer. It should also be noted that isometric strength outcomes may differ between testing devices (i.e., isokinetic versus handheld dynamometry). For the anterior step-down test, the box height used was 12 inches which did not allow for standardized knee flexion angles between patients of different limb lengths. Lastly, the generalizability is limited to adolescent patients who underwent ACLR with a hamstring autograft over a relatively short term (6.5 ± 0.9 months) follow up period.

CONCLUSION

Three-month isometric quadriceps peak torque significantly predicted isokinetic quadriceps peak torque at six months after ACLR in adolescents with hamstring autograft and accounted for 36.6% of the variance. The 3-month functional tests were limited in predictive value, with the YBT-LQ anterior reach only accounting for a small proportion of the variance (1.9%). At three months post-ACLR, isometric strength testing appears to be more appropriate than using other functional tests for predicting isokinetic quadriceps peak torque in later stages of rehabilitation for adolescents. Clinicians should use objective measures of strength at three months if aiming to predict isokinetic quadriceps peak torque at six months post-ACLR, rather than using functional tests such as the YBT-LQ or anterior step-down.

DECLARATIONS OF INTEREST

The authors declare no conflicts of interest.

Submitted: June 05, 2023 CST, Accepted: September 24, 2023 CST
REFERENCES


Appendix 1
REFERENCES


Original Research

Training Load and Current Soreness Predict Future Delayed Onset Muscle Soreness in Collegiate Female Soccer Athletes

Brett S. Pexa1, Christopher J. Johnston2, Jeffrey B Taylor3, Kevin R. Ford4

1 Athletic Training, High Point University, 2 Beaufort County School District, 3 Physical Therapy, High Point University, 4 School of Health Sciences, High Point University

Keywords: Soccer, Soreness, Training Load, Wearable

https://doi.org/10.26603/001c.89890

International Journal of Sports Physical Therapy

Background

Delayed onset muscles soreness (DOMS) is an indication of muscle stress and trauma that develops from excessive musculoskeletal loads. Musculoskeletal loads can be measured with wearable devices, but there is limited research on specific training load metrics that most correlate with DOMS after activity.

Purpose

To determine the predictive capabilities of training load variables on the development of lower extremity DOMS in female collegiate soccer athletes throughout an entire season.

Study Design

Prospective Cohort

Methods

Twenty-seven collegiate female soccer athletes reported their lower extremity DOMS each day prior to all soccer activity. Participants wore Polar heart rate and global positioning monitors to capture training load measures. Pearson correlation coefficients were used to assess the relationships between the training load variables and change in DOMS when collapsed across dates. Separate linear mixed models were performed with the following day’s DOMS as the outcome variable, training load and the current day’s DOMS as predictor variables, and participants serving as random intercepts.

Results

All training load variables significantly predicted change in DOMS, with number of decelerations (p=0.72, p <0.001), minutes spent at greater than 80% of maximum heart rate (HRmax) (p=0.71 , p <0.001), and distance (p=0.70 , p <0.001) best correlating with change in DOMS. Linear mixed models revealed a significant interaction of all training load and current day’s DOMS on the following day’s DOMS (p<0.001), but number of decelerations, HRmax, and total number of accelerations demonstrated the highest coefficient of determination (R^2 marginal=33.2% - 29.2%, R^2 conditional= 46.9% - 44.8%).

Corresponding Author:
Brett S. Pexa PhD, ATC, LAT
Assistant Professor
Department of Athletic Training
Congdon School of Health Sciences
High Point University
High Point, NC, 27268
612-269-2428
bpexa@highpoint.edu

1 Pexa BS, Johnston CJ, Taylor JB, Ford KR. Training Load and Current Soreness Predict Future Delayed Onset Muscle Soreness in Collegiate Female Soccer Athletes. IJSPT. Published online December 1, 2023:1271-1282. doi:10.26603/001c.89890
Conclusions
Training load variables paired with the current day’s DOMS significantly predict lower extremity DOMS in the future, with number of decelerations, accelerations, and HRmax best predicting future DOMS. Although this demonstrates that training load variables predict lower extremity DOMS, future research should incorporate objective measures of strength or jump kinetics to identify if similar relationships exist.

Level of Evidence
Level 3

INTRODUCTION
Soccer activity leads to significant amounts of lower extremity injury,1 pain, and delayed onset muscle soreness (DOMS).2 Despite these negative aspects of training, consistent and appropriately prescribed training will create positive adaptations to enhance sport performance.3 To minimize the negative aspects of training, clinicians have begun relying on wearable devices to capture internal and external training loads.4–7 These measures aid in predicting injury1,6–8 and performance capabilities,5 in addition to having impacts on athlete wellness measures.9–11 Tracking training loads is now extremely clinically feasible,4,12,13 however, there are numerous methods of tracking training loads, such as global positioning systems,10,12,14 heart rate monitors,6,15,16 and accelerometers.12 Additionally, these devices create many different training load outcome measures,8 such as heart rate, distances, velocities, accelerations, and all the banded derivatives of these measures, such as heart rate zones, speed zones, or acceleration intensities.17,18 These different combinations may cause confusion among sport stakeholders on which measures may be most beneficial to ensure their athletes are training and competing without excessively overloading tissue(s).14

By tracking training loads, sport stakeholders aim to identify the early development of injury and create data informed rest and recovery decisions. After training and competition, athletes experience decreased lower extremity force production,19,20 altered mental state,9,10 and increased reports of pain and DOMS.21 With appropriate rest and recovery, the body returns to homeostasis,2,19,21 eventually making positive adaptations that contribute to an athlete’s injury resilience.3 However, in competitive sport with high competition demand, such as American collegiate athletics, athletes often partake in high intensity activities before the body has completely recovered. Participating in competition or training with negative changes present may create additional musculoskeletal stress and trauma,22–24 culminating in an athlete who must remove themselves from play due to inability to compete without pain and/or dysfunction. Additionally, significant muscular stress and trauma could lead to lower force and power output and altered movement biomechanics,25 thus placing collegiate athletes at further risk for lower extremity injury.26 Therefore, it would be imperative to measure the dose of activity, via training load outcomes,27 and pair it with the response to activity, such as strength,21 wellness variables,9,10 or musculoskeletal DOMS.2,28,29 Delayed onset muscle soreness and force production demonstrate similar negative changes after activity2,30,31 for up to 72 hours after strenuous exercise,2,30,32 so DOMS could be used as an indicator of muscle stress, trauma, and fatigue. Since DOMS can reflect the fatigue and underlying structural changes, then it may also provide insight into alterations in strength output and movement biomechanics,25 which place collegiate athletes at risk for lower extremity injury.26

Sport stakeholders are looking for training load collection methods and measurements that will accurately reflect the response to activity. However, there is no consensus on which training load measure best predicts the positive and negative aspects of training. Research points to high-speed distance as one of the best predictors of acute and residual fatigue17 after soccer matches, and other research indicates that subjective measures, such as rating of perceived exertion, may be most beneficial for injury development.8 Training load measures should be able to predict day-to-day changes of musculoskeletal health regardless of whether they are based around a match. If training loads alter musculoskeletal health and subsequently lead to injury, then they should also predict day-to-day changes in musculoskeletal stress and trauma measures. With this information and the appropriate training load measure, stakeholders will create optimal training programs to optimize athlete health, wellness, and performance. Therefore, the purpose of this study was to determine the predictive capabilities of training load variables on the development of lower extremity DOMS in female collegiate soccer athletes throughout an entire season. It is hypothesized that the number of decelerations and high-speed distance will best predict future lower extremity DOMS after accounting for the current day’s DOMS and intra-individual effects.

MATERIALS AND METHODS
To answer the research question, a prospective research design was created to track an athlete’s daily lower extremity DOMS and training load throughout an entire competitive collegiate soccer season. Participants were sent a custom smartphone enabled survey to log DOMS location and intensity throughout the season. In the current study, DOMS was operationally defined as the self-reported soreness or pain experienced by the participants. Participants were asked to log their DOMS on all days during the competitive season. The raw DOMS data was collected and reported to the soccer coaches, athletic trainer, and strength coach daily for use within the team. Training load was tracked with a wearable sensor which incorporated global
positioning systems (GPS), accelerometers, and a heart rate monitor to derive many different training load measures.

After institutional approval, participants were recruited from the active members of the university’s female soccer team. To be included, participants had to participate in team functions, have access to a smartphone, and be able to wear a training load tracking device during all on-field team activities. Participants were excluded if they did not participate in team on-field training. Twenty-seven collegiate female soccer athletes (age: 20.6 ± 1.4 years, height: 168.2 ± 5.2, mass: 67.8 ± 7.2) participated in the current study. After signing consent forms from the university IRB, participants were sent a DOMS tracking sensor and assigned a wearable load tracking sensor.

SORENESS COLLECTION

A custom smartphone enabled survey was created and distributed to each team member. At preseason testing times, participants were instructed to upload the survey as an application on their smartphone, so they were able to complete the survey each day. The survey collected measures of readiness, fatigue, stress, sleep quality and DOMS. For DOMS, participants were first asked “Are you experiencing any soreness or pain today?”. If the participant selected “No”, then the survey was completed. If the participant selected “Yes”, the participant was shown a body map with outlined areas corresponding to specific body regions. Participants would place a marker at a specific body location, indicating that they were actively experiencing DOMS at this location. Participants could place up to 10 different markers. After placing a marker in a specific region, participants would then rate their overall DOMS in that region from 1 to 10, with 1 representing mild DOMS, and 10 representing severe DOMS/pain. If the participants responded to the initial DOMS question with “No”, or if the participant did not place a marker in a specific body region, the DOMS intensity rating was set as 0.

To attain lower extremity specific DOMS level, all lower extremity body regions’ DOMS intensity was summed. The specific body regions included the posterior glutes, posterior thigh/hamstrings, anterior thigh/quadriceps, anterior and posterior knee, posterior lower leg/calf, anterior and posterior ankle, anterior and posterior foot, anterior and posterior hip, and anterior lower leg/shin, and the athletes could select a region on either or both sides of the body. These regions were selected as body regions of interest based on the expertise of the authors and based on feedback from the team of sports medicine professionals. The body map which was used was validated and demonstrates high levels of reliability for reporting pain (ICC = 0.93). Since the participants could place up to 10 different locations of pain, and at each location the participant could indicate up to 10/10 soreness intensity, the overall scale of the DOMS outcome measure could be between 0-100.

TRAINING LOAD COLLECTION

Each day during on-field soccer activities, participants wore a chest-mounted training load monitor via a elastic strap (Team Polar Pro, Polar Electro Oy, Kempele, Finland). The training load monitor incorporates a heart rate monitor, accelerometer, and GPS that is attached to a monitoring strap placed immediately beneath the xiphoid process of the sternum. To begin the training, participants were told to clip the training load monitor into their strap. The team’s athletic trainer would monitor the on-field activity and set the start and stop time. The entire session was collected, and all training load measures were captured and reported between the start and stop time. The training load data was viewable on a team issued tablet and, on a cloud-based service. The data were extracted from the cloud-based service at the end of the year and used for the current project. Specific training load data that was used is listed in Table 1.

DATA REDUCTION AND STATISTICAL ANALYSES

Data were reduced into daily values. Lower extremity DOMS information was taken from the daily surveys and synchronized with training load data. In instances where athletes reported the daily wellness survey twice, the average of lower extremity DOMS was used. It was expected that the training load variables would impact the future DOMS, so the next day’s lower extremity DOMS score was synchronized with the current day’s training load variables and the current day’s DOMS. With this data in place, a raw change score was calculated between the current day’s DOMS and the following day’s DOMS (Post – Pre). On days where the participants did not have training or they did not wear their training load monitor, the data row was removed due to the absence of data. Overall survey compliance was calculated as the total number of responses divided by the total number of player days from the start of the year to the end of the year. Outliers were assessed and removed if they were deemed extreme (> 3 standard deviations from the mean). To assess the correlation between team DOMS and the team’s daily training load, data were reduced into average daily values for all training load and lower extremity DOMS scores. Separate Pearson correlation coefficients were performed to assess the relationship between each training load measure and the raw change in DOMS between today and tomorrow’s DOMS. To assess the predictive capabilities of training load measures on individual level DOMS, separate linear mixed models were used with the following day’s lower extremity DOMS score as the outcome measure, the current day’s lower extremity DOMS score and each training load variable as a fixed factor along with an interaction term between the current day’s DOMS score and the training load variable. To account for the individual level variance that often comes with subjective repeated measures data, participant was used as a random intercept to allow for the differences in DOMS interpretation. To ensure that the training load measures significantly contributed to the overall model, a model with only the current day’s DOMS and the random intercept was created to compare to the training load model. Comparisons were performed with a chi-square test. If significant (p<0.05), the chi-square test would indicate that the training load model contributed to the overall amount of variance better than
Table 1. Description of Training Load measure outcomes

<table>
<thead>
<tr>
<th>Measure</th>
<th>Abbreviation</th>
<th>Description</th>
<th>Monitor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>Duration</td>
<td>Total time from start to cessation of official practice</td>
<td>Team Athletic Trainer tracked on tablet</td>
</tr>
<tr>
<td>Distance</td>
<td>Distance</td>
<td>Total displacement during on-field session</td>
<td>GPS</td>
</tr>
<tr>
<td>Average Speed</td>
<td>SpdAvg</td>
<td>Average velocity during on-field training</td>
<td>GPS</td>
</tr>
<tr>
<td>High Speed Distance</td>
<td>HISPdDist</td>
<td>Total distance over 16.9 km/h</td>
<td>GPS</td>
</tr>
<tr>
<td>Sprint</td>
<td>Sprint</td>
<td>Total number of high intensity sprints recorded</td>
<td>GPS and Accelerometer</td>
</tr>
<tr>
<td>Average Heart Rate</td>
<td>HRavg</td>
<td>Average heart rate during the training</td>
<td>Heart rate monitor</td>
</tr>
<tr>
<td>High Intensity Heart Rate Minutes</td>
<td>HIlIntHR</td>
<td>Number of minutes spent over 80% of Heart rate max</td>
<td>Heart Rate Monitor</td>
</tr>
<tr>
<td>Accelerations</td>
<td>Accels</td>
<td>Total number of accelerations over 2.00 m/s²</td>
<td>Accelerometer</td>
</tr>
<tr>
<td>Decelerations</td>
<td>Decels</td>
<td>Total number of accelerations under -2.00 m/s²</td>
<td>Accelerometer</td>
</tr>
<tr>
<td>Calories</td>
<td>Cals</td>
<td>Estimated number of calories expended during training</td>
<td>Accelerometer, GPS, and Heart Rate Monitor</td>
</tr>
<tr>
<td>Training Impulse</td>
<td>TRIMP</td>
<td>Estimated Bannister’s Training Impulse³⁴ (Banister, 1975 #47)</td>
<td>Accelerometer, GPS, and Heart Rate Monitor</td>
</tr>
</tbody>
</table>

the raw DOMS only model. To attain the level of variance predicted by the models, both the conditional and marginal R² values were calculated. The conditional R² represents the amount of variance predicted by both the fixed and the random factors, while the marginal R² represents the amount of variance predicted by the fixed factors alone. All analyses were performed in the R coding language and analyses were deemed significant at p<0.05.

RESULTS

The average daily athlete wellness survey compliance was 84.2%, ranging from 47.5% to 98.8%. During data analysis, it was evidenced that participants’ compliance was lower than normal off days, so when removing off days from the dataset, the daily athlete wellness survey compliance was 91%. Descriptive statistics for the training load measures are presented in Table 2. Pearson correlation coefficients indicated that all training load variables were significantly associated with the raw change in DOMS (p<0.05). The training load variables that best predicted the DOMS change were number of decelerations (R² = 0.58), high intensity heart rate minutes (R² = 0.56), total distance (R² = 0.51), and calories expended during training (R² = 0.49). Figure 1 shows the Pearson correlation coefficients of all training load variables.

The linear mixed models demonstrated that all training load variables predicted the following day’s DOMS. Table 3 indicates the models and their impact on future DOMS. The training load variables that best predicted future DOMS were the number of decelerations (conditional R² = 0.45, marginal R² = 0.32, Figure 2), the number of minutes spent at high intensity heart rates (conditional R² = 0.45, marginal R² = 0.30, Figure 3), and the number of accelerations (conditional R² = 0.45, marginal R² = 0.27 Figure 4). The

Table 2. Descriptive statistics of Training Load measure outcomes

<table>
<thead>
<tr>
<th>Training Load Variable</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (m)</td>
<td>4633.0 ± 2813.0</td>
</tr>
<tr>
<td>Accelerations (count)</td>
<td>699.0 ± 297.0</td>
</tr>
<tr>
<td>Calories (kCal)</td>
<td>405.0 ± 182.0</td>
</tr>
<tr>
<td>Decelerations (count)</td>
<td>265.0 ± 157.0</td>
</tr>
<tr>
<td>High Speed Distance (m)</td>
<td>184.0 ± 237.0</td>
</tr>
<tr>
<td>Average Heart Rate (bpm)</td>
<td>132.0 ± 18.5</td>
</tr>
<tr>
<td>Duration (min)</td>
<td>120.0 ± 46.7</td>
</tr>
<tr>
<td>Training Impulse (AU)</td>
<td>42.5 ± 23.9</td>
</tr>
<tr>
<td>High Intensity Heart Rate Minutes (min)</td>
<td>25.5 ± 22.3</td>
</tr>
<tr>
<td>Sprint (count)</td>
<td>12.2 ± 8.8</td>
</tr>
<tr>
<td>Average Speed (km/h)</td>
<td>2.6 ± 0.9</td>
</tr>
</tbody>
</table>

Chi-Square test revealed that the models with the training load variable and the interaction term fit the data better than the raw DOMS model (p<0.001).

DISCUSSION

This study aimed to investigate the predictive capability of different training load variables on future DOMS in collegiate female soccer athletes. The results indicated that the number of decelerations, number of minutes spent at high intensity heart rates, and the number of accelerations best predicted future DOMS, after accounting for the current day’s DOMS. Additionally, all the training load models added additional variance when compared to models that had DOMS only. All the training load variables predicted fu-
Figure 1. Pearson Correlation Coefficients of each Training Load variable on the raw lower extremity soreness score change.

Decelerations are whole body eccentric movements, and there is a substantial amount of literature indicating that eccentric muscle activity affects DOMS. Chapman et al. showed that high velocity eccentric contractions led to higher DOMS, higher creatine kinase levels, and larger decrements to muscle strength than slow velocity contractions in a controlled laboratory setting. In the current study, we demonstrated that the whole body decelerations were predictive of future soreness, thus translating Chapman’s work into a sport setting. Monitoring and tracking DOMS would be beneficial for sport stakeholders, including sports medicine professionals, strength and conditioning coaches, and sport coaches. When paired with a training load monitor, stakeholders could use this data in combination for practice planning, rehabilitation, and strength programming to appropriately load athletes and reduce negative aspects of trainings around important dates, such as competitions.

Training loads can be captured with many different methods, including global positioning units, accelerometers, heart rate monitors, and subjective surveys. Anecdotally, some training load monitoring devices will create exports with over 200 columns of information. With so much information, it can be tough to navigate training load measures to create usable conclusions from the data. However, recent recommendations indicate that training load should be viewed as a dose of activity, and a response variable should be used to determine the ef-
Table 3. Model Estimates of Training Load models on the following day's soreness score.

<table>
<thead>
<tr>
<th>Training Load Model</th>
<th>Parameter</th>
<th>Estimate</th>
<th>SE</th>
<th>DF</th>
<th>t value</th>
<th>p-value</th>
<th>R²c</th>
<th>R²m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decelerations</td>
<td>(Intercept)</td>
<td>-0.0448</td>
<td>0.357</td>
<td>43.800</td>
<td>-0.125</td>
<td>0.901</td>
<td>45.1</td>
<td>32.0</td>
</tr>
<tr>
<td></td>
<td>Current Soreness</td>
<td>0.2062</td>
<td>0.041</td>
<td>1074.000</td>
<td>5.036</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Training Load</td>
<td>0.0057</td>
<td>0.001</td>
<td>1065.000</td>
<td>8.047</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interaction</td>
<td>0.0010</td>
<td>0.000</td>
<td>1074.000</td>
<td>7.061</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Intensity Heart Rate Minutes</td>
<td>(Intercept)</td>
<td>0.4679</td>
<td>0.339</td>
<td>31.910</td>
<td>1.381</td>
<td>0.177</td>
<td>44.6</td>
<td>30.4</td>
</tr>
<tr>
<td></td>
<td>Current Soreness</td>
<td>0.2608</td>
<td>0.035</td>
<td>1074.000</td>
<td>7.467</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Training Load</td>
<td>0.0401</td>
<td>0.005</td>
<td>1070.000</td>
<td>8.074</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interaction</td>
<td>0.0077</td>
<td>0.001</td>
<td>1074.000</td>
<td>6.980</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accelerations</td>
<td>(Intercept)</td>
<td>-0.3303</td>
<td>0.423</td>
<td>60.370</td>
<td>-0.781</td>
<td>0.438</td>
<td>42.7</td>
<td>27.0</td>
</tr>
<tr>
<td></td>
<td>Current Soreness</td>
<td>0.1440</td>
<td>0.054</td>
<td>1046.000</td>
<td>2.642</td>
<td>0.008</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Training Load</td>
<td>0.0026</td>
<td>0.000</td>
<td>1042.000</td>
<td>7.115</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interaction</td>
<td>0.0009</td>
<td>0.000</td>
<td>1052.000</td>
<td>6.008</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated Calories</td>
<td>(Intercept)</td>
<td>-0.1438</td>
<td>0.418</td>
<td>55.170</td>
<td>-0.344</td>
<td>0.732</td>
<td>42.8</td>
<td>26.9</td>
</tr>
<tr>
<td></td>
<td>Current Soreness</td>
<td>0.1018</td>
<td>0.051</td>
<td>1048.000</td>
<td>2.012</td>
<td>0.045</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Training Load</td>
<td>0.0042</td>
<td>0.001</td>
<td>1043.000</td>
<td>6.896</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interaction</td>
<td>0.0009</td>
<td>0.000</td>
<td>1051.000</td>
<td>6.927</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance</td>
<td>(Intercept)</td>
<td>0.0397</td>
<td>0.403</td>
<td>37.550</td>
<td>0.098</td>
<td>0.922</td>
<td>43.7</td>
<td>24.8</td>
</tr>
<tr>
<td></td>
<td>Current Soreness</td>
<td>0.2330</td>
<td>0.042</td>
<td>1062.000</td>
<td>5.529</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Training Load</td>
<td>0.0003</td>
<td>0.000</td>
<td>1053.000</td>
<td>8.000</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interaction</td>
<td>0.0001</td>
<td>0.000</td>
<td>1060.000</td>
<td>5.619</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Heart Rate</td>
<td>(Intercept)</td>
<td>-1.9300</td>
<td>0.890</td>
<td>634.600</td>
<td>-2.169</td>
<td>0.030</td>
<td>39.0</td>
<td>23.7</td>
</tr>
<tr>
<td></td>
<td>Current Soreness</td>
<td>-0.5303</td>
<td>0.146</td>
<td>1072.000</td>
<td>-3.636</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Training Load</td>
<td>0.0259</td>
<td>0.006</td>
<td>1077.000</td>
<td>4.109</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interaction</td>
<td>0.0074</td>
<td>0.001</td>
<td>1077.000</td>
<td>6.530</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Training Impulse</td>
<td>(Intercept)</td>
<td>0.4151</td>
<td>0.426</td>
<td>39.940</td>
<td>0.974</td>
<td>0.336</td>
<td>40.4</td>
<td>20.8</td>
</tr>
<tr>
<td></td>
<td>Current Soreness</td>
<td>0.2021</td>
<td>0.043</td>
<td>1055.000</td>
<td>4.724</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Training Load</td>
<td>0.0274</td>
<td>0.005</td>
<td>1050.000</td>
<td>5.673</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interaction</td>
<td>0.0063</td>
<td>0.001</td>
<td>1055.000</td>
<td>5.532</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Speed Distance</td>
<td>(Intercept)</td>
<td>0.9081</td>
<td>0.397</td>
<td>26.730</td>
<td>2.285</td>
<td>0.030</td>
<td>41.9</td>
<td>20.6</td>
</tr>
<tr>
<td></td>
<td>Current Soreness</td>
<td>0.3141</td>
<td>0.031</td>
<td>1039.000</td>
<td>10.133</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Training Load</td>
<td>0.0045</td>
<td>0.001</td>
<td>1041.000</td>
<td>7.930</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interaction</td>
<td>0.0006</td>
<td>0.000</td>
<td>1048.000</td>
<td>3.872</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration</td>
<td>(Intercept)</td>
<td>0.2621</td>
<td>0.466</td>
<td>56.860</td>
<td>0.563</td>
<td>0.576</td>
<td>39.2</td>
<td>18.9</td>
</tr>
<tr>
<td></td>
<td>Current Soreness</td>
<td>0.0852</td>
<td>0.061</td>
<td>1065.000</td>
<td>1.395</td>
<td>0.163</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Training Load</td>
<td>0.0117</td>
<td>0.002</td>
<td>1053.000</td>
<td>5.030</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interaction</td>
<td>0.0025</td>
<td>0.001</td>
<td>1064.000</td>
<td>4.952</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Sprints</td>
<td>(Intercept)</td>
<td>0.7734</td>
<td>0.405</td>
<td>33.800</td>
<td>1.908</td>
<td>0.065</td>
<td>38.2</td>
<td>18.7</td>
</tr>
<tr>
<td></td>
<td>Current Soreness</td>
<td>0.2710</td>
<td>0.038</td>
<td>1077.000</td>
<td>7.085</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Training Load</td>
<td>0.0713</td>
<td>0.014</td>
<td>1070.000</td>
<td>5.110</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interaction</td>
<td>0.0113</td>
<td>0.003</td>
<td>1077.000</td>
<td>3.555</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Speed</td>
<td>(Intercept)</td>
<td>0.0589</td>
<td>0.514</td>
<td>71.420</td>
<td>0.114</td>
<td>0.909</td>
<td>37.8</td>
<td>16.1</td>
</tr>
<tr>
<td></td>
<td>Current Soreness</td>
<td>0.1867</td>
<td>0.064</td>
<td>1065.000</td>
<td>2.929</td>
<td>0.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Training Load</td>
<td>0.6058</td>
<td>0.128</td>
<td>1072.000</td>
<td>4.739</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interaction</td>
<td>0.0844</td>
<td>0.027</td>
<td>1070.000</td>
<td>3.081</td>
<td>0.002</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

R²c = Conditional R²; R²m = Marginal R².

The effect of the dose, as is done in medical and epidemiological research. If training load acts as the dose of sport, then in the current study, DOMS acts as a response variable to understand which of the doses is best predicting the response variable. The number of decelerations, number of high intensity heart rates, and number of accelerations best
predicted DOMS. Sport stakeholders who are searching for training load monitoring systems may want to ensure that these variables are included in the system prior to purchase and application.

It is important to note that all of the training load variables significantly predicted next day soreness to some degree, but the number of decelerations accounted for up to 15% more variance than other training load variables. Previous literature has emphasized using training load measures such as total distance and high-speed distance with soccer athletes,\textsuperscript{18,21} but in the current study, the total number of decelerations accounted for 8% and 12% more variance, respectively. This is the first study to identify decelerations as the best predictor of athlete soreness, potentially due to the innovative measurement of soreness. If put into practice, clinicians would have more confidence using number of decelerations to predict future soreness rather than distance or accelerations, as these may be better suited to view long-term for injury risk reduction. The current study did not include more than one training load variable in each model, as there was significant amount of collinearity between the training load variables. Future research that uses models robust enough to deal with high collinearity could provide even more predictive power, such that future soreness could be predicted and mitigated through thoughtful scheduling and program creation.

Training load measures are often thought of as either external\textsuperscript{9,10,17,40} or internal.\textsuperscript{9,40,41} External loads are primarily the work that is being performed, such as distance, accelerations, or duration. Internal loads are perceptual or physiological measures that correspond to the external load being performed, and these are often measured as rating of perceived exertion, heart rate, or training impulse. In the current study, both internal and external measures of load were significantly associated with the following day’s DOMS. Both external load measures and internal load measures could be used to predict future soreness, so clinicians should feel comfortable selecting training load monitoring methods that capture any training load measure.

Although clinicians should use internal and external load measures, they should also use a response variable to determine the impact of that training load. Response variables provide key context for clinicians to identify athletes who are struggling or thriving. Previous authors have used force plate assessments,\textsuperscript{20} strength measurements,\textsuperscript{19,42,43} wellness surveys,\textsuperscript{9,10} or heart rate variability\textsuperscript{16} to determine fatigue status of athletes. The current study collected DOMS via a smartphone enabled survey with a body map that has established reliability and validity.\textsuperscript{35} This method

\textbf{Figure 2.} Plot demonstrating the scatterplot between the next day soreness and number of decelerations, current soreness, and the interaction term. The predicted versus actual data is plotted on the right hand side.
is cost-effective, easy to implement, and could aid both sports medicine clinicians and strength and conditioning coaches to ensure that athletes are not being overloaded. Clinicians could also use this method over time to track return to play and use data driven decision making to prescribe future load. Future research should track other objective measures of fatigue to identify if training load predicts these measures in the same fashion that training load predicts DOMS. Additionally, the DOMS collection method in this study could be useful for many other research projects where repeated measures or return to play are being investigated.

This study is not without limitations. Training load measures were not collected during strength training sessions where additional load may have been accumulated. The load is likely to be consistent across athletes, except for internal load measures of heart rate indices, so future research should incorporate strength training sessions into the training load calculations. It was assumed that athletes were honest in their responses regarding lower extremity DOMS. The data were collected and reported back to the sport staff, so athletes may have altered the truth to look good for the staff. Prior to the beginning of the study, honesty was emphasized to the participants, and the coaching staff was educated on appropriate responses to the wellness survey. Additionally, although questions were asked about DOMS and athletes were instructed on the difference between DOMS and other sources of pain, the DOMS outcome scores could have come from another source, such as overuse injury or direct contact that does not require removal from sport. Finally, the training load data were significantly correlated, so data was modeled with one training load variable at a time. Although future projects intend to analyze the data with more robust models to gain greater predictive capability, the authors elected to move forward with a single training load variable in each model.

CONCLUSIONS

The results of the current study demonstrate that training load measures significantly predicted lower extremity DOMS in collegiate female soccer athletes. The strongest predictors were the number of declarations, number of minutes spent at high heart rate, and number of accelerations. Clinicians who work with female soccer players should consider training load monitoring methods that collect these training load variables. Additionally, when high number of decelerations, minutes spent at high heart rates,
Figure 4. Plot demonstrating the scatterplot between the next day soreness and number of accelerations, current soreness, and the interaction term. The predicted versus actual data is plotted on the right hand side.

and number of accelerations are present within a practice, the sport staff should expect higher lower extremity soreness in the following days. Future research should use similar methods to determine if training load variables can predict changes in objective fatigue measures in a similar fashion to the current study.

COI STATEMENT

This study was funded in part by a National Athletic Trainers Association New Investigator's Grant (#2021NIP01). The authors have no other conflicts to disclose.

Submitted: June 28, 2023 CST, Accepted: October 12, 2023 CST
REFERENCES


Validation of a Portable Wireless Force Platform System To Measure Ground Reaction Forces During Various Tasks

Vasileios Mylonas1, Christos Chalitsios1, Thomas Nikodelis1

1 Physical Education and Sport Science, Aristotle University of Thessaloniki

Keywords: force-plates, postural control, multiple jumps

Background

Force platforms are widely used in biomechanics to measure ground reaction forces (GRF) during various human movements. However, traditional force plates are not easily used outside a research lab. To overcome this issue, researchers and manufacturers are developing low-cost portable force platforms that can be used in a variety of settings, including outdoors.

Purpose

To validate the kinetic data obtained from a pair of portable K-Deltas force platforms compared to gold standard platforms fixed in the lab and to examine the measurement reliability between this pair of portable force platforms.

Methods

Force-time curves from known masses, countermovement vertical jumps, and balance tests were used to assess validity of K-Deltas using a pair of Bertec force plates as a gold standard and between the K-Deltas pair of plates. Bland-Altman plots were used to evaluate the differences between K-Deltas and Bertec force plates. For the assessment of countermovement vertical jumps, impulse, peak rate of force development and peak force were calculated for both instruments and checked for agreement between instruments. Three young adults (2 male, 1 female, 25.4±0.83 years) participated in the study.

Results

The percentage of Bland-Altman plot point within the limits of agreement was 94.59 % for the comparison between K-Deltas and Bertec and 94.83% between the pair of K-Deltas.

Conclusion

The results show that the portable force platforms could be utilized successfully for assessing pertinent parameters in clinical and sports biomechanics. The findings suggest that portable force platforms can be used as an alternative to traditional laboratory equipment for field assessment, providing significant improvements compared to the past.

Level of Evidence

Level 3
INTRODUCTION

Force platforms are devices that are widely used in biomechanics and sports science to measure vertical or three-dimensional (3D) ground reaction forces during various human movements like gait,\textsuperscript{1-3} running,\textsuperscript{4,5} vertical jumps\textsuperscript{6,7} and balance.\textsuperscript{8} In special cases they are used to detect asymmetries by comparing the ground reaction forces exerted by the left and right lower\textsuperscript{9} or upper limbs.\textsuperscript{10} Nevertheless, such instruments are usually expensive, mounted on the ground of a laboratory, not easily portable, and in most cases only used by scientists/researchers.

Although force plates and other force transducers are commercially available, the aforementioned features are negatively associated with their use during sports and in clinical practice. Researchers and manufacturers are looking into more useful alternatives, based on cost and portability, in an effort to broaden the application of kinetic instrumentation during on-field assessment and daily practice. Portable force plates can make it easier for practitioners, athletes, and researchers to record vertical force data. Currently, the availability of low-cost portable force platforms with weight and dimensions that make it possible to use it in a variety of different settings, allowing for a quick installation and removal while traveling for competitions or training sessions is improving. Much of the focus is due to the mobile technology advances, i.e., modern instruments that can record and store the measured data wirelessly in the cloud through a mobile device and a dedicated application.

Although the above-mentioned features provide significant improvements compared to the past, the quality of every measuring instrument is largely dependent on its accuracy and precision. As an alternative to the typical laboratory equipment, new pieces of equipment that can be used outdoors for ‘ecological’ measurements during a variety of sports would be of great assistance to applied research in the field of sports science.

The purpose of this study was to validate the kinetic data obtained from a pair of portable K-Deltas force platforms compared to gold standard platforms fixed in the lab and to examine the measurement reliability within this pair of portable force platforms. Force-time curves from known masses (dead weights), counter movement jumps (CMJ), and balance tests were chosen as representative tasks to be used for validity comparisons. The balance task was also used for testing the reliability between the two portable platforms.

The working hypothesis was that the portable force plates could be utilized successfully for the purpose of assessing pertinent parameters in clinical and sports biomechanics.

METHODS

PARTICIPANTS

Three participants (2 male, 1 female, 25.4±0.83 years, 85.4±18.5 kg, 181.6±9.4 cm) conducted the trials. Participants were physical education students and had no recent injury or medical issue of any kind, who were postgraduate students in sport biomechanics, had graduated from a sport science department, so they were all to some extent familiar with the tasks. They all signed a participation consent form. The study was approved by the ethics committee of the university (133750/2019).

INSTRUMENTS

The portable force plate system (K-Deltas, Kinvent Inc, Montpellier, France) was tested for validity to a force plate system commonly used in research laboratories around the globe, a pair of Bertec force plates (FP4060-08, 40 cm x 60 cm) as a gold standard. (Bertec Inc., Ohio, USA). The K-Deltas plates were used with the K-Invent physio dedicated application (Kinvent Inc, Montpellier, France). The Android application was used to record the data via Bluetooth (BLE 5.1) with a sampling frequency of 1000Hz. The Bertec plates were recorded through Vicon Nexus software (Nexus 2.15.0) via a cable connection. The forces from the Bertec platforms were recorded at 960Hz. Since the K-Deltas are 1-D force plates only vertical ground reaction force data were used from the Bertec devices.

EXPERIMENTAL PROCEDURE

Prior to the comparison with the gold standard, the K-Deltas were validated using standard weights. Four distinct weight plates ranging from 20.04 kg to 82.18 kg were utilized. The weight was recorded for two seconds. Both plates underwent the same procedure. The sampling frequency for these tests was set at 75 Hz.

After the weight validation each participant performed a total of two postural stability trials. The first was a bipedal stance held for 60 seconds while standing on the two K-Deltas plates that were placed on top of the Bertec force plates. The Bertec plates were calibrated so that the weight of the Deltas would be zeroed out (Setup A, Figure 1A). Ground reaction force (GRF) was measured, and the center of pressure (CoP) was calculated for each lower limb separately. The second test was another 60-second bipedal stance using only one Bertec plate, and the two K-Deltas plates were stacked on top of it, one above the other. A baseline process ensured the zeroing of the instruments (Setup B, Figure 1B). GRF and CoP were extracted and calculated as a total, representing the whole body. For Setup B, comparisons were made between the top K-Deltas plate and the Bertec (D1-B) and the bottom K-Deltas plate and the Bertec (D2-B) to test validity, as well as between the two Deltas (D1-D2) to test reliability in between the pair. In both setups double-sided tape was utilized to fixate the plates to ensure that they would be tightly fixed on one another.

Finally, each subject performed 10 consecutive counter-movement vertical jumps. After each landing, the participant returned to the upright stance to start the next jump. A metronome was used that instructed the subject to jump every two seconds. The setup used for the multiple jumps was identical to Setup A of postural trials (Figure 1A). No jumps were performed on Setup B.
Table 1. Bland Altman plot results for experimental Setup A

<table>
<thead>
<tr>
<th>Subject</th>
<th>Lower Limb</th>
<th>Axis</th>
<th>Out Perc (%)</th>
<th>Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male 1</td>
<td>Left</td>
<td>X</td>
<td>4.68</td>
<td>0.14 (cm)</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>Y</td>
<td>4.93</td>
<td>0.43 (cm)</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>X</td>
<td>5.12</td>
<td>0.21 (cm)</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>Y</td>
<td>5.2</td>
<td>0.38 (cm)</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>Force</td>
<td>5.22</td>
<td>0.49 (N)</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>Force</td>
<td>5.17</td>
<td>0.55 (N)</td>
</tr>
<tr>
<td>Male 2</td>
<td>Left</td>
<td>X</td>
<td>5.03</td>
<td>0.69 (cm)</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>Y</td>
<td>6.07</td>
<td>0.66 (cm)</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>X</td>
<td>6.65</td>
<td>0.4 (cm)</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>Y</td>
<td>5.07</td>
<td>0.11 (cm)</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>Force</td>
<td>5.43</td>
<td>0.06 (N)</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>Force</td>
<td>5.52</td>
<td>0.93 (N)</td>
</tr>
<tr>
<td>Female</td>
<td>Left</td>
<td>X</td>
<td>5.73</td>
<td>0.09 (cm)</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>Y</td>
<td>5.13</td>
<td>0.2 (cm)</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>X</td>
<td>4.75</td>
<td>0.24 (cm)</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>Y</td>
<td>4.63</td>
<td>0.68 (cm)</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>Force</td>
<td>4.97</td>
<td>0.5 (N)</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>Force</td>
<td>5.2</td>
<td>0.27 (N)</td>
</tr>
</tbody>
</table>

Figure 1. Experimental setups. Figure 1A depicts experimental Setup A and Figure 1B depicts experimental Setup B

Participants were verbally instructed to perform a heel strike at the start and at the end of the trial. The two pairs of devices were externally synchronized using the spike in vertical force signal from the heel strike.

DATA ANALYSIS

A dual pass second-order low-pass Butterworth filter was used with cutoff frequencies of 40 Hz for the K-Deltas plates (1000 Hz sampling frequency) and 58 Hz for the Bertec plates (960 Hz sampling frequency). The cutoff frequencies were selected using residual analysis and the method proposed by Winter\textsuperscript{11} for choosing the appropriate cut-off frequency with respect to the sampling frequency.

For the analyses of the posture trials, the GRF and the CoP outputs of both instruments were tested for agreement. Bland-Altman plots\textsuperscript{12} were used to present the level of agreement between the two-time series. Limits of agreement were set as ±2 times the standard deviation of the difference. To quantify the agreement, the percentage of data points outside the limits of agreement relative to the total points was determined. Each participant was subjected to individual analyses. The total GRF time-series of each instrument and jump were used to calculate the impulse, maximum force (maxF), and maximum rate of force development (maxRFD). These variables served as the key variables for each of the ten jumps and were used to achieve agreement between the instruments for the jump measurements. Both the stacked plates protocol and the Bland Altman plot approach to validate the results have been used in previous literature.\textsuperscript{13}

RESULTS

Measurements with weights were performed for both force plates of the K-Deltas pair. Deviations from the known masses were 0.05 ± 0.06 kg at 0 kg, 0.01 ± 0.04 kg for 20.04 kg, 0.01 ± 0.05kg for 40.06 kg and 0.02 ± 0.05kg at 58.2 kg. 0.04 ± 0.05kg for 82.18 kg. This error was comparable with the data sheet provided by Bertec which reports less than 0.2% error for the vertical component.\textsuperscript{14}

Regarding the postural stability tests, the comparison of the two instruments was quantified by the number of points outside the limits of agreement of the Bland Altman plots. These numbers are presented as percentages of the total data points for Setup A (Table 1) and Setup B (Table 2).
Table 2. Bland Altman plot results for experimental Setup B

<table>
<thead>
<tr>
<th>Subject</th>
<th>Comparison</th>
<th>Axis</th>
<th>Out Perc (%)</th>
<th>Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male 1</td>
<td>D1-D2</td>
<td>X</td>
<td>5.07</td>
<td>0.09 (cm)</td>
</tr>
<tr>
<td></td>
<td>D1-D2</td>
<td>Y</td>
<td>5.18</td>
<td>0.06 (cm)</td>
</tr>
<tr>
<td></td>
<td>D1-D2</td>
<td>Force</td>
<td>5.02</td>
<td>0.82 (N)</td>
</tr>
<tr>
<td></td>
<td>D1-B</td>
<td>X</td>
<td>6.17</td>
<td>0.05 (cm)</td>
</tr>
<tr>
<td></td>
<td>D1-B</td>
<td>Y</td>
<td>7.7</td>
<td>0.27 (cm)</td>
</tr>
<tr>
<td></td>
<td>D1-B</td>
<td>Force</td>
<td>5.35</td>
<td>0.24 (N)</td>
</tr>
<tr>
<td></td>
<td>D2-B</td>
<td>X</td>
<td>6.03</td>
<td>0.14 (cm)</td>
</tr>
<tr>
<td></td>
<td>D2-B</td>
<td>Y</td>
<td>7.35</td>
<td>0.21 (cm)</td>
</tr>
<tr>
<td></td>
<td>D2-B</td>
<td>Force</td>
<td>4.93</td>
<td>0.58 (N)</td>
</tr>
<tr>
<td>Male 2</td>
<td>D1-D2</td>
<td>X</td>
<td>5.13</td>
<td>0.03 (cm)</td>
</tr>
<tr>
<td></td>
<td>D1-D2</td>
<td>Y</td>
<td>5.38</td>
<td>0.01 (cm)</td>
</tr>
<tr>
<td></td>
<td>D1-D2</td>
<td>Force</td>
<td>5.02</td>
<td>0.82 (N)</td>
</tr>
<tr>
<td></td>
<td>D1-B</td>
<td>X</td>
<td>4.97</td>
<td>0.01 (cm)</td>
</tr>
<tr>
<td></td>
<td>D1-B</td>
<td>Y</td>
<td>4.9</td>
<td>0.02 (cm)</td>
</tr>
<tr>
<td></td>
<td>D1-B</td>
<td>Force</td>
<td>5.35</td>
<td>0.24 (N)</td>
</tr>
<tr>
<td></td>
<td>D2-B</td>
<td>X</td>
<td>5</td>
<td>0.04 (cm)</td>
</tr>
<tr>
<td></td>
<td>D2-B</td>
<td>Y</td>
<td>5.37</td>
<td>0.03 (cm)</td>
</tr>
<tr>
<td></td>
<td>D2-B</td>
<td>Force</td>
<td>4.93</td>
<td>0.58 (N)</td>
</tr>
<tr>
<td>Female</td>
<td>D1-D2</td>
<td>X</td>
<td>5.25</td>
<td>0.14 (cm)</td>
</tr>
<tr>
<td></td>
<td>D1-D2</td>
<td>Y</td>
<td>5.48</td>
<td>0.09 (cm)</td>
</tr>
<tr>
<td></td>
<td>D1-D2</td>
<td>Force</td>
<td>5.02</td>
<td>0.82 (N)</td>
</tr>
<tr>
<td></td>
<td>D1-B</td>
<td>X</td>
<td>5.57</td>
<td>0.04 (cm)</td>
</tr>
<tr>
<td></td>
<td>D1-B</td>
<td>Y</td>
<td>5.7</td>
<td>0.24 (cm)</td>
</tr>
<tr>
<td></td>
<td>D1-B</td>
<td>Force</td>
<td>5.35</td>
<td>0.24 (N)</td>
</tr>
<tr>
<td></td>
<td>D2-B</td>
<td>X</td>
<td>5.7</td>
<td>0.1 (cm)</td>
</tr>
<tr>
<td></td>
<td>D2-B</td>
<td>Y</td>
<td>5.22</td>
<td>0.15 (cm)</td>
</tr>
<tr>
<td></td>
<td>D2-B</td>
<td>Force</td>
<td>4.93</td>
<td>0.58 (N)</td>
</tr>
</tbody>
</table>

Regarding the analysis of the jumps, impulse, maximum RFD and maximum force were computed separately for the two instruments and tested for agreement for all jumps. Bland Altman plots are presented in Figure 2.

**DISCUSSION**

These findings indicate a high degree of agreement in measurements between the two instruments. This supports the hypothesis that the K-Deltas force plates are valid in comparison to the Bertec force plates, which are considered the gold standard instrument. The validity of the K-Delta plates is also supported by the results of the weight testing. In all cases, the measured values varied by less than 100 grams from the true (known weight), and the CoP mean difference was less than 1 cm, values that were similar to or less than previous results in other validation studies. The high levels of agreement in the GRF measurements during the quiet standing trials suggest that K-Deltas portable force plates are as capable as embedded lab force plates to measure postural stability. The comparisons of the CoP time series also indicate that K-Deltas can be used to accurately evaluate the postural stability of human subjects.

The Bland-Altman analysis revealed on average satisfactory levels of agreement between the K-Deltas and Bertec force plates. Specifically, for the variable "Impulse," the limits of agreement ranged from approximately -0.52 to 5.54 N.s. For "MaxF," the limits were between -1.93 and 4.15 N, and for "MaxRFD," they ranged from -0.0096 to 0.0296 N/s. The limits of agreement indicate a strong concordance between the two instruments. In comparison to previous validation studies, the mean limits of agreement from this study align well and are narrower, further reinforcing the validity of K-Deltas force plates.

In comparison to previous validation studies, the limits of agreement in the current study are narrower. It is worth noting that previous studies employed different postural trials, which may introduce trial-to-trial variability affecting the limits of agreement. The current study's methodology, involving simultaneous recording, addresses this limitation and possibly results in a more reliable estimate of agreement. Moreover, the high sampling rate of 1000Hz and strong agreement in jump parameters further validate the efficacy of K-Deltas in capturing vertical GRF, even when mathematical processes like integration are involved.
Figure 2. Bland Altman plots present the average plotted against the difference of the two measurements. Each column presents the results of the different variables (Column 1: Impulse (Newton seconds [N·s]), Column 2: Max force [Newtons], Column 3: Max rate of force development [N/s]). Each row is a different participant (Row 1: Male 1, Row 2: Male 2, Row 3: Female 1).
Therefore, these findings not only validate the use of K-Deltas force plates but also contribute to the existing literature by providing an alternate methodological approach to assessing instrument agreement.

Previous studies that have attempted to validate force plates have used different setups. Different postural trials were used, with participants being measured separately using each of the two instruments and then measuring the Intraclass Correlation between the two trials. Postural control, however, is a skill composed of many factors interacting with each other and it is expected that postural metrics present variability from trial to trial. Thus, the authors of the current study used a protocol that simultaneously recorded data from the two pairs of plates to overcome this limitation which has been reported in literature.

The computation of jump parameters requires high frequency rates and accurate GRF measurements. For this test, the K-Deltas measured GRF with 1000Hz sampling rate wirelessly. High accuracy is also necessary when using mathematical processes such as integration (present in the computation of impulse) because a small measurement error would cumulate and lead to large error. Results of the comparison between parameters computed from the two instruments indicate strong agreement. Therefore, the K-Deltas are capable of measuring vertical GRF accurately in multiple jumps and report valid results with respect to the floor-embedded gold standard plates.

However, limitations include the possibility of slippage of the portable force plates relative to the mounted surface as they are not permanently fixed, especially in dynamic conditions like jump tests. Also, the fact that the specific plates are 1-D limits their use when comprehensive, multidimensional analysis is needed like including joint moments and torques during gait, as an example. Another possible limitation could be the low number of participants, as a larger sample could account for the greater general variance in the population. Finally, it must be acknowledged that in the setup of the present study the force dispersion may not be the same across force plates as the contact surface of the upper one is the "foot" while for those below (each is not directly on the solid floor surface), and force is being measured as it is transmitted through the four contact points of each plate. Although this is not expected to affect the vertical force component, it is still a limitation since the setup is not identical to prior studies.

CONCLUSIONS

The reliability and validity of a portable, wireless pair of force plates, the K-Deltas, were examined relative to a floor-embedded system that has been repeatedly demonstrated to be valid. The results indicate that the K-Deltas plates are a valid alternative to the gold standard for vertical GRF measurements. The portable and wireless design of this product makes it more versatile than a conventional force plate for many types of users. Both standing and jumping can be measured accurately outside of the laboratory. Although the current analyses were performed using raw time series, the end user is not required to go through this process and can select the automated filtering techniques that are available in the app based on the type of test that is being conducted. The dedicated app builds a PDF report right after the measurement with all key variables according to the selected test. Nevertheless, extracting the raw signal is important as a function as users can perform their own more detailed analyses.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to the director and the members of the laboratory of Motor Behavior and Adapted Physical Activity of Aristotle University of Thessaloniki for their technical support and assistance.

Submitted: April 19, 2023 CST, Accepted: September 24, 2023 CST

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


INTRODUCTION

Previous studies have reported a gradual decrease in biceps femoris (BF) electromyography (EMG) activity after the break-point angle (BPA) during the Nordic hamstring exercise (NHE). However, no investigation has been conducted on BF EMG activity before and after BPA as calculated using a smartphone application (Nordic Angle app).

HYPOTHESIS/PURPOSE

The aim of this study was to investigate the BF EMG activity before and after BPA, as calculated using the Nordic Angle app. The hypotheses were that BF EMG activity would peak near the BPA and gradually diminish afterward.

METHODS

After a warm-up, participants performed three repetitions of prone leg curls to discern maximum voluntary isometric contraction (MVIC) of the hamstrings. The peak value of the BF EMG activity during the prone leg curl was used to convert BF EMG activity during NHE to %MVIC. BPA during NHE was calculated using the Nordic Angle app by analyzing a movie recorded with an iPhone camera. Additionally, the knee flexion angle during NHE was determined using two-dimensional motion analysis software based on video data. To compare EMG activity before and after BPA calculated by the Nordic Angle app, the knee flexion angle was divided into seven phases: 10-15° before BPA, 5-10° before BPA, BPA ± 5°, 5-10° after BPA, 10-15° after BPA, 15-20° after BPA, and 20-25° after BPA.

RESULTS

There was no significant difference between the BPA of the Nordic angle and the knee flexion angle at peak BF EMG activity (d = 0.13, p = 0.678). The BF EMG activity at 20-25° after BPA was significantly lower than the BF EMG activity at BPA ± 5° (d = 0.87, p = 0.011).

CONCLUSIONS

To prevent the recurrence of hamstring injuries, it is important to incorporate knee flexion exercises that enhance BF EMG activity at 15-35° of knee flexion (0° indicates a fully extended knee). Thus, it is recommended to keep the BPA of the Nordic Angle within 35° to effectively prevent recurrent hamstring injuries during NHE.

Level of evidence

3b
INTRODUCTION

Hamstring injuries are prevalent in football (soccer), a sport characterized by high-speed running. Previous study have shown that the incidence of hamstring injuries has doubled from 12% to 24% between 2001 and 2022. Additionally, more than 50% of athletes with prior hamstring injury experience a recurrence of hamstring injury within 25 days of returning to play. Considering that players typically resume full team training in approximately 20 days, it is imperative to not only prevent initial hamstring injury but also reduce the risk of recurrence for improved athletic performance in football.

The biceps femoris (BF) muscle is primarily affected during high-speed running, making it susceptible to hamstring injuries. Individuals with a history of hamstring injury often exhibit inhibited BF electromyography (EMG) activity during isokinetic knee flexion exercises. Notably, the reduction in BF EMG activity is particularly prominent at knee flexion angles of 15-35° (0° indicates a fully extended knee), which align with the angles at which hamstring injuries commonly occur. It has also been reported that isokinetic knee flexion training incorporating eccentric loading up to 20° knee flexion can effectively prevent recurrent hamstring injuries. Therefore, the implementation of knee flexion exercises that enhance BF EMG activity at angles of 15-35° might play a crucial role in preventing the recurrence of hamstring injuries.

The Nordic hamstring exercise (NHE) is one such exercise used to improve eccentric knee flexion strength. It involves maintaining a straight posture from the knees to the head while leaning the upper body forward to a level that the hamstring muscles can tolerate. The knee flexion angle at which the knee flexor strength cannot resist the external knee flexion moment accompanying the forward leaning of the trunk is referred to as the break-point angle (BPA). Given that the BPA is approximately 50° even in trained soccer players, BF EMG activity at 15-35° knee flexion angle is likely diminished with standard NHE in many athletes.

The recent development of a smartphone application (Nordic Angle) has introduced the automatic calculation of BPA, eliminating the need to import data to a personal computer. Although it has been reported that BF EMG activity peaks near the BPA and gradually diminishes afterward, the investigation of BF EMG activity before and after BPA, as calculated by the Nordic Angle, remains unexplored. If the BPA value obtained using the Nordic Angle determines whether BF EMG activity is enhanced at knee flexion angles of 15-35°, it could significantly benefit the field of sports medicine. Additionally, if the angle of the lower leg slope for NHE can be adjusted based on the BPA value calculated by the Nordic Angle, it may further optimize BF EMG activity at knee flexion angles of 15-35°.

Therefore, the aim of this study was to investigate the BF EMG activity before and after BPA, as calculated using the Nordic Angle app. A secondary purpose was to reassess the validity of the Nordic Angle app by comparing its BPA values with those obtained through motion analysis. The hypotheses were that BF EMG activity would peak near the BPA and gradually diminish afterward, and that the BPA calculated using the Nordic Angle would demonstrate high validity.

METHODS

STUDY DESIGN

After a warm-up, the participants underwent three repetitions of the prone leg curl with maximum voluntary isometric contraction (MVIC). The peak value of BF EMG activity during the prone leg curl was used to convert the BF EMG activity during NHE to %MVIC. The participants then performed three NHE repetitions, which were recorded using an iPhone 12 high-speed camera. The BPA during NHE was calculated using two-dimensional motion analysis software and the Nordic Angle application (Figure 1). To quantify BF EMG activity before and after BPA, EMG and kinematic data from the motion analysis were synchronized. To compare BF EMG activity before and after BPA calculated by Nordic Angle, the knee flexion angle was divided into seven phases (10-15° before BPA, 5-10° before BPA, BPA ± 5°, 5-10° after BPA, 10-15° after BPA, 15-20° after BPA, and 20-25° after BPA), where 0° represented the fully extended position of the knee. The Friedman test was employed to compare the BF EMG activity in these seven phases. The validity of the Nordic Angle data was examined using the Pearson correlation coefficient test for consistency with the motion analysis data, and the agreement between these measurements was examined using the Bland-Altman analysis.

PARTICIPANTS

The sample size was calculated a priori based on Pearson’s correlation coefficient analysis (G-Power version 3.1, Heinrich Heine Universität, Düsseldorf, Germany). The input parameters (correlation ρ H1 = 0.75, alpha = 0.05, and power = 0.8) were set with reference to the effect size of a previous study. This setting resulted in a sample size of 11 participants. Therefore, 15 male volunteers majoring in sports science (age, 25.2 ± 2.6 years; height, 174.3 ± 5.1 cm; and body mass, 70.5 ± 8.2 kg; all measured in mean ± standard deviation [SD]) participated in this study. Inclusion criteria included healthy males aged of 18-35 years engaged in sports activities without musculoskeletal pain, while the exclusion criterion was the inability to perform NHE due to lower extremity injury. The experimental protocol was approved by the institutional review board of Waseda University’s ethical committee (approval number: 2022-531), and all procedures adhered to the principles of the Declaration of Helsinki. Informed consent was obtained from all participants after providing them with detailed information about the study.

PROCEDURES

Participants performed a warm-up comprising light aerobic activity (2 min of alternating stepping on a 15-cm high
box), a 15-second static hamstring stretch (standing hamstring stretch on one leg), and 1 set of 10 repetitions of dynamic hamstring stretching (forward leg swing). Hamstring stretching was performed on both legs. After the warm-up, surface EMG electrodes were attached to the BF of the right leg, and participants completed three repetitions of the prone leg curl with MVIC. The knee flexion angle during the prone leg curl was 30° and was performed against manual resistance. EMG measurements were performed with reference to "Standards for Reporting EMG Data." The examiner instructed the participants to reach maximal effort for 2 s and then maintain it for 2 s in each MVIC. There was at least 1 min of rest between each MVIC trial. The participants then performed three NHE trials with two additional familiarized repetitions before the trials. There was at least 2 min of rest between each NHE trial. The experiment was conducted under the supervision of a National Strength and Conditioning Association Certified Strength and Conditioning Specialist.

NORDIC HAMSTRING EXERCISE

Participants assumed a kneeling position on a bench of approximately 50 cm, with their elbows bent and hands open in front of them (Figure 1). They were instructed to lean forward slowly while maintaining a straight posture from the knee to the head. A certified examiner ensured correct execution of the NHE.

ELECTROMYOGRAPHY

The EMG signal was sampled at 1000 Hz and bandpass-filtered (10–450 Hz) using a wireless telemetry and surface EMG silver electrodes (DL-5000 with m-Biolog2; S&ME Inc., Tokyo, Japan). The electrode had a bar length of 1 cm, bar width of 0.1 cm, and distance of 1 cm between the recording sites. The participants’ skin was shaved the hair around the target site and cleaned using cotton dampened with alcohol to reduce noise. BF electrode placement was midpoint between the ischial tuberosity and the lateral condyle of the tibia. Participants were verbally encouraged to ensure maximal effort. Peak EMG activity during the prone leg curl and NHE was calculated based on the peak root mean square (RMS) value. The RMS value was computed for a 100 ms window.

TWO-DIMENSIONAL MOTION ANALYSIS

The iPhone 12 camera was set to 240 fps, and the camera was positioned approximately 3 m from the right side of the participants at a height of approximately 0.9 m. After transferring the recorded movie to a personal computer, two-dimensional motion analysis was performed using motion analysis software (Frame-DIAS V; DKH Inc., Tokyo, Japan). Reflective markers were attached to the greater trochanter, lateral epicondyle of the femur, and the lateral malleolus to calculate the knee flexion angle through digitization. The knee flexion angle was defined as an anatomical angle with a value of 0°, indicating full knee extension. In addition, the knee extension angular velocity was calculated based on the knee flexion angle and time.

DATA ANALYSIS

Kinematic data obtained through motion analysis were smoothed using a Butterworth low-pass filter with a cut-off frequency of 6 Hz. BPA for two-dimensional motion analysis was defined as the knee flexion angle at which the knee extension angular velocity exceeded 30°/s. The average BPA values from the motion analysis and the Nordic Angle

Figure 1. Nordic Angle screen information during the Nordic hamstring exercise. 1: Knee flexion angle (0° indicates the fully extended position of the knee); 2: BPA determined by the Nordic Angle; 3: Current time from the movie data start.
Values were calculated from the BPA values of the three NHE trials.

To calculate the knee flexion angle at the peak BF EMG activity, BF EMG activity and knee flexion were synchronized using a trigger mechanism with a synchronization lamp (TRIAS; DKH Inc., Tokyo, Japan) (Figure 2). To assess the BF EMG activity before and after BPA calculated using the Nordic Angle, the knee flexion angle was divided into seven phases (Figure 2). The average BF EMG activity in the seven phases before and after the BPA was calculated from the BF EMG activity values of the three NHE trials.

**STATISTICAL ANALYSIS**

Values are expressed as mean ± SD. The Shapiro–Wilk test was used to assess normality. Normality was not confirmed for BPA calculated by both Nordic Angle and motion analyses, whereas normality was not confirmed for one of the BF EMG activities in the seven knee flexion angle ranges. Differences in BF EMG activity in seven phases (10-15° before BPA, 15-10° before BPA, BPA ± 5°, 5-10° after BPA, 10-15° after BPA, 15-20° after BPA, 20-25° after BPA) before and after BPA were compared using Friedman test. The paired t-test was performed to confirm the difference in BPA calculated by the Nordic Angle and the knee flexion angle at peak BF EMG activity. Cohen’s d was classified based on the following effect size criteria: trivial, <0.2; small, 0.2 to 0.49; medium, 0.5 to 0.79; and large, >0.8. The validity of the Nordic Angle data was examined using the Pearson correlation test for consistency with the motion analysis data. The magnitude of the correlation was established based on the following criteria: r = 1, perfect correlation; 1 > r >= 0.9, nearly perfect; 0.9 > r >= 0.7, very large; 0.7 > r >= 0.5, large; 0.5 > r >= 0.3, moderate; 0.3 > r > 0.1, small; and 0.1 ≤ r, trivial. The agreement between the Nordic Angle and motion analysis was examined using the Bland–Altman analysis. The paired t-test was performed to confirm the difference in BPA between the Nordic Angle and motion analysis data. The limits of agreement in the Bland–Altman analysis were calculated by multiplying SD by ±1.96. Statistical analyses were performed using SPSS version 29 (IBM SPSS, Armonk, NY, USA). The significance level was set at p < 0.05.

**RESULTS**

**THE BF EMG ACTIVITY IN SEVEN PHASES BEFORE AND AFTER BREAK-POINT ANGLE**

The BPA values of the Nordic Angle and knee flexion angle at the peak BF EMG activity were 61.6 ± 10.7° and 62.9 ± 9.9°, respectively, with no significant difference observed between the two (d = 0.15, p = 0.678). Figure 3 shows the BF EMG activity magnitude before and after BPA, as calculated using the Nordic Angle. The BF EMG activity at 20-25° after BPA was significantly lower than at BPA ± 5° (d = 0.87, p = 0.011).

**THE VALIDITY OF THE NORDIC ANGLE**

Figure 4 shows the correlation between the BPA of the Nordic Angle and the motion analysis. The Pearson correlation between the Nordic angle and the angle deter-
Figure 3. The BF EMG activity before and after BPA.
Abbreviations: B10-15°, 10-15° before BPA; B5-10°, 5-10° before BPA; BPA ± 5°; A5-10°, 5-10° after BPA; A10-15°, 10-15° after BPA; A15-20°, 15-20° after BPA; A20-25°, 20-25° after BPA. The symbols * BPA ± 5° vs. A20-25° indicates statistically significant difference ($d = 0.87, p = 0.011$).

Figure 4. The correlation between the BPA obtained from the Nordic Angle and that determined through motion analysis.

Figure 5 shows the agreement between the BPA of the Nordic Angle and motion analysis. The BPAs obtained from the Nordic Angle and motion analysis were 61.6 ± 10.7° and 58.7 ± 11.2°, respectively, indicating a significant difference between the two datasets ($d = 0.27, p = 0.029$). The mean difference between the Nordic Angle and motion analysis values was 3.0 ± 4.3°, with the limits of agreement ranging from -5.5° to 11.4°.

International Journal of Sports Physical Therapy
DISCUSSION

The investigation of BF EMG activity before and after BPA, as calculated by the Nordic Angle, remains unexplored. In addition, there is no verification of the validity of Nordic Angle. Therefore, this study aimed to investigate the BF EMG activity before and after BPA, calculated using the Nordic Angle. In addition, it sought to re-examine the validity of the Nordic Angle by comparing the BPA values with motion analysis. The main outcomes are as follows: (a) No significant difference between the BPA of Nordic Angle and knee flexion angle at the peak BF EMG activity (d = 0.15, p = 0.678); (b) The BF EMG activity at 20-25° after BPA was significantly lower than the BF EMG activity at BPA ± 5° (d = 0.87, p = 0.011); (c) The Pearson correlation between the Nordic angle and the angle determined using motion analysis was perfect (r = 0.92, p < 0.001); (d) A significant difference between mean BPA values of the Nordic Angle and motion analysis was 3.0 ± 4.3° (d = 0.27, p = 0.029), and the limits of agreement ranged from -5.5 to 11.4 showing there was no statistical difference and good agreement between the two methods of measurement. These results supported the hypothesis.

Specifically, there was no significant difference between the BPA calculated using the Nordic Angle and the knee flexion angle at peak BF EMG activity (d = 0.15, p = 0.678), indicating that BF EMG activity peaked near the BPA. In addition, the BF EMG activity at 20-25° after BPA was significantly lower than that at BPA ± 5° (d = 0.87, p = 0.011) (Figure 5). This suggests that high BF EMG activity is maintained up to 20° after BPA, but it significantly decreases beyond 20° of BPA as calculated by the Nordic Angle. Soga et al. investigated the magnitude of BF EMG activity before and after BPA calculated by motion analysis during NHE variations with different lower leg slope angles. They reported that BF EMG activity peaks near the BPA during NHE variations with 20° or 40° lower leg slope, and decreases toward the shallow knee flexion position during NHE variations with 0° lower leg slope (similar to standard NHE). The results of this study support these findings, emphasizing the importance of knee flexion exercises that enhance BF EMG activity at 15-35° knee flexion to effectively prevent recurrent hamstring injuries, the BPA of the Nordic Angle should be kept within 35° to be effective in preventing recurrent hamstring injuries with standard NHE. Since the BPA is approximately 50° even for trained soccer players, incorporating lower leg slope assistance during NHE might be necessary to enhance its efficacy in preventing hamstring injuries in many athletes. The BPA changes proportionally with the angle of the lower leg slope, so if the Nordic Angle calculates a BPA of 75°, setting the lower leg slope angle to 40° would theoretically result in a BPA of 35°.

This study also assessed the validity of the Nordic Angle’s BPA determination. The findings confirmed a nearly perfect correlation between the BPA of the Nordic Angle and the BPA determined by motion analysis (r = 0.92, p < 0.001) (Figure 5). Comparatively, a previous study by Soga et al. using similar methodology did not achieve statistical significance in Spearman correlation (p = 0.052), but reported a very large correlation (rs = 0.75). They attributed the lack of significant differences to a small sample size (n = 7). In contrast, the current study with a larger sample size (n = 15) revealed a nearly perfect correlation, demonstrat-
ing that the Nordic Angle not only exhibits perfect reliability\textsuperscript{18} but also has high validity.

The results of this study revealed a significant difference between the mean BPA values of the Nordic Angle and motion analysis, amounting to $3.0 \pm 4.3^\circ$ ($d = 0.27$, $p = 0.029$), with the limits of agreement ranging from $-5.5^\circ$ to $11.4^\circ$ (Figure 5). These findings slightly differ from those of a previous study conducted by Soga et al., who compared the mean BPA of the Nordic Angle with the BPA of motion analysis using a methodology similar to that applied in this study. Their reported difference between the BPA of the Nordic Angle and motion analysis was $0.4 \pm 2.1^\circ$, which was not significantly significant. This discrepancy in results might be partly attributed to the different digitization locations used in the two studies. In the previous study, the knee flexion angle was calculated by digitizing the greater trochanter, center of the knee joint, and lateral malleolus, whereas in this study, it was calculated by digitizing greater trochanter, lateral epicondyle of the femur, and lateral malleolus. Although this variation might be responsible for the observed significant difference in BPA values, the small discrepancy of approximately $3^\circ$ ($d = 0.27$, $p = 0.029$) is not a major concern. Furthermore, Soga et al. reported that the limits of agreement ranged from $-3.9^\circ$ to $4.6^\circ$\textsuperscript{18} in their previous study, whereas in the present study, the limits of agreement were wider. This disparity in results could be attributed to the number of NHE trials conducted, with the previous study utilizing 12 trials, while the current study employed only three trials. It is likely that the variation in the number of trials affected the measurement precision. Therefore, it is recommended to perform BPA measurements using the Nordic Angle with at least 5 trials and calculate the average for improved accuracy.

This study has four limitations. First, the measurement method was limited to a two-dimensional motion analysis. It is crucial for future research to examine the validity of three-dimensional motion analysis to enhance the comprehensiveness of findings. Second, the data collected from repeated trials within a single day hindered the ability to draw conclusions about inter-session testing. Third, because the EMG electrodes were placed without the use of ultrasound etc., there may have been some crosstalk with other hamstring muscles. Finally, the age of the participants was $25.2 \pm 2.6$ years. This limits the generalizability of the findings of this study.

CONCLUSIONS

The results of this study indicate that BF EMG activity at $20-25^\circ$ after BPA was significantly lower than at BPA $\pm 5^\circ$ ($d = 0.87$, $p = 0.011$) and that there were no significant differences between BPA angles measured by the Nordic app and knee flexion angle at the peak BF EMG activity, and the correlations between these measures were nearly perfect. However, the mean difference between the Nordic Angle and motion analysis values was $3.0 \pm 4.3^\circ$, with the limits of agreement ranging from $-5.5^\circ$ to $11.4^\circ$.

ACKNOWLEDGMENTS

The authors would like to acknowledge the Graduate School of Sport Sciences, Waseda University for the valuable support and assistance provided throughout this study. The datasets generated during and/or analyzed during the current study are not publicly available but are available from the corresponding author, who was involved in organizing the study. This work was supported by both JST SPRING (Grant Number: JPMJSP2128) and JSPS KAKENHI (Grant Number: JP25K1988).

CONFLICT OF INTEREST DECLARATION

Nordic Angle is a smartphone application developed in collaboration with S-CADE. Co., Ltd. and Athletic Training Laboratory at Waseda University (instructed by Professor Norikazu Hirose). The first author of the article collected and analyzed the data. However, the authors of the current study assert no conflicts as they do not receive any fees from S-CADE. Co., Ltd. for developing the Nordic Angle, and the installation of the Nordic Angle app is free.

Submitted: July 24, 2023 CST, Accepted: September 26, 2023 CST
REFERENCES


Original Research

The Basas Spanish Squat: Superimposition of Electrical Stimulation to Optimize Patellar Tendon Strain: A Case Series

Carlos Basas 1, Naoaki Ito 2,3, Karin Grävare Silbernagel 2,3,a, Fernando Reyes-Gil 4, Ángel Basas

1 Department of Physical Therapy, Real Federación Española de Atletismo, 2 Department of Physical Therapy, University of Delaware, 3 Biomechanics and Movement Science Program, University of Delaware, 4 Department of Physical Therapy and Sport Science, Olympia Medical Center

Keywords: tendinopathy, acl, ultrasound imaging, mechanotherapy

https://doi.org/10.26603/001c.89267

International Journal of Sports Physical Therapy

Background
The Basas Spanish Squat with electrical stimulation (E-stim) has shown promising results as a potential key exercise in treatment of athletes with patellar tendinopathy. Gold standard exercise therapy for tendon injuries consists of tendon loading exercises, or exercises that appropriately applies high levels of mechanical strain to the tendon. The theoretical pathway in which the Basas Spanish Squat with E-stim improves tendinopathy has been speculated to be the additional strain applied through the patellar tendon during superimposition of E-stim. This theory, however, has yet to be confirmed.

Purpose
The purpose of this case series was to compare patellar tendon strain, during the Basas Spanish Squat with, and without E-stim, and open kinetic chain knee extension.

Methods
Four healthy participants performed the three exercises while a physical therapist collected simultaneous unilateral ultrasound images from the patellar tendon. Strain was calculated as the change in patellar tendon length during contraction divided by the resting length.

Results
Amongst all participants, patellar tendon strain was smallest during the Basas Spanish Squat without E-stim, followed by the open kinetic chain knee extension at 60% maximum voluntary isometric contraction. The Basas Spanish Squat with E-stim yielded approximately double or more strain compared to the without E-stim condition and demonstrated higher level of strain compared to open kinetic chain knee extension in all participants.

Conclusion
The findings reflect a clear trend of increased strain through the patellar tendon when E-stim was superimposed. The results support the theory that the Basas Spanish Squat with E-stim increases patellar tendon strain and could explain the reported clinical benefits in individuals with patellar tendinopathy.

Level of Evidence
4, Case series

a Corresponding Author:
Karin Grävare Silbernagel
540 S. College Ave, Newark, DE 19713, USA
Email: kgs@udel.edu; Phone: 302-831-4808; Fax: 302-269-8011
INTRODUCTION

The "Basas" Spanish Squat has been presented in literature as a recommended exercise for treatment of patients with patellar tendinopathy.1-4 A variation of the exercise which included superimposed electrical stimulation (E-stim) during the exercise was first introduced in 2014.2,3 Incorporating the Basas Spanish Squat with, and without E-stim has shown promising results for reducing pain in athletes with patellar tendinopathy.3,4 When performed correctly with the appropriate setup, the Basas Spanish Squat can be a challenging exercise for the quadriceps even when the movement is isometric and seems simple. The highest level of evidence regarding exercise therapy for tendon injuries entails heavy loaded exercises that subsequently maximize load through the tendon,1,5-8 commonly referred to as mechanotherapy,9 and the Basas Spanish Squat exercise with and without E-stim is thought to do that with a simple setup. At the biomechanical level, tendon load can be defined as a high level of tendon force,10,11 which results in higher levels of mechanical strain10,12-15 within the targeted tendon. This high level of mechanical strain is what induces therapeutic changes at the cellular and molecular level which leads to recovery.5

Evidence is clear that tendon loading is key for successful treatment of patients with patellar tendon injuries.1,5,7,16-18 What is less commonly discussed, however, is that prescribing "tendon loading exercises", does not always equate to optimal "tendon loading". Quadriceps inhibition is common in patients with patellar tendon injuries.19 and biomechanical analyses have quantified that patients with knee pathologies compensate by shifting load towards the contralateral limb (during bilateral tasks), and their hip and ankle joints on the ipsilateral side.20-23 This can be problematic in the clinical setting, since unless there are clear visible deviations in mechanics, there is no objective way to know if the "tendon loading exercise" prescribed is in fact loading the tendon. The mechanism by which the Basas Spanish Squat with E-stim is thought to overcome this issue, is through the additional electrically stimulated contraction of the quadriceps muscles which gives the patient no choice but to load the patellar tendon.5,24 This could mean that patients with quadriceps inhibition or with significant compensations during exercises can still optimize patellar tendon load through superimposed E-stim. This additional contraction from E-stim likely induces higher levels of mechanical strain at the patellar tendon, but this has yet to be confirmed using objective measurements of tendon load.

Ultrasound imaging technology has advanced in recent years and methods for measuring tendon strain, a surrogate to tendon forces or "load", have been described.25,26 Specifically, Edama et al. described their methods to be near excellent (ICC = 0.804 – 0.946) in reliability when measuring patellar tendon strain during open kinetic chain knee extensions and during squatting.25 These methods are simple, timely, and can be implemented easily into clinical practice if appropriate equipment is available.27 Arampatzis et al. suggest the use of objective clinical assessments of tendon strain for targeted intervention when treating patients with tendinopathy.28 Given the importance of tendon loading for tendon rehabilitation, and the advancements in technology and recommendations for quantifying tendon strain, there is a need to evaluate exercises and methods that augment strain in the targeted tendon. The purpose of this case series was to calculate and compare patellar tendon strain using ultrasound imaging during the Basas Spanish Squat with, and without E-stim, and open kinetic chain knee extension.

METHODS

PARTICIPANTS

Four healthy active participants29 with no history of major lower extremity injuries, surgeries, or current symptoms in their patellar tendon30 were tested (Table 1). Testing was performed unilaterally on a leg chosen using a random number generator.

ULTRASOUND IMAGING

Extended field of view ultrasound images (GE Healthcare, Logiq e, Frequency: 10MHz, Depth: 2-3 cm) were collected at rest and during exercises at 90 degrees of knee flexion31 for all exercises to calculate patellar tendon strain. Patellar tendon length was defined by the deep attachment of the patellar tendon at the tibia and at the patella.32 Strain was defined as the change in patellar tendon length (contracted – resting) divided by the resting length and expressed as a percentage (%). Each resting length and concurrent exercise images were captured three times, and an average was used to calculate strain.

OPEN KINETIC CHAIN KNEE EXTENSION

After a standardized warm-up, knee extension maximum voluntary isometric contraction (MVIC) tests were performed on an isokinetic dynamometer in 90 degrees of knee flexion (Biodex System 3, Shirley, NY). Peak MVIC was then used to calculate 60% MVIC and participants performed three trials of isometric contractions with a visual target line while simultaneous ultrasound images were collected (Figure 1 and Supplementary File 1). Sixty percent MVIC was chosen as the reference point for this study, as data presented by Edama et al.25 has established reliability of this method up to this intensity.

BASAS SPANISH SQUAT WITHOUT E-STIM

The Basas Spanish squat was performed by setting up a rigid strap fixation immediately below the knee joint line. The participants were asked to squat while keeping the trunk upright until they reached 90 degrees of knee flexion (Figure 2). Knee joint angle was tracked throughout the movement using a goniometer and ultrasound images were taken once the participant reached 90 degrees of flexion in the limb being tested. Resting lengths were calculated with the participants sitting upright in a chair with the quadriceps
Table 1. Participant demographics.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Sex</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>PAS</th>
<th>VISA-P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Male</td>
<td>29</td>
<td>185</td>
<td>79</td>
<td>6</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>Male</td>
<td>29</td>
<td>180</td>
<td>82</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>Male</td>
<td>24</td>
<td>175</td>
<td>67</td>
<td>4</td>
<td>90</td>
</tr>
<tr>
<td>4</td>
<td>Female</td>
<td>27</td>
<td>170</td>
<td>89</td>
<td>5</td>
<td>100</td>
</tr>
</tbody>
</table>

PAS = physical activity scale, VISA-P = Victorian Institute of Sports Assessment

---

**Figure 1.** Example trial of simultaneous ultrasound imaging during isometric contractions.

**Figure 2.** Example Basas Spanish Squat without E-stim

clops relaxed and knee at 90 degrees (same position as during the squat).

**Figure 3.** Electrode placement over proximal and distal quadriceps motor points

**BASAS SPANISH SQUAT WITH E-STIM**

E-stim was delivered using a commercial electrical stimulator (Chattanooga, Continuum. Settings: biphasic pulse, 75Hz, 400μs, 0 second ramp, trigger activated) with a trigger and two 3 inch × 5 inch electrodes placed over the quadriceps motor points.

The stimulation was initially dosed to maximal tolerance (i.e., the highest possible level of quadriceps contraction tolerated by the participant) with the participant in the bottom position of the Basas Spanish Squat prior to the testing trials. Once maximum tolerance was identified, the participant performed the same procedure as the condition without E-stim, but this time the trigger was activated manually by the participant once the knee reached 90 degrees of flexion (Figure 4 and Supplementary File 2). Patellar tendon lengths were then collected in this position to calculate strain.
RESULTS

Open kinetic chain knee extensions at 60% MVIC yielded higher levels of strain compared to the Basas Spanish Squat without E-stim in all four healthy participants. Once the E-stim was added, strain approximately doubled in three out of the four participants and increased seven-fold in one participant (Table 2). This one participant did, however, demonstrate minimal strain during the "without E-stim" condition which may have exaggerated the percent increase in strain once E-stim was added. This small cohort also demonstrated a large variability in strain, yet the relative relationship between each testing condition was consistent and clear amongst the four participants; lowest during the Basas Spanish Squat without E-stim, followed by the open kinetic chain knee extension at 60% MVIC, and highest during the Basas Spanish Squat with E-stim (Table 2).

DISCUSSION

The purpose of this case series was to calculate and compare patellar tendon strain, using ultrasound imaging, during the Basas Spanish Squat with, and without E-stim, and open kinetic chain knee extension in a small healthy cohort. Even with a small cohort, a clear pattern emerged from our results; superimposition of E-stim during the Basas Spanish Squat increases tendon strain during the exercise. The findings suggest that if the target of an exercise intervention is to induce additional load (or strain) to the patellar tendon, adding E-stim during the Basas Spanish Squat is an option. The level of increase in strain varied slightly among the four participants, but this may be attributed to each participants’ tolerance to E-stim (i.e., those who tolerated higher levels of current may have demonstrated greater increase in strain).

The results from this case series may in part explain the mechanism behind the positive findings by Basas et al., who incorporated the Basas Spanish Squat with E-stim during rehabilitation of high-level athletes with chronic patellar tendinopathy (over multiple seasons) to manage symptoms throughout competition. The additional strain the patellar tendon experienced from superimposition of E-stim may affect tendon remodeling and recovery in ways not achieved with voluntary muscle contraction alone. Further investigation, however, on the effects of additional strain from the E-stim on tendon properties and clinical outcomes are necessary. Superimposition of E-stim during a slow sit-to-stand exercise has also shown similar improvements for strength and symptoms in a cohort of 32 patients with patellar tendinopathy while limiting the pain experienced during exercise compared with heavy, slow resisted exercise. A similar effect of E-stim on patellar tendon strain may occur during exercises other than the Basas Spanish Squat, thus, clinicians may consider application of E-stim during other patellar tendon loading exercises.

While results presented are from a small healthy cohort, quadriceps inhibition, or the inability to fully activate all motor units in the muscle, is common after knee injuries. Patients with patellar tendon injuries who produce weaker voluntary quadriceps contraction to load the patellar tendon may see further benefit of using superimposition of E-stim in their care. Quadriceps inhibition and disuse can lead to subsequent underloading of the patellar tendon, meaning forced contraction of the muscle through E-stim may be necessary to appropriately provide mechanical strain. Patients with patellar tendinopathy commonly shift load towards their hip and ankle joints during exercise, which can lead to performing prescribed exercises while subconsciously shifting load away from the targeted muscle and tendon even if appropriate instruction is given. This alteration is not specific to the performance of the Basas Spanish Squat, and E-stim can be used during open kinetic

Table 2. Patellar tendon strain during each exercise condition.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Open kinetic chain knee extension at 60% MVIC (%)</th>
<th>Basas Spanish Squat without E-stim (%)</th>
<th>Basas Spanish Squat with E-stim (%)</th>
<th>Percent increase in strain with additional E-stim (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.82</td>
<td>3.45</td>
<td>7.83</td>
<td>226.9</td>
</tr>
<tr>
<td>2</td>
<td>3.85</td>
<td>0.74</td>
<td>5.69</td>
<td>769.9</td>
</tr>
<tr>
<td>3</td>
<td>8.52</td>
<td>5.66</td>
<td>10.83</td>
<td>191.6</td>
</tr>
<tr>
<td>4</td>
<td>15.40</td>
<td>9.48</td>
<td>18.37</td>
<td>193.8</td>
</tr>
</tbody>
</table>

MVIC = maximum voluntary isometric contraction
chain knee extension exercises or other closed kinetic chain exercises as well, depending on the needs of each patient. If dosed appropriately, superimposition of E-stim bypasses quadriceps weakness and inhibition that limits voluntary quadriceps force production, as this method provides additional involuntary contraction at the quadriceps and induces higher levels of patellar tendon strain.

The appropriate dose and settings for superimposition of E-stim to manage patellar tendon injuries varies within the literature, and clinicians considering the use of this modality may question what parameters they should be using for their patients. The authors believe that the exact stimulation parameters and dosing is likely not the most important, given that the literature in treatment of tendinopathy continues to suggest that the type of loading (eccentric vs concentric vs isometric) does not influence outcomes. Tendons respond to mechanical load, so parameters and repetition schemes that can achieve the highest level of strain while minimizing discomfort at the quadriceps and pain at the patellar tendon, is likely the best to use. Information on optimal E-stim parameters has been documented in the neuromuscular electrical stimulation (NMES) literature that has traditionally targeted recovering quadriceps strength after traumatic knee injuries such as anterior cruciate ligament injuries. Available evidence and clinical recommendations were considered in choosing the parameters used for this study. The authors recommend that clinicians use these parameters as guidelines, but also modify parameters as necessary to individualize for comfort and maximize knee extension torque output. The other key component for appropriate dosing is the ability to measure patellar tendon strain and/or knee extensor torque during the exercises. If imaging modalities are available, it is beneficial to quantify and confirm the amount of strain the patellar tendon experiences during exercises to appropriately dose the exercise.

Some limitations must be considered. Given the small cohort and explorative nature of this case series, further investigation with a larger sample is necessary, however, clear effects using reliable methods were found. There is also a need to compare clinical and functional outcomes following implementation of this exercise as part of a protocol treating a cohort of patients with patellar tendon injuries.

CONCLUSION

The Basas Spanish Squat with E-stim should be considered as a key exercise in optimizing rehabilitation of athletes with patellar tendon injuries through maximizing tendon strain and promoting tendon recovery and remodeling.

CORRESPONDING AUTHOR

Karin Grävare Silbernagel
540 S. College Ave, Newark, DE 19713, USA
Email: kgs@udel.edu; Phone: 302-831-4808; Fax: 302-269-8011

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

ACKNOWLEDGEMENTS

This study is based on a collaboration that began when Carlos Basas was visiting the Delaware Tendon Research Lab and shared the Basas protocol, developed by his father Ángel Basas, that was utilized in Spain to treat athletes with patellar tendinopathy. During the manuscript preparation Ángel and Carlos Basas passed away in a tragic accident. The publication of this manuscript is in honor of their hard work in pursuing excellence in their profession to help those with tendon injuries recover and perform at their best.

Submitted: June 21, 2023 CST, Accepted: September 24, 2023 CST
REFERENCES


International Journal of Sports Physical Therapy

SUPPLEMENTARY MATERIALS

Supplemental file 1

Supplemental file 2
Is There an Association Between Injury History and Lower Extremity Joint Injury During Canada Games Competition?

Umar Yousufy1, Nicole J. Chimera1 a

1 Faculty of Applied Health Science, Brock University

Keywords: athlete, previous injury, incidence, likelihood

https://doi.org/10.26603/001c.89273

International Journal of Sports Physical Therapy

Background
Injuries during elite level competition like the Canada Games, occur frequently and injury history is one of the strongest predictors of future injury; however, this association is unknown in the Canada Games.

Purpose
To determine the association between injury history and incidence of lower extremity joint injury during Canada Games competition.

Methods
Data from the 2009 – 2019 Canada Games (8710 male and 8391 female athletes) competitions were de-identified by the Canada Games Council for analysis. Injury data were cleaned and categorized for previous injury and injury type and location. Injury history was self-reported and included concussion, major surgical procedure, neck and back, trauma to joint or bone, and trauma to ligament or tendon. Injury from the Canada Games competitions were categorized to include ankle, knee, hip, and patellofemoral joint injuries. Chi-Square (Χ2) test of independence determined association between injury history and incidence of lower extremity joint injury during Canada Games competition. IBM SPSS (Version 26) was used for statistical analysis (p-value < 0.05).

Results
Four hundred and seventy-five ankle, 503 knee, 253 hip, and 106 patellofemoral joint injuries were reported during 10 years of Canada Games competitions. There were significant associations between history of neck and back injuries with ankle injuries and knee injuries, history of trauma and overuse of ligament or tendon with hip injuries and history of trauma or overuse of joint or bone with patellofemoral joint injuries.

Conclusion
These findings support previous literature suggesting that injury history is associated with future injury.

Level of Evidence
3

Corresponding Author:
Nicole J Chimera, PhD, CAT(C), ATC, CSCS
1812 Sir Issac Brock Way
St.Catharines, ON, L2S 3A1
905-688-5550 x6755
nchimera@brocku.ca
INTRODUCTION

The Canada Games competition is the highest level of competition where amateur Canadian athletes can showcase their skills and talents during various events while competing against other athletes from other provinces or territories. These athletes must train for many years to qualify for the Canada Games, which may result in injuries that can be due to overtraining, inadequate nutrition, insufficient recovery, and poor technique. Previous studies have noted that injury history is considered one of the strongest predictors of future injury in athletes. For example, in Australian football players Orchard et al. reported that previous injuries increased the risk of sustaining a muscle strain at the same location in the hamstrings, as well as in the quadriceps and calf muscles, using an observational cohort studying 5 high school sports over 3 years. Rauh et al. found that previous injuries increased the risk of future injuries at the same location as the prior injury as well as to different regions. This relationship between injury history and future injury may be attributed to deficits in muscular strength, proprioception, altered movement patterns, reduced range of motion (ROM), and accumulation of scar tissue.

Lower extremity injuries in an active, healthy adult population lead to intrinsic changes at the initial point of injury, which may contribute to increase risk of future injury. For example, having previous knee joint trauma has been associated with a two-to-three-fold increase in risk of future knee injury. Many recurrent injuries can be attributed to inadequate rehabilitation and premature return to play; however, some injuries may increase the risk of re-injury regardless of time interval between initial injury and future injury. Further, regional interdependence is an important factor of how movement occurring within the kinetic chain can contribute to future re-injury specifically to the lower extremity.

The lower limb is the most common anatomical site injured among Olympic-level athletes with ankle and knee injuries reported most commonly amongst British and US athletes. Ankle injuries are said to be one of the most commonly reported injuries in sports, including soccer, basketball, football, and volleyball. Athletes who suffer an ankle injury can have symptoms such as mechanical instability, stiffness and swelling, and cartilage damage which can lead to degenerative changes. At the knee, anterior cruciate ligament injury (ACL) is the most common knee injury reported in athletes; this injury can be detrimental to athletes because of post injury altered gait and knee kinematics, muscle weakness, and deficits in functional assessments, which are associated with long-term risk of meniscal tears, osteoarthritis, and chondral lesions. Further, the prevalence of patellofemoral joint injury is high and it mainly impacts athletes with no structural abnormalities. Rathleff et al. reported that 25% of recreational athletes with patellofemoral joint injuries stopped participating in sports due to knee pain. Other lower extremity injuries such as those to the hip are also problematic in athletes as these have been associated with decline in athletic performance in various sports due to factors such as weaker hip adductor muscles, age, and ROM deficits. Multiple authors have noted that history of injury can increase risk of lower extremity joint injuries. However, the association between injury history and lower extremity joint injury is still unknown in the Canada Games.

Therefore, the purpose of this study was to examine the association between injury history and lower extremity joint injury during the Canada Games Competition between 2009-2019. The authors hypothesized that there would be a significant association between injury history and lower extremity joint injury across 10 years of Canada Games competition.

METHODS

STUDY DESIGN

This research study was a retrospective cohort design that assessed the association between injury history and incidence of lower extremity joint injury during the Canada Games competition between 2009-2019.

PARTICIPANTS

Seventeen thousand, one-hundred and one athletes competed in the Canada Games over 10 years of competition (8710 males and 8391 females). For the purposes of this study, the authors focused on lower extremity joint injury and examined reports of ankle, knee, hip, and patellofemoral injuries from a larger sample in which the descriptive epidemiology of Canada Games data were determined.

PROCEDURES

This secondary analysis of data was approved by the Brock University Ethics Board. Following approval, the Canada Games Council provided anonymized data for any athletes seeking medical attention during competition; athletes competing in the Canada Games gave consent for their data to be used for research purposes. All athletes provided the Canada Games with their medical history from an intake form that was provided to the athletes from the Canada Games Council; this medical history asked athletes to self-report if they previously experienced any of the following: concussion, major surgical procedures, neck and back injuries, trauma to joint or bone injuries and trauma to ligament or tendon injuries. The medical history, as well as injury data for athletes seeking medical attention, were provided to the researcher in a de-identified manner and included information such as, injury history, injury assessments, injury location and type of injury for each injury assessments.

Previous injuries (medical history) were then categorized and coded for concussion, major surgical procedures, neck or back injuries, trauma to joint and bone injuries and trauma to ligament or tendon injuries. For injuries incurred during the Canada Games competition, data were cleaned and coded in a descriptive epidemiological study, a fur-
ther subset of this dataset was used for this current analysis based on injury location (ankle, knee, hip and patellofemoral joint) and injury type (fractures, sprains, meniscus, contusion, tendinopathy, arthritis, and patellofemoral pain syndrome). Additionally, information on athlete’s sex, province and sport were also provided. Data were inclusive of the Canada Games competition from 2009-2019. Following categorization and coding of the data the total number of ankle, knee, hip, and patellofemoral joint injuries across 10 years of competition were determined using Microsoft Excel. Chi-Square test of Independence was performed to determine the association between injury history and lower extremity joint injury location and injury types. The statistical analysis was conducted using SPSS (IBM SPSS Version 26, Armonk, NY) and p < .05 indicated statistical significance.

RESULTS

The initial data consisted of 17101 athletes (8710 male; 8391 females) who competed in the Canada Games competition between 2009-2019. From the sample 475 ankle injuries, 253 hip injuries, 505 knee injuries, and 106 patellofemoral injuries that were categorized as fractures, sprains, meniscus, contusion, tendinopathy, arthritis, and patellofemoral pain syndrome were identified during Canada Games competitions between 2009-2019. From 2009-2019 there were 125 fractures, 477 sprains, 68 meniscus, 133 contusions, 106 tendinopathy, 36 arthritis, or 96 patellofemoral pain syndromes were identified involving lower extremity joint injuries (Table 2). The relationship between reported cases of history of injury categories and injuries to the lower extremity joints are indicated in Table 1; while Table 2 demonstrates the relationship between history of injury categories and reported injury type.

There was a significant association between history of neck and back injuries with ankle and knee injuries. There was also a significant association between history of trauma or overuse of ligament or tendon with hip injuries. History of trauma or overuse of joint or bone was significantly associated with patellofemoral joint injuries (Table 3). Ankle and knee injuries were six times more likely with prior neck and back injuries. Hip injuries were four times more likely with previous trauma or overuse of any ligament or tendon injuries and patellofemoral joint injuries were seven times more likely with previous trauma or overuse of joint or bone injuries (Table 3).

There was a significant association between history of major surgical procedures with meniscus injury. History of trauma or overuse of joint or bone injuries was significantly associated with contusion, tendinopathy, and patellofemoral pain syndrome. History of trauma or overuse of ligament or tendon was significantly associated with sprains (Table 4). Contusions were four and a half times more likely with a history of trauma or overuse of joint or bone injuries. Tendinopathy and patellofemoral pain syndrome were four and seven times more likely respectively, with trauma or overuse of any joint or bone injuries. Sprains were four times more likely with previous trauma or overuse of any tendon or ligament injuries (Table 4).

DISCUSSION

The purpose of this study was to determine the association between injury history and lower extremity joint injuries during the Canada Games competition from 2009-2019. The key findings from this study were (1) previous injuries such as previous neck and back injuries, trauma or overuse of any ligament or tendon, and trauma or overuse of any joint or bone were associated with lower extremity joint injury and (2) any prior major surgical procedure, trauma or overuse of any ligament or tendon, and trauma or overuse of any joint or bone were associated with sprains, meniscus, contusion, tendinopathy, and patellofemoral pain syndrome. These findings are consistent with previous literature suggesting that injury history may increase the risk of future injuries.5,4,25,26 Multiple authors have suggested that re-injury can be attributed to neuromuscular factors that are present following initial injury.27,28 Following injury, alterations occurring in overall strength, proprioceptive abilities, and kinematics impact motor and cognitive function, which may be potential risk factors for re-injury. These factors may suggest areas for clinicians to target through rehabilitation strategies aimed to mitigate the risk of re-injury and/or new future injury.

Neck and back injuries were associated with ankle and knee injuries across 10 years of the Canada Games competition. These findings are similar to those reported in collegiate athletes as a history of lower back pain is a strong predictor of knee, ACL and other ligamentous injuries.29 The mechanisms behind this may include lower back pain resulting in alterations in trunk motor control, impaired postural control, delayed muscle latencies, and abnormal trunk muscle recruitment patterns.30,31 Further, there is an established association between previous neck and back injuries with lower extremity joint injuries in varsity-level athletes, which may be attributed to patients with lower back pain adopting a trunk-flexed posture and moving with greater knee extension.32 It is important to acknowledge that multiple authors have indicated a relationship between history of back injuries and hip rotation range of motion.33,34 However, no association was present in this current study. This may be due to the type of movement patterns involved in various sports that places different stresses on the joints of the lower extremity or it could be related to a self-report bias of injury history that may be present in this current study. To the authors’ knowledge, this study is the first to observe an association between previous neck injuries with ankle and knee injuries; however, because neck and back were grouped together it is possible that this association may be related to back injuries rather than neck injuries. Due to the retrospective nature of this study, the authors are unable to ascertain if previous injury history was related specifically to the neck or the back. Further investigation is needed to determine if there is a relationship between neck injuries and lower extremity injuries. Sprains were four times more likely with previous trauma or overuse of any tendon or ligament injuries (Table 4).
Table 1. Results from 2x2 Contingency Table from Chi-Square analysis examining injury history and lower extremity joint injury.

<table>
<thead>
<tr>
<th>Injury History</th>
<th>Lower Extremity Joint Injury During Canada Games Competitions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ankle</td>
</tr>
<tr>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>Head &amp; Concussion Injuries</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Major Surgical Procedure</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Neck &amp; Back Injuries</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Trauma or overuse of Joint &amp; Bone</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Trauma or Overuse of Ligament &amp; Tendon</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>N</td>
</tr>
</tbody>
</table>

*Y = Yes, N = No
*Y = Yes in both horizontal and vertical categories indicate having experienced both previous injury history on the vertical axis as well as experiencing an injury to the joint indicated on the horizontal axis, N = No in both the horizontal and vertical categories indicates not having experienced the previous injury on the vertical axis and the injury to the joint indicated on the horizontal axis. For example, in the upper left-hand box there were 25 participants who reported a history of a head and concussion injury and an ankle injury during competition, and there were 450 participants in the upper left-hand box that did not report a history of a head and concussion injury; however, did experience an ankle injury.

joint injuries. If this relationship does exist, future research should consider the mechanisms that may contribute to the association between neck injuries and ankle and knee injuries.

Previous trauma or overuse to joint or bone was associated with patellofemoral joint injuries. Common risk factors for patellofemoral joint injury include training loads, movement technique, strength of lower extremity musculature, and type of footwear.35,36 There is a paucity of literature linking an association between previous joint or bone injuries with patellofemoral joint injuries. However, one study suggested a relationship between injury history and patellofemoral joint injuries as patellar dislocation or subluxation and surgeries have been noted to increase risk of future patellofemoral injuries.37 Previous authors have hypothesized that the mechanisms behind this association may be due to altered biomechanics, proprioceptive abilities, and neuromuscular control that may predispose an individual to future patellofemoral joint injuries.38-40 In addition, individuals with patellofemoral pain often demonstrate hip weakness, suggesting an association may exist between hip strength and patellofemoral joint injuries.31,42 Further investigation is needed to verify if altered biomechanics, proprioception, and neuromuscular control are the mechanisms for the association in this current study. Of note, one previous study indicated an association between major surgical procedures and patellofemoral joint injuries23; however, the current findings differ as there was no association between major surgical procedures and patellofemoral joint injuries. It is possible that variations in operational definitions between studies and/or a recall bias could have led to these differences. Additionally, foot abnormalities such as pes cavus are very common in athletes with patellofemoral joint injuries43; thus, it is possible that foot abnormalities may be one the factors behind the association between injury history and patellofemoral joint injuries. Other risk factors such as compressive instability, patellar trauma, soft tissue lesions, overuse syndromes, and osteochondritis may increase the risk of a patellofemoral joint injury suggesting an association with previous trauma or overuse of joint and bone injury.38

In this study, previous trauma or overuse of any ligament or tendon was associated with hip injuries. This is consistent with previous reports indicating that there is an association between injury history and hip injuries.39 One study reported weakness in the hip abductor muscles in individuals with a history of ankle sprains this may suggest that weakness in hip stabilizing musculature resulting in joint deviations and decreased hip stability, was related to proximal kinetic chain maladaptation resulting from ankle ligamentous instability.44 After lower limb ligamentous injuries, dynamic postural stability of the lumbopelvic complex decreases, which can increase the risk of hip injuries.45 Athletes with prior ligamentous injury may experience sensory and motor behavior deficits, which have been attributed to the lack of connection between mechanoreceptors and nervous system restoration.10 For example, deficits in knee joint position sense during passive and action range of motion have been observed with athletes with ACL injuries.4 Researchers have speculated that decrease in hip musculature can contribute to faulty lower extremity mechanics during dynamic tasks.

The current findings of association between previous trauma or overuse of ligament or tendon injury and sprains are consistent with conclusions of multiple authors indicating that previous injuries were the most important risk factors for sprains.46-48 For example, Bahr & Bahr49 reported that there is a six-to-ten-fold increase in future ankle sprains with prior history of ankle injuries. Multiple
Table 2. Results from 2x2 Contingency Table from Chi-Square analysis examining injury history and injury type.

<table>
<thead>
<tr>
<th>Injury History</th>
<th>Fracture</th>
<th>Sprain</th>
<th>Meniscus</th>
<th>Contusion</th>
<th>TP</th>
<th>Arthritis</th>
<th>PFPS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Head &amp; Concussion Injury</td>
<td>5</td>
<td>77</td>
<td>25</td>
<td>57</td>
<td>7</td>
<td>75</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>1140</td>
<td>452</td>
<td>808</td>
<td>126</td>
<td>1134</td>
<td>102</td>
</tr>
<tr>
<td>Major Surgical Procedure</td>
<td>6</td>
<td>78</td>
<td>23</td>
<td>61</td>
<td>9</td>
<td>75</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>119</td>
<td>1139</td>
<td>454</td>
<td>804</td>
<td>125</td>
<td>1133</td>
<td>97</td>
</tr>
<tr>
<td>Neck &amp; Back Injuries</td>
<td>2</td>
<td>35</td>
<td>15</td>
<td>22</td>
<td>0</td>
<td>37</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>123</td>
<td>1182</td>
<td>462</td>
<td>843</td>
<td>68</td>
<td>1237</td>
<td>128</td>
</tr>
<tr>
<td>Trauma or Overuse of Joint &amp; Bone</td>
<td>Y</td>
<td>18</td>
<td>194</td>
<td>74</td>
<td>6</td>
<td>206</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>107</td>
<td>1023</td>
<td>403</td>
<td>727</td>
<td>62</td>
<td>1068</td>
<td>120</td>
</tr>
<tr>
<td>Trauma or Overuse of Ligament &amp; Tendon</td>
<td>Y</td>
<td>17</td>
<td>201</td>
<td>91</td>
<td>11</td>
<td>207</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>108</td>
<td>1016</td>
<td>386</td>
<td>738</td>
<td>57</td>
<td>1067</td>
<td>117</td>
</tr>
</tbody>
</table>

*Y= Yes, N = No.

*Yes, in both horizontal and vertical categories indicates having experienced both previous injury history on the vertical axis as well as experiencing injury type indicated on the horizontal axis, N = No in both the horizontal and vertical categories indicates not having experienced the previous injury on the vertical axis and injury type indicated on the horizontal axis. For example, in the upper left hand box, there were 5 participants who reported a history of a head and concussion injury and a fracture during competition, and there were 120 participants in the upper left hand box that did not report a history of a head and concussion injury; however, did experience a fracture during competition.

TP= Tendinopathy, PFPS= Patellofemoral Pain Syndrome
Table 3. Significant Association and Likelihood Ratio between injury history and lower extremity joint injury

<table>
<thead>
<tr>
<th>Injury History</th>
<th>Lower Extremity Joint Injuries During Canada Games Competition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ankle</td>
</tr>
<tr>
<td>Head &amp; Concussion Injuries</td>
<td>$\chi^2 = 0.920$ $df = 1$ $p = 0.338$ $LR = 0.940$</td>
</tr>
<tr>
<td>Major Surgical Procedure</td>
<td>$\chi^2 = 2.517$ $df = 1$ $p = 0.113$ $LR = 2.614$</td>
</tr>
<tr>
<td>Neck &amp; Back Injuries</td>
<td>$\chi^2 = 5.793$ $df = 1$ $p = 0.016$ $LR = 5.509$</td>
</tr>
<tr>
<td>Trauma or Overuse of Joint &amp; Bone</td>
<td>$\chi^2 = 0.102$ $df = 1$ $p = 0.750$ $LR = 0.102$</td>
</tr>
<tr>
<td>Trauma or Overuse of Ligament &amp; Tendons</td>
<td>$\chi^2 = 2.814$ $df = 1$ $p = 0.093$ $LR = 2.771$</td>
</tr>
</tbody>
</table>

*Bolded = Statistically significant difference, LR = Likelihood Ratio

authors have hypothesized the increase in future ankle sprains may be due to the mechanical (persistent ligamentous laxity) and functional (proprioceptive deficits) instability of the joint. To the authors’ knowledge, this is the first study to report an association between previous major surgical procedures and contusions; however, the potential mechanisms involved in this association is currently unknown. Further, investigation is required to determine the potential mechanism involved.

This current study did not focus on the differences in the association of injury history and lower extremity joint injury between male and female athletes so the authors are unable to ascertain if biological sex may have been a factor in injury risk. Further, self-reported injury history was utilized in this study, and although this is a commonly accepted practice, it results in potential recall bias of athletes underestimating or overestimating their injury history. Previous literature has suggested that athletes neglect reporting symptoms of concussion to medical personnel which means that it is likely that history of concussions may be underreported. LaBotz et al. reported 48% of collegiate athletes reported signs and symptoms of concussions using the Concussion Symptom Survey Design (CSS), but only 17% reported symptoms of concussions using the Pre-Participation Physical Exam (PPE). It is possible that an underreporting of concussion history during the medial history intake in this study led to the lack of association between concussion history and lower extremity joint injury in the Canada Games athletes included in this study. Internal risk factors, such as an athlete’s psychological disposition are poised to modify injury risk. Further, Renon et al. reported a positive association between athlete identity (eg, depressive symptoms, performance traits, self-worth, motivation) and behaviour (eg, adherence and playing through pain) with injury-related outcomes. Additionally, risk-taking behavior and various psychological factors may be important to consider, especially for athletes who are repeatedly injured. While this current study did not obtain information on athletes’ psychological disposition it may be advantageous for researchers to consider these factors in future association studies. While this is the first study to look at the association between self-reported injury history and injury occurrence in athletes participating in the Canada Games competition these findings lack external validity as they cannot be generalized to the general population. Further, due to the de-identified dataset, the authors are not able to ascertain the number of participants who had competed in the Canada Games more than once. Finally, in this study, information regarding injury history was limited to the categorization of previous injuries based on Canada Games medical history intake forms; thus, the criteria that were used for gathering injury history data were non-modifiable. However, this is the only study to specifically assess the association of prior injuries with future injuries incurred in the lower extremity joints, and this is the first study to examine the association between injury history and lower extremity joint injury in the Canada Games.

CONCLUSION

The results of the current study confirm the hypothesis that injury history is associated with lower extremity joint injury across 10 years of Canada Games competitions. Association between history of neck and back injuries with ankle and knee injuries, history of trauma or overuse of ligament or tendon and hip injuries and history of trauma or overuse.
Table 4. Significant Association and Likelihood Ratio between injury history and injury type

<table>
<thead>
<tr>
<th>Injury History</th>
<th>Fractures</th>
<th>Sprain</th>
<th>Meniscus</th>
<th>Contusion</th>
<th>TP</th>
<th>Arthritis</th>
<th>PFPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Injuries &amp; Concussion</td>
<td>$\chi^2 = 1.070$</td>
<td>$\chi^2 = 0.975$</td>
<td>$\chi^2 = 0.193$</td>
<td>$\chi^2 = 0.185$</td>
<td>$\chi^2 = 1.095$</td>
<td>$\chi^2 = 0.319$</td>
<td>$\chi^2 = 0.004$</td>
</tr>
<tr>
<td></td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
</tr>
<tr>
<td></td>
<td>$p = 0.301$</td>
<td>$p = 0.324$</td>
<td>$p = 0.661$</td>
<td>$p = 0.667$</td>
<td>$p = 0.295$</td>
<td>$p = 0.572$</td>
<td>$p = 0.953$</td>
</tr>
<tr>
<td></td>
<td>LR = 1.196</td>
<td>LR = 0.996</td>
<td>LR = 0.182</td>
<td>LR = 0.192</td>
<td>LR = 1.245</td>
<td>LR = 0.289</td>
<td>LR = 0.003</td>
</tr>
<tr>
<td>Major Surgical Procedure</td>
<td>$\chi^2 = 0.500$</td>
<td>$\chi^2 = 2.606$</td>
<td>$\chi^2 = 5.914$</td>
<td>$\chi^2 = 0.015$</td>
<td>$\chi^2 = 0.977$</td>
<td>$\chi^2 = 0.764$</td>
<td>$\chi^2 = 1.711$</td>
</tr>
<tr>
<td></td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
</tr>
<tr>
<td></td>
<td>$p = 0.479$</td>
<td>$p = 0.106$</td>
<td>$p = 0.015$</td>
<td>$p = 0.902$</td>
<td>$p = 0.323$</td>
<td>$p = 0.382$</td>
<td>$p = 0.191$</td>
</tr>
<tr>
<td></td>
<td>LR = 0.537</td>
<td>LR = 2.708</td>
<td>LR = 4.660</td>
<td>LR = 0.015</td>
<td>LR = 0.892</td>
<td>LR = 0.948</td>
<td>LR = 1.514</td>
</tr>
<tr>
<td>Neck &amp; Back Injuries</td>
<td>$\chi^2 = 0.688$</td>
<td>$\chi^2 = 0.415$</td>
<td>$\chi^2 = 2.031$</td>
<td>$\chi^2 = 0.553$</td>
<td>$\chi^2 = 1.412$</td>
<td>$\chi^2 = 0.000$</td>
<td>$\chi^2 = 0.175$</td>
</tr>
<tr>
<td></td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
</tr>
<tr>
<td></td>
<td>$p = 0.407$</td>
<td>$p = 0.520$</td>
<td>$p = 0.154$</td>
<td>$p = 0.457$</td>
<td>$p = 0.235$</td>
<td>$p = 0.994$</td>
<td>$p = 0.676$</td>
</tr>
<tr>
<td></td>
<td>LR = 0.796</td>
<td>LR = 0.407</td>
<td>LR = 3.903</td>
<td>LR = 0.504</td>
<td>LR = 1.845</td>
<td>LR = 0.000</td>
<td>LR = 0.190</td>
</tr>
<tr>
<td>Trauma or Overuse to Joint &amp; Bone</td>
<td>$\chi^2 = 0.202$</td>
<td>$\chi^2 = 0.045$</td>
<td>$\chi^2 = 2.619$</td>
<td>$\chi^2 = 4.026$</td>
<td>$\chi^2 = 4.053$</td>
<td>$\chi^2 = 0.021$</td>
<td>$\chi^2 = 8.158$</td>
</tr>
<tr>
<td></td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
</tr>
<tr>
<td></td>
<td>$p = 0.653$</td>
<td>$p = 0.832$</td>
<td>$p = 0.106$</td>
<td>$p = 0.045$</td>
<td>$p = 0.044$</td>
<td>$p = 0.885$</td>
<td>$p = 0.004$</td>
</tr>
<tr>
<td></td>
<td>LR = 0.207</td>
<td>LR = 0.045</td>
<td>LR = 3.010</td>
<td>LR = 4.493</td>
<td>LR = 3.697</td>
<td>LR = 0.021</td>
<td>LR = 7.164</td>
</tr>
<tr>
<td>Trauma or Overuse in Ligament &amp; Tendons</td>
<td>$\chi^2 = 0.708$</td>
<td>$\chi^2 = 4.366$</td>
<td>$\chi^2 = 0.000$</td>
<td>$\chi^2 = 1.927$</td>
<td>$\chi^2 = 0.582$</td>
<td>$\chi^2 = 0.278$</td>
<td>$\chi^2 = 0.477$</td>
</tr>
<tr>
<td></td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
<td>df = 1</td>
</tr>
<tr>
<td></td>
<td>$p = 0.400$</td>
<td>$p = 0.037$</td>
<td>$p = 0.988$</td>
<td>$p = 0.165$</td>
<td>$p = 0.445$</td>
<td>$p = 0.598$</td>
<td>$p = 0.490$</td>
</tr>
<tr>
<td></td>
<td>LR = 0.739</td>
<td>LR = 4.287</td>
<td>LR = 0.000</td>
<td>LR = 2.066</td>
<td>LR = 0.561</td>
<td>LR = 0.265</td>
<td>LR = 0.460</td>
</tr>
</tbody>
</table>

*Bolded = Statistically significant difference, TP=Tendinopathy, PFPS=Patellofemoral Pain Syndrome,
LR = Likelihood Ratio

International Journal of Sports Physical Therapy
of joint or bone and patellofemoral joint injuries were all noted.

ACKNOWLEDGEMENTS

Thank you to the Canada Games Council for providing de-identified data for this study. This study was supported by a Brock University Match of Minds Grant and Brock University Canada Games Grant. Nicole Chimera is supported in part by funding from the Social Sciences and Humanities Research Council.

CONFLICT OF INTEREST

The authors have no additional conflicts of interest related to this study to disclose.

Submitted: June 26, 2023 CST, Accepted: October 12, 2023 CST

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


Comparison of Intervention Programs to Improve Trunk Stability for Active Females

Kate Schwartzkopf-Phifer, MD, Katie Whetstone, MD, Mark Marchino, MD, Kevin Brown, MD, Kyle Matsel, MD

1 Department of Physical Therapy, University of Evansville, 2 Rehabilitation and Performance Institute

Keywords: trunk stability, female, Functional Movement Screen, core, Pilates, push up

https://doi.org/10.26603/001c.89667

International Journal of Sports Physical Therapy

Background
Current literature illustrates a disparity in trunk stability push up performance (TSPU), as measured by the Functional Movement Screen (FMSTM), in females throughout the lifespan when compared to their male counterparts.

Hypothesis/Purpose
The purpose of this study was to evaluate the effectiveness of a novel exercise approach to a trunk stability (NEATS) program compared to a standard Pilates program on TSPU performance in active females aged 18-45 years. It was hypothesized that subjects in the NEATS program would have greater improvements on outcomes related to trunk stability than subjects in the Pilates program.

Study Design
Randomized controlled trial

Methods
All subjects were tested at baseline on Beighton criteria, the FMSTM, Y-Balance Test Upper Quarter and Lower Quarter, and grip strength by an evaluator blinded to group allocation. Subjects were randomized into the NEATS (n=17) or the Pilates group (n=19). The intervention period lasted eight weeks, with exercise progression at weeks two, four, and six.

Results
The main outcome was between-group pass rates on the TSPU. At posttest, 41% (n=7) of the NEATS group and 42% (n=8) of the Pilates group passed the TSPU, though there was no difference between groups (p=0.97). Significant differences were noted on the TSPU (Pilates, NEATS p=0.01) and composite scores (Pilates p=0.01; NEATS p=0.03). No within-group improvements were noted on the individual scores of the FMSTM (p=0.05-0.66). Within-group differences were noted on the posterolateral reach on the Y-Balance Test Lower Quarter (p=0.05) in the Pilates group. Between-group posttest continuous measures were not significantly different (p=0.17-0.96).

Conclusion
Improvements in trunk stability were comparable between the multi-planar NEATS program and a standard Pilates program suggesting that both can be used to improve trunk stability performance in active females.

Corresponding Author
Kate Schwartzkopf-Phifer, DPT, PhD, OCS
Department of Physical Therapy
University of Evansville
Fax number: 833-345-3918
Phone number: 812-488-2453
Email: ks148@evansville.edu
INTRODUCTION

Though core stability may be an important risk factor to address in females, it is inherently difficult to measure: no standardized definition of core stability currently exists, therefore no standard measurement exists. Examples of core stability measures include isometric strength tests of the trunk and hip,\textsuperscript{1,2} trunk endurance holds,\textsuperscript{3} and planking or bridging activity.\textsuperscript{4} Due to the variability in definitions, it may be more economical to utilize a measurement that captures all of these factors simultaneously.

The Trunk Stability Push Up (TSPU) is a component of the Functional Movement Screen (FMS\textsuperscript{TM}). The FMS\textsuperscript{TM} is a battery of seven fundamental movement patterns designed to quickly screen for quality and symmetry of movement. In a recent meta-analysis, composite scores on the FMS\textsuperscript{TM} have been shown to have an association with future injury risk, and poor performance on any individual component, including the TSPU, has been shown to increase risk for future injury.\textsuperscript{5,6} The association between FMS\textsuperscript{TM} performance and injury may also be impacted by sex as demonstrated by Moore et al., with a larger effect observed for females.\textsuperscript{7} To perform the TSPU competently (i.e. scoring a 2 or higher), adequate muscle activation of the upper extremities, trunk, and hip/pelvis is required. Thus, the TSPU may be a functional, field-expedient alternative to comprehensively capture the construct of core stability.

It is well-established in the literature that females perform worse on the TSPU than their male counterparts. In adolescents, a significant difference (p<0.000) in TSPU performance was noted by Abraham et al.\textsuperscript{8} Lower scores in adolescents on the TSPU have been noted in female hockey players (1.20 +/- .45) and non-active females (1.18 +/- .40).\textsuperscript{9} Anderson et al reported a 69% failure rate on the TSPU in high school females, compared to only 13% in males.\textsuperscript{10} This gender difference has been observed in collegiate athletes as well, with females scoring significantly lower than males (p<0.001).\textsuperscript{11} The gender difference persists into adulthood, with more than 60% of active females failing the TSPU compared to less than 10% of active males.\textsuperscript{12} Currently, the highest pass rate for females on the TSPU in empirical evidence is 42% without previous intervention, with 45 of 108 active, healthy females scoring a 2 or 3 in a cross-sectional study.\textsuperscript{12} Additionally, a low number of females are included in corrective programs focusing on improving fundamental movements like the TSPU, further contributing to a lack of improvement. The highest proportion of female subjects in a program like this is 11%.\textsuperscript{11} Taken collectively, evidence suggests that poor performance on the TSPU develops early and persists into adulthood for females; though they are most likely to benefit from corrective programming, they are least likely to be included.

One commonly researched program to improve core stability for females is Pilates. Pilates focuses on movement, postural control, and breathing, while increasing the endurance of trunk musculature. Many systematic reviews exist in the literature, with populations studied including women,\textsuperscript{13} older adults,\textsuperscript{14} dancers,\textsuperscript{15} and individuals with low back pain.\textsuperscript{16} Like most of the core or trunk stability literature, outcome measures vary between studies. However, Pilates has demonstrated effectiveness in improving trunk muscular endurance, as well as other core stability measures, in older women,\textsuperscript{17} in healthy populations,\textsuperscript{18} and females with low back pain.\textsuperscript{19} Therefore, Pilates is a well-researched program across populations and across the lifespan, and it represents the standard of care for many conditions.

Development of a comprehensive program to improve performance on the TSPU that focuses on the population most likely to benefit from programming will provide necessary information for clinicians struggling to improve TSPU performance in active female populations. A pilot study exploring a novel exercise approach to improve trunk stability (NEATS program) outcomes in active females, which included multi-planar and closed kinetic chain exercises, yielded a 45% pass rate (9 of 20) in a recent pilot study.\textsuperscript{20} What remains unknown is how the novel program improvements in TSPU performance compare to the current standard of care (Pilates). The purpose of this study was to evaluate the effectiveness of a novel exercise approach to a trunk stability (NEATS) program compared to a standard Pilates program on TSPU performance in active females aged 18-45 years. It was hypothesized that subjects in the NEATS program would have greater improvements on outcomes related to trunk stability than subjects in the Pilates program. The primary hypothesis was that higher pass rates on the TSPU would be observed in the NEATS program compared to the Pilates program. Secondary hypotheses included greater improvements in the NEATS program compared to the Pilates program on scores of grip strength, dynamic stability, and fundamental movements.

METHODS

Active women, ages 18-45 years, were recruited from the Stone Family Center for Health Sciences and the University of Evansville campus via email, university-approved flyers, and in-person presentations to participate in the study. Individuals that self-identified as female and met the weekly activity guidelines according to the American Heart Association were included in the study. Exclusion criteria included the following: pain with lumbar or shoulder clearing tests; limitations in the active straight leg raise or shoulder mobility; history of lumbar or shoulder surgery; lumbar or upper extremity pain within the prior three months; history of anterior shoulder instability (or recurrent shoulder dislocations); current pregnancy; other non-musculoskeletal issue resulting in exercise restrictions from a healthcare provider; successful performance (score of 3) on the TSPU. All data collection procedures were approved by the Institutional Review Board at the University of Evansville.
DATA COLLECTION PROCEDURES

After reading and signing consent forms, subjects were asked to complete a demographic form, which included injury history, age, and current activity levels. Height and weight were collected after completion of the demographic form. Next, subjects were screened for pain with the lumbar clearing test (performing a prone press up) and shoulder clearing tests (reaching across the body and lifting the elbow). Limitations in shoulder mobility (reaching over and behind the head with one hand while reaching under and behind the lower back i.e. “scratch test”) and active straight leg raising (lying supine, raising one leg toward the ceiling) were assessed.

Subjects also completed the following tests/assessments: Beighton criteria, the FMS^TM^ (as described by Cook et al\(^{21}\)), the upper (YBT-UQ) and lower quarter (YBT-LQ) Y-Balance Test, and a grip strength assessment. Beighton criteria, a commonly used clinical screen for generalized hypermobility, screens for hypermobility in the following joints: fifth metacarpal-phalangeals, thumbs, knees, elbows, and spine/hips through forward flexion. All movements, except forward flexion, are assessed bilaterally, and the total number of hypermobile joints is recorded. Scoring for the Beighton criteria has demonstrated good reliability in adult women.\(^{22}\) Next, the FMS^TM^ was performed using previously established procedures for conducting and scoring the screen.\(^ {5}\) Next, the Y-Balance tests for the upper and lower body were performed per established procedures using the YBT kit. Reliability of both the YBT-UQ\(^ {23}\) and the YBT-LQ are excellent.\(^ {24}\) Subjects performed the reaching task for the YBT-UQ and YBT-LQ on both sides, three times each. Finally, grip strength was assessed using a handheld grip dynamometer. Grip strength testing using a Jamar dynamometer has excellent reliability.\(^ {25}\) Subjects completed three trials of maximal gripping in three positions: elbow extended at the side, elbow flexed to 90°, and elbow extended overhead. Subjects had 30 seconds of rest between each trial, and the best trial was used for analysis.

All data collection procedures were completed by the primary investigator, three additional physical therapy faculty members, and one staff physical therapist. All data collectors were blinded to group allocation and participated in pretest and posttest data collection only. All faculty members have more than 10 years of experience delivering care in the outpatient physical therapy setting, are currently or had previously been certified clinical specialists through the American Board of Physical Therapy Specialties, and they have been faculty members for two to six years. The staff physical therapist has six years of experience in an outpatient physical therapy setting.

INTERVENTIONS

Subjects that were unsuccessful on the TSPU were randomized to receive either instruction in the NEATS program or a Pilates program using demonstrations, return-demonstrations, and written handouts from one of the student physical therapists. In both the NEATS and Pilates programs, student physical therapists used standardized checklists to ensure proper instruction and performance of exercises.

The NEATS program was investigated in a pilot study to determine effectiveness in active females; based on previous results, it was modified to include an additional two weeks of higher intensity and resistance exercises. In brief, the program is a dynamic, multiplanar program that progressed through neurodevelopmental postures to increase stability demands. External loads, through a variety of equipment, were also added throughout the progression of the program. All participants in the NEATS program were issued a medium resistance band, 8kg kettlebell, and 10lb medicine ball at data collection for use throughout the intervention period. For detailed descriptions of exercises, see Appendix A.

The Pilates program is a direct replication of the intervention used by Elmore et al, which demonstrated improvements on similar outcomes in a sample of collegiate dancers. In brief, the Pilates program utilized standard Pilates exercises with an emphasis on breathing technique. All participants in the Pilates program were issued a yoga block, yoga mat, and medium resistance band for use throughout the intervention program. For detailed descriptions of exercises, see Appendix B.

The exercises issued for both programs were performed at least once daily, and compliance was documented by subjects in an exercise journal. Subjects returned for follow-ups at week 2, week 4, and week 6 for further instruction in exercise progression for both programs. All subjects were encouraged to continue their normal daily activities and fitness routines.

Post testing occurred eight weeks after initial data collection, which was performed by the original data collection team and included all original assessments.

STATISTICAL METHODS

With a 2-tailed alpha level of significance equal to 0.05, 32 subjects were needed to have >80% power to detect the primary hypothesis described above based on a chi-square test. All data were analyzed using SPSS (IBM, version 28). Shapiro-Wilk tests were performed on all secondary, continuous outcomes to determine normality of data distributions. Means and standard deviations were calculated for all continuous outcomes, and between-group and within-group analyses included independent and dependent t-tests, respectively. All ordinal data were analyzed using Mann Whitney U and categorical changes were analyzed using Wilcoxon Signed Ranks.

RESULTS

Thirty-seven women (NEATS [n=18]; Pilates [n=19]) were included in the study. One subject from the NEATS group was lost to follow-up, so the remaining 17 subjects were used for the final analysis (Figure 1). Demographics are summarized in Table 1. No significant differences between groups were observed in demographics at pretest. Median Beighton scores were 2 for the NEATS group and 3 for the
Pilates group (range=0–9), though no significant differences were observed (p=.39).

The main outcome was between-group pass rates on the TSPU, with a "pass" defined as scoring a 2 or higher. At posttest, 41% (n=7) of the NEATS group and 42% (n=8) of the Pilates group had passing scores on the TSPU, though the between groups difference was not significant (χ²=0.001, p=0.97, Table 2). In the NEATS group, one significant difference was noted in the within-group analysis. Grip strength on the right with the elbow flexed to 90 degrees decreased from 72.82 to 69.82, (p=0.04). No other significant differences were observed in the NEATS group on the remaining continuous variables (p=.10-.96; Table 3). Within-group improvements were noted in the Pilates group as well, though only one (posterolateral reach on the YBT-LQ) reached a statistically significant difference (pre 96.56 [SD 8.26], post 99.03 [SD 8.23]; p=0.03; Table 4). All other differences in continuous outcomes in the Pilates group were not significantly different (p=0.06-0.86). Between-group differences on all posttest continuous measures were not significant (p=0.18-0.95; Table 5), though posttest means were higher in the Pilates group in all but one measure (inferolateral reach of the YBT-UQ on the left).

No significant differences in individual FMS™ scores or composite scores were observed between groups at posttest using the Mann Whitney U (p=0.41-0.78, Table 6). Though group comparisons are typical for the study design, individual outcomes were also analyzed using the Wilcoxon Signed Ranks. A frequency count of categorical changes was tracked for each movement of the FMS™. If a subject made an improvement, defined as a posttest score higher than the pretest score, this categorical change was documented as a "+". If a subject's posttest score decreased from baseline, it was documented as a "-". If no changes from baseline were noted, this was documented as a tie and was dropped from the analysis per standard Wilcoxon Signed Ranks procedures. Within-group improvements on categorical changes in individual scores on the FMS™ were noted in both the TSPU (NEATS, p=0.03; Pilates, p=0.01) and total FMS™ scores (NEATS, p=0.01; Pilates, p=0.01, Table 6).
Table 2. Between groups posttest pass rates on the trunk stability push up.

<table>
<thead>
<tr>
<th></th>
<th>Pass</th>
<th>Fail</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEATS</td>
<td>7</td>
<td>10</td>
<td>17</td>
</tr>
<tr>
<td>Pilates</td>
<td>8</td>
<td>11</td>
<td>19</td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td>20</td>
<td>34</td>
</tr>
</tbody>
</table>

NEATS=Novel Experimental Approach to Trunk Stability.

Table 3. NEATS—within-group differences for continuous outcomes.

<table>
<thead>
<tr>
<th>Factor</th>
<th>NEATS (n=17)</th>
<th>Pre</th>
<th>Post</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grip</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overhead-R</td>
<td>78.00 (11.77)</td>
<td>78.18 (11.00)</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td>Overhead-L</td>
<td>74.82 (12.41)</td>
<td>75.00 (12.86)</td>
<td>0.93</td>
<td></td>
</tr>
<tr>
<td>Elbow flexed-R</td>
<td>72.82 (11.91)</td>
<td>69.82 (11.31)</td>
<td>0.04*</td>
<td></td>
</tr>
<tr>
<td>Elbow flexed-L</td>
<td>68.88 (12.20)</td>
<td>68.53 (10.08)</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>Elbow extended-R</td>
<td>73.00 (12.22)</td>
<td>71.76 (10.92)</td>
<td>0.37</td>
<td></td>
</tr>
<tr>
<td>Elbow extended-L</td>
<td>68.59 (10.82)</td>
<td>68.82 (11.00)</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>YBT-UQ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial-R</td>
<td>78.21 (9.15)</td>
<td>80.41 (7.69)</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Medial-L</td>
<td>79.29 (7.39)</td>
<td>79.47 (7.49)</td>
<td>0.88</td>
<td></td>
</tr>
<tr>
<td>Posterolateral-R</td>
<td>57.12 (10.76)</td>
<td>58.00 (11.00)</td>
<td>0.58</td>
<td></td>
</tr>
<tr>
<td>Posterolateral-L</td>
<td>58.29 (11.35)</td>
<td>57.88 (11.89)</td>
<td>0.74</td>
<td></td>
</tr>
<tr>
<td>Anterior-R</td>
<td>61.34 (6.38)</td>
<td>61.85 (7.00)</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>Anterior-L</td>
<td>61.59 (5.57)</td>
<td>61.65 (7.09)</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td>Posteromedial-R</td>
<td>99.71 (7.54)</td>
<td>99.56 (8.90)</td>
<td>0.93</td>
<td></td>
</tr>
<tr>
<td>Posteromedial-L</td>
<td>99.74 (6.30)</td>
<td>100.35 (6.47)</td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td>Posterolateral-R</td>
<td>96.35 (7.20)</td>
<td>95.82 (10.18)</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td>Posterolateral-L</td>
<td>94.35 (6.81)</td>
<td>96.00 (8.44)</td>
<td>0.30</td>
<td></td>
</tr>
</tbody>
</table>

NEATS=Novel Exercise Approach to Trunk Stability; YBT-UQ=Upper quarter Y-Balance Test; YBT-LQ=Lower quarter Y Balance Test; R=right; L=left.

DISCUSSION

Current literature suggests that poor performance on the TSPU for females begins in early adolescence and persists through adulthood. Though active females have the greatest need for intervention programs targeting trunk stability outcomes, they are often underrepresented in the literature. Subjects in both the NEATS and Pilates programs improved TSPU performance from pretest to posttest, as well as total FMSTM score. Though no significant between-group differences were observed in pass rates for the TSPU, both programs yielded among the highest pass rates for active females in empirical literature.

The purpose of this study was to compare effectiveness of the NEATS to an established trunk stability program (Pilates) on trunk stability outcomes for active females. The primary hypothesis was that subjects in the NEATS program would demonstrate greater pass rates on the TSPU compared to the Pilates program. No significant between-group differences were observed, indicating that this hypothesis was not supported. However, the pass rates observed in this study (NEATS=41%, Pilates=42%) are comparable to our pilot study, which yielded a 45% pass rate with the NEATS program.20 These findings suggest that both programs, though different in approach and external resistance loads, can be effective in improving trunk stability outcomes for a moderate proportion of active females. The ability to match interventions based on the preferences of either the patient or provider has been shown to positively impact patient outcomes.26 This study provides several options for exercise prescription and progression, creating the opportunity to leverage preferences as a means to improve clinical outcomes.

There are a limited number of intervention studies designed to improve FMSTM scores. The interventions vary from individualized correctives to group yoga, and most are effective at improving composite FMSTM scores.27–33 Unfortunately, only four intervention studies include females,27, 29,30,33 ranging in sample sizes of four to eighteen, for a total of 45 female subjects between the four studies. As described previously, there are significant differences in performance on the FMSTM between males and females, yet
Table 4. Pilates—within-group differences for continuous outcomes.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Pre (µ, SD)</th>
<th>Post (µ, SD)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grip</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overhead-R</td>
<td>78.11 (14.39)</td>
<td>79.68 (12.78)</td>
<td>0.23</td>
</tr>
<tr>
<td>Overhead-L</td>
<td>76.63 (11.38)</td>
<td>76.95 (12.78)</td>
<td>0.81</td>
</tr>
<tr>
<td>Elbow flexed-R</td>
<td>72.26 (15.53)</td>
<td>73.74 (14.90)</td>
<td>0.41</td>
</tr>
<tr>
<td>Elbow flexed-L</td>
<td>68.11 (13.31)</td>
<td>71.26 (12.58)</td>
<td>0.13</td>
</tr>
<tr>
<td>Elbow extended-R</td>
<td>70.79 (15.57)</td>
<td>74.26 (13.23)</td>
<td>0.06</td>
</tr>
<tr>
<td>Elbow extended-L</td>
<td>68.79 (12.30)</td>
<td>69.79 (11.73)</td>
<td>0.62</td>
</tr>
<tr>
<td>YBT-UQ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial-R</td>
<td>78.89 (8.43)</td>
<td>80.84 (7.35)</td>
<td>0.14</td>
</tr>
<tr>
<td>Medial-L</td>
<td>78.42 (10.46)</td>
<td>79.66 (9.45)</td>
<td>0.53</td>
</tr>
<tr>
<td>Inferolateral-R</td>
<td>77.82 (13.85)</td>
<td>78.24 (14.22)</td>
<td>0.75</td>
</tr>
<tr>
<td>Inferolateral-L</td>
<td>76.45 (15.77)</td>
<td>76.87 (14.69)</td>
<td>0.86</td>
</tr>
<tr>
<td>Superolateral-R</td>
<td>59.68 (12.73)</td>
<td>61.71 (11.12)</td>
<td>0.16</td>
</tr>
<tr>
<td>Superolateral-L</td>
<td>60.61 (12.23)</td>
<td>62.00 (13.36)</td>
<td>0.35</td>
</tr>
<tr>
<td>YBT-LQ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior-R</td>
<td>63.71 (10.14)</td>
<td>62.47 (5.74)</td>
<td>0.54</td>
</tr>
<tr>
<td>Anterior-L</td>
<td>64.47 (11.58)</td>
<td>63.45 (5.46)</td>
<td>0.67</td>
</tr>
<tr>
<td>Posteromedial-R</td>
<td>98.18 (8.61)</td>
<td>100.21 (9.41)</td>
<td>0.19</td>
</tr>
<tr>
<td>Posteromedial-L</td>
<td>99.92 (8.88)</td>
<td>101.21 (8.48)</td>
<td>0.38</td>
</tr>
<tr>
<td>Posterolateral-R</td>
<td>96.56 (8.26)</td>
<td>99.03 (8.23)</td>
<td>0.03</td>
</tr>
<tr>
<td>Posterolateral-L</td>
<td>95.61 (11.59)</td>
<td>99.87 (8.32)</td>
<td>0.11</td>
</tr>
</tbody>
</table>

YBT-UQ=Upper quarter Y Balance Test; YBT-LQ=Lower quarter Y Balance Test; R=right; L=left.

effectiveness of intervention programs has almost exclusively been studied in male populations. The assumption that these programs should be the gold standard for female populations is problematic; anecdotaly, many clinicians struggle to improve TSPU performance in active females, and this struggle is supported through empirical literature. Additionally, rigorous designs comparing high quality programs for females are non-existent. Of the three studies using control groups,\textsuperscript{27,28,33} only two utilized randomization\textsuperscript{27,33} and only one implemented blinding.\textsuperscript{33} Not only is the current study the only intervention study to include an all-female sample, but it is also one of the most rigorously-designed.

The NEATS program was modified from its original length of six weeks to eight weeks. Other corrective programs have also utilized eight-week intervention periods,\textsuperscript{28,32,34} adding more credibility to an extended intervention period. Unfortunately, pass rates from both the NEATS program and the Pilates program did not exceed the pass rates of previously published studies. Though self-reported compliance to both programs was high, the additional time and complexity of exercises did not appear to aid in performance improvements.

The Pilates program used in this study was replicated from a previous study by Elmore et al., which aimed to improve functional outcomes in collegiate dancers.\textsuperscript{35} Though typical Pilates-based exercises were used in this program, the biweekly progression of exercises utilized a neurodevelopmental approach, which increased stability demands through postural changes. Initial Pilates exercises were performed in low level postures, such as supine neutral spine dynamic stabilization, and eventually progressed to standing exercises like a resisted horizontal press. This neurodevelopmental approach was also utilized in the NEATS program, where initial exercises included quadruped lumbar flexion and extension before progressing to higher level postures like standing med ball throws. Increasing postural demands through a developmental sequence is thought to improve coordination of trunk musculature,\textsuperscript{36} which is necessary for active populations. Mahdieh et al\textsuperscript{57} compared a neurodevelopmental approach to a routine physical fitness program and observed significant improvements in scores on the FMS\textsuperscript{TM} and YBT-LQ in a sample of adult females. Improvements in outcomes utilizing neurodevelopmental postures have been noted in other populations as well. Increased diaphragmatic activity and thickness of the transversus abdominis and internal oblique were observed in patients following stroke.\textsuperscript{38} Taken collectively, these findings suggest that it is possible that the similarity in postural progressions, rather than the exercises themselves, played an important role in the positive findings, leading to similarities in pass rates as well.

Secondary hypotheses included changes in grip strength, dynamic balance, and fundamental movements. Despite the inclusion of several continuous secondary outcomes, no between-group differences were observed. The exclusion criteria in this study included limitations in shoulder mobility and active straight leg raise—two of the seven movements of the FMS\textsuperscript{TM}—to ensure that improvements in primary or secondary outcomes would not be prohibited by
Table 5. Posttest between-group differences—continuous outcomes

<table>
<thead>
<tr>
<th></th>
<th>NEATS (x, SD)</th>
<th>Pilates (x, SD)</th>
<th>Difference</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>YBT-LQ</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior—R</td>
<td>61.85 (7.00)</td>
<td>62.47 (5.74)</td>
<td>-0.62</td>
<td>0.77</td>
</tr>
<tr>
<td>Anterior—L</td>
<td>61.65 (7.09)</td>
<td>63.45 (5.46)</td>
<td>-1.80</td>
<td>0.40</td>
</tr>
<tr>
<td>Posteromedial—R</td>
<td>99.56 (8.90)</td>
<td>100.21 (9.41)</td>
<td>-0.65</td>
<td>0.83</td>
</tr>
<tr>
<td>Posteromedial—L</td>
<td>100.35 (6.47)</td>
<td>101.21 (8.48)</td>
<td>-0.86</td>
<td>0.74</td>
</tr>
<tr>
<td>Posterolateral—R</td>
<td>95.82 (10.18)</td>
<td>99.03 (8.23)</td>
<td>-3.21</td>
<td>0.31</td>
</tr>
<tr>
<td>Posterolateral—L</td>
<td>96.00 (8.44)</td>
<td>99.87 (8.32)</td>
<td>-3.87</td>
<td>0.18</td>
</tr>
<tr>
<td><strong>YBT-UQ</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial—R</td>
<td>80.41 (7.69)</td>
<td>80.84 (7.35)</td>
<td>-0.43</td>
<td>0.87</td>
</tr>
<tr>
<td>Medial—L</td>
<td>79.47 (4.49)</td>
<td>79.66 (9.45)</td>
<td>-0.19</td>
<td>0.95</td>
</tr>
<tr>
<td>Inferolateral—R</td>
<td>75.79 (13.32)</td>
<td>78.24 (14.22)</td>
<td>-2.44</td>
<td>0.60</td>
</tr>
<tr>
<td>Inferolateral—L</td>
<td>78.85 (12.68)</td>
<td>76.87 (14.67)</td>
<td>1.98</td>
<td>0.67</td>
</tr>
<tr>
<td>Superolateral—R</td>
<td>58.00 (11.00)</td>
<td>61.71 (11.12)</td>
<td>-3.71</td>
<td>0.32</td>
</tr>
<tr>
<td>Superolateral—L</td>
<td>57.88 (11.89)</td>
<td>62.00 (13.36)</td>
<td>-4.12</td>
<td>0.34</td>
</tr>
<tr>
<td><strong>Grip Strength</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overhead—R</td>
<td>78.18 (11.00)</td>
<td>79.68 (12.78)</td>
<td>-1.51</td>
<td>0.71</td>
</tr>
<tr>
<td>Overhead—L</td>
<td>75.00 (12.86)</td>
<td>76.95 (12.78)</td>
<td>-1.95</td>
<td>0.65</td>
</tr>
<tr>
<td>Side, Elbow flexed—R</td>
<td>69.82 (11.33)</td>
<td>73.74 (14.90)</td>
<td>-3.91</td>
<td>0.39</td>
</tr>
<tr>
<td>Side, Elbow flexed—L</td>
<td>68.53 (10.08)</td>
<td>71.26 (12.58)</td>
<td>-2.73</td>
<td>0.48</td>
</tr>
<tr>
<td>Side, Elbow extended—R</td>
<td>71.76 (10.92)</td>
<td>74.26 (13.23)</td>
<td>-2.50</td>
<td>0.54</td>
</tr>
<tr>
<td>Side, Elbow extended—L</td>
<td>68.82 (11.00)</td>
<td>69.79 (11.73)</td>
<td>-0.97</td>
<td>0.80</td>
</tr>
</tbody>
</table>

NEATS=Novel Exercise Approach to Trunk Stability; x=mean; SD=standard deviation; YBT-UQ=Upper quarter Y Balance Test; YBT-LQ=Lower quarter Y-Balance Test; R=right; L=left.

Table 6. FMS™ Outcomes.

<table>
<thead>
<tr>
<th>Functional Movement Screen</th>
<th>Within-Group Rank Changes (Wilcoxon Signed Ranks)</th>
<th>Between Group Rank Differences (Mann Whitney U)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
<td>NEATS (n=17) Pilates (n=19) p Value</td>
<td>p Value</td>
</tr>
<tr>
<td>Squat</td>
<td>+ 1 0 .32</td>
<td>+ 5 1 0.08</td>
</tr>
<tr>
<td>Hurdle—Final</td>
<td>+ 1 1 .10</td>
<td>+ 3 0 .08</td>
</tr>
<tr>
<td>In-line Lunge—Final</td>
<td>+ 6 4 .53</td>
<td>+ 3 2 .65</td>
</tr>
<tr>
<td>Shoulder Mobility—Final</td>
<td>+ 3 1 .32</td>
<td>+ 1 0 .32</td>
</tr>
<tr>
<td>Active Straight Leg Raise—Final</td>
<td>+ 2 0 .16</td>
<td>+ 4 0 .06</td>
</tr>
<tr>
<td>Rotary Stability—Final</td>
<td>+ 6 2 .16</td>
<td>+ 4 4 1.00</td>
</tr>
<tr>
<td>Trunk Stability Push Up</td>
<td>+ 7 1 .03*</td>
<td>+ 8 0 0.01*</td>
</tr>
<tr>
<td>FMS—Final</td>
<td>+ 10 2 .01*</td>
<td>+ 12 3 0.01*</td>
</tr>
</tbody>
</table>

FMS=Functional Movement Screen; NEATS=Novel Exercise Approach to Trunk Stability.

major mobility limitations. Therefore, significant improvements in some movements were not anticipated. However, within-group differences were noted in the right posterolateral reach of the YBT-LQ in the Pilates group, and right grip strength with the elbow flexed in the NEATS group. Given that no other differences were noted, the cause of these differences is not well-understood. However, research has demonstrated that the secondary outcomes selected for this study measure different constructs related to trunk musculature. The authors believe that this inconsistent response in the current findings further supports that these tests are measuring different things, and should be considered in comprehensive assessments of trunk stability outcomes.
Comparison of Intervention Programs to Improve Trunk Stability for Active Females

One major difference between programs was the emphasis on breathing patterns. In the Pilates group, subjects were instructed to pair inhalation and exhalation with specific portions of the exercise. In the NEATS group, no specific instructions on breathing were provided. This manipulation of breath with activity, such as in hypopressive exercises, is becoming common in pelvic health physical therapy. Hypopressive exercises, where a full exhalation is utilized to recruit deep core musculature, have shown some promise in the literature. In healthy females, surface electromyography captured increased activation of pelvic floor muscles during hypopressive exercise. Utilizing surface electromyography and vaginal dynamometry, hypopressive exercises were shown to increase activation of pelvic floor and abdominal muscles in a sample of multiparous women. Given the important role that these muscles play in trunk stability, emphasizing conscious recruitment through emphasis on structured breathing may lead to improved trunk stability outcomes.

LIMITATIONS

The study findings should be interpreted with caution, as limitations were noted. First, subjects were recruited through multiple sites using digital and physical flyers as well as word of mouth. However, 66% (n=24) were physical therapy students from the local health sciences center where the study took place. Though it was intended to recruit women aged 18-45 years, only five subjects were over the age of 30, limiting generalizability. Second, all subjects were free of musculoskeletal pain prior to beginning and throughout the duration of the study, which limits applicability of these findings to patients seeking orthopedic care for musculoskeletal symptoms like low back pain. Finally, though subjects were considered healthy, information regarding subjects’ history of pregnancies, childbirth, and pelvic floor dysfunction was not collected. These additional details may have provided valuable insight into individual variability in outcomes. Therefore, clinicians should utilize clinical reasoning before implementing either program in patients currently experiencing or recovering from musculoskeletal symptoms.

CONCLUSION

Though poor trunk stability in females develops at a young age and appears to persist through adulthood, a disparity exists in the inclusion of females in intervention programs. Given the link between poor trunk stability and musculoskeletal injury, as well as sex difference in performance on trunk stability measures, there is a critical need to develop effective programs for females to address trunk stability deficits. Improvements in trunk stability were comparable between the multi-planar NEATS program and a Pilates program, providing two options for clinicians to utilize in active female populations.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the following people for their contributions to this project: Sarah Gehres, McKenzi Goeber, Lauren Rennie, Parker Rose, Andrew Patton, Kyle Patton, Jamie Vance, and Kourtney West.

Submitted: June 29, 2023 CST, Accepted: October 12, 2023 CST

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


32. Stanek JM, Dodd DJ, Kelly AR, Wolfe AM, Swenson RA. Active duty firefighters can improve Functional Movement Screen (FMS) scores following an 8-week individualized client workout program. *Work.* 2017;56(2):213-220. doi:10.3233/wor-172493


SUPPLEMENTARY MATERIALS

Appendix A

Appendix B
Non-Operative Rehabilitation Principles for Use in Individuals with Acetabular Dysplasia: A North American Based Delphi Study

Ashley E. Disantis, RobRoy L. Martin, Keelan Enseki, Victoria Spaid, Michael McClincy

1 Adolescent and Young Adult Hip Preservation Program, UPMC Children’s Hospital of Pittsburgh, 2 Rangos School of Health Sciences, Department of Physical Therapy, Duquesne University, 3 UPMC Freddie Fu Center for Sports Medicine, UPMC Rehabilitation Institute, 4 Department of Orthopaedic Surgery, UPMC Children’s Hospital of Pittsburgh, 5 Adolescent and Young Adult Hip Preservation Program, UPMC Children’s Hospital of Pittsburgh

Keywords: acetabular dysplasia, rehabilitation, consensus statement, return to sport

https://doi.org/10.26603/001c.89265

Background
Acetabular dysplasia (AD) is defined as a structurally deficient acetabulum and is a well-recognized cause of hip pain in young adults. While treatment of severe AD with a periacetabular osteotomy has demonstrated good long-term outcomes, a trial of non-operative management is often recommended in this population. This may be especially true in patients with milder deformities. Currently, there is a paucity of research pertaining to non-operative management of individuals with AD.

Purpose
To present expert-driven non-operative rehabilitation guidelines for use in individuals with AD.

Study Design
Delphi study

Methods
A panel of 15 physiotherapists from North America who were identified as experts in non-operative rehabilitation of individuals with AD by a high-volume hip preservation surgeon participated in this Delphi study. Panelists were presented with 16 questions regarding evaluation and treatment principles of individuals with AD. A three-step Delphi method was utilized to establish consensus on non-operative rehabilitation principles for individuals presenting with AD.

Results
Total (100%) participation was achieved for all three survey rounds. Consensus, defined a priori as > 75%, was reached for 16/16 questions regarding evaluation principles, activity modifications, appropriate therapeutic exercise progression, return to activity/sport criteria, and indications for physician referral.

Conclusion
This North American based Delphi study presents expert-based consensus on non-operative rehabilitation principles for use in individuals with AD. Establishing guidelines for non-operative management in this population will help reduce practice variation and is the first step in stratifying individuals who would benefit from non-operative management. Future research should focus on patient-reported outcomes.
and rate of subsequent surgical intervention to determine the success of the guidelines reported in this study.

**Level of Evidence**

Level V

**BACKGROUND**

Acetabular dysplasia (AD) is defined as a structurally deficient acetabulum, both in shape and orientation, resulting in poor coverage of the femoral head and is a well-recognized cause of hip pain in young adults.1-4 As a result of poor acetabular coverage, excessive wear on the acetabular articular cartilage and labrum can occur to potentially produce degenerative changes.5-8 Without appropriate management, AD can lead to severe pain and disability.9,10

Acetabular dysplasia may result in hip osteoarthritis due to the increased shear forces and loading of the acetabulum and labrum.11,12 The labrum attenuates 1-2% of the joint load in a normal hip during gait. However, the labrum is responsible for 4-11% of the total joint load in an individual with AD secondary to increased antero-superior loading of the acetabulum.13,14 Individuals with AD have also been shown to demonstrate muscle strength deficits, as well as iliopsoas and adductor related pain 56%.15 While treatment of severe AD with a periacetabular osteotomy has demonstrated good long-term outcomes, a trial of non-operative management is often recommended in this population.16-18 This is especially true in those with mild deformities. The role of non-operative rehabilitation in an individual with AD is to re-establish strength and functional control of the lumbopelvic and hip musculature to improve dynamic stability of the hip and lower extremity in the setting of osseous instability as well as to provide activity modification strategies to reduce joint irritability.

Currently, there is a lack of research pertaining to non-operative management of individuals with AD. Establishing expert-based non-operative rehabilitation recommendations, including initial evaluation principles, activity modifications, therapeutic exercise progression, return to activity criteria, and indications for physician referral, will provide guidance and reduce variation in a practice area where research is lacking. Additionally, this study will set the groundwork to determine those who are most likely to benefit from non-operative rehabilitation. The purpose of this study is to present expert-driven non-operative rehabilitation guidelines for use in individuals with AD.

**METHODS**

**DELPHI PANEL**

The panel of experts who participated in this study consisted of 15 physiotherapists who were identified as experts in the non-operative physiotherapy management of individuals with AD. To avoid bias, panelists were selected from various geographic locations across the United States and Canada. Participants were selected based on the following criteria, including (1) identification as an expert in non-operative management of individuals with AD by a high-volume hip preservation surgeon and (2) treating at least 20 patients diagnosed with AD per year. Participants were blinded for the entirety of the study.

**DELPHI STRUCTURE AND DATA COLLECTION**

A three-step classic Delphi method was used for the current study. Methods are similar to those described by Disantis et al.19 In summary, panelists were presented with three iterative survey rounds via an emailed link. For each survey round, analysis of participants responses was completed by two study members (AD and RM). Any disagreements were resolved by a third team member (MM). Survey responses were deidentified for analysis.

Panelists were presented with 16 free-response questions on 9 topics regarding non-operative rehabilitation principles for AD. The topic areas are listed below:

1. Initial evaluation principles
2. Activity limitations
3. Therapeutic exercise progression
4. Lumbopelvic and lower extremity neuromuscular control
5. Rehabilitation of the hip flexor complex
6. Muscle stretching principles
7. Cardiovascular fitness
8. Return to recreational activity/sports
9. Referral back to a hip specialist

During the first survey round, responses were coded for common thematic content. Common responses reported by ≥ 50% of panelists were considered modal, while common responses reported by ≥35% of panelists formed a second tier of responses. During the second survey round, panelists received nine topic related questions and were asked to agree or disagree with the modal response. Those who disagreed were provided a response including the second-tier items as well as the option for free text. The same process was repeated for round three. Consensus for 15/16 questions was reached in survey round two. Consensus for 16/16 questions was reached in survey round three.

**RESULTS**

The expert panel in the current study consisted of 15 physiotherapists who were identified as experts in the non-operative physiotherapy management of individuals with AD. All 15 therapists (100%) participated in the three Delphi rounds. Consensus was achieved for 100% of the 16 questions provided to the expert panel regarding non-operative rehabilitation principles for AD.
INITIAL EVALUATION PRINCIPLES (RANGE OF MOTION, MUSCLE STRENGTH, SPECIAL TESTS, AND FUNCTIONAL TESTS)

1. 14/15 (93%) of panelists agreed that hip flexion and hip internal (IR) and external rotation ER, in supine and prone, ROM measurements are the most important. One dissenting panelist felt that hip abduction should also be measured.

2. 14/15 (93%) of panelists agreed that muscle strength measures for the hip abductors, hip extensors, deep rotators, and core are the most important. One dissenting panelist felt that the quadriceps strength should also be measured.

3. 15/15 (100%) of panelists agreed that a battery of special tests, including flexion/adduction/internal rotation (FADIR), flexion/abduction/external rotation (FABER), log roll, and apprehension testing should be utilized.

4. 15/15 (100%) of panelists agreed that SL activities should be utilized to assess functional control. Examples of functional tests included a SL stance, SL squat, and SL step down.

ACTIVITY MODIFICATIONS

5. 15/15 (100%) of panelists agreed that activities that do not increase pain should be permitted and painful activities should be modified or discontinued.

THERAPEUTIC EXERCISE PROGRESSION

6. 15/15 (100%) of panelists agreed that progression from local to global exercise should be based upon quality of movement and irritability of the hip joint. Examples of quality of movement parameters included adequate muscle activation and minimal compensatory strategies.

7. 14/15 (95%) of panelists agreed that progression from isometric to concentric exercises should be based on reported pain level and progression from concentric to eccentric exercises should be based on quality of movement. Examples of quality of movement included adequate muscle activation through palpation and minimal compensatory strategies. One dissenting panelist thought that progression from isometrics should be initiated as soon as possible, incorporating these exercises with concentric exercises to fatigue.

LUMBOPELVIC AND LOWER EXTREMITY NEUROMUSCULAR CONTROL

8. 15/15 (100%) of panelists agreed these tasks should challenge both the pelvis and lower quarter with a focus on SL control. These tasks should include both static and multidirectional tasks and be progressed based on quality of movement, beginning in low level positions progression to high level positions. Exercise examples to facilitate lumbopelvic neuromuscular control should include transversus abdo-

minis firing in various positions while exercises to facilitate lower extremity neuromuscular control should include double and SL activities. All panelists (100%) agreed progression from double to SL activities are appropriate when the patient exhibits no trunk or pelvic compensations during double leg activities and the patient can maintain pelvic and lower extremity control during a basic SL task.

REHABILITATION OF THE HIP FLEXOR COMPLEX

9. 15/15 (100%) of panelists agreed therapeutic exercise should begin only after the patient has demonstrated an improvement in posterolateral hip muscle strength and a reduction in hip joint irritability. These exercises should begin in a short lever (knee flexed) position, when appropriate.

10. 14/15 (95%) of panelists agreed that these exercises may only be necessary based on sporting demands and be used only in the setting of tolerance to short lever hip flexion exercises and reduced hip irritability. Examples of sports that may require prescription of long lever exercises including dancers. One dissenting panelist thought that long lever exercises should be utilized with all patients if there is no pain with hip flexor muscle activation.

MUSCLE STRETCHING PRINCIPLES

11. 13/15 (87%) of panelists agreed muscle stretching should not be a focus of rehabilitation as hip dysplasia is a diagnosis related to joint instability. Two dissenting panelists thought that muscle stretching should be incorporated based upon findings of physical examination.

CARDIOVASCULAR FITNESS

12. 15/15 (100%) of panelists agreed low impact activities should be encouraged when pain-free. Examples of such activities include cycling and swimming (with a pool buoy if necessary). Higher impact cardiovascular activities may be initiated as strength improves and hip joint irritability decreases.

RETURN TO RECREATIONAL ACTIVITY/SPORTS

13. 14/15 (95%) of panelists agreed individuals may begin running when they demonstrate a decrease in hip joint irritability, appropriate pelvic and lower extremity neuromuscular control during SL activities, and a normal gait pattern with ambulation. One dissenting panelist recommended the use of functional testing including the Vail Sport Test and the Selective Functional Movement Assessment (SFMA) should be utilized in conjunction with these measures.

14. 15/15 (100%) of panelists agreed individuals may begin plyometric exercises when they report minimal to no pain and appropriate pelvic and LE neuromuscular control during all running and low-level agility tasks.
15. 15/15 (100%) of panelists agreed individuals may be cleared for full return to sports when they demonstrate adequate pelvic and LE neuromuscular control during all SL tasks, normalized strength, and tolerance to all sport specific tasks, including running and plyometrics.

REFERRAL TO A PHYSICIAN HIP SPECIALIST

16. 13/15 panelists agreed a patient should be referred to a physician specializing in hip-related injuries if they are exhibiting no decrease in symptoms despite improved strength and neuromuscular control after 4-8 weeks of physiotherapy. Two dissenting panelists felt that individuals should undergo at least 12 weeks of therapy before referring to a physician hip specialist. The patient may be referred to a physician hip specialist for an initial or return consultation depending on the route physical therapy management was initiated.

DISCUSSION

A trial of physiotherapy to improve strength and neuromuscular control is often recommended before surgical intervention in individuals presenting with AD. Currently, there is no consensus regarding non-operative rehabilitation principles, including evaluation, therapeutic exercise and neuromuscular control recommendations, return to activity criteria, and criteria for referral back to a hip specialist, for individuals with AD. This Delphi study was conducted to establish expert-based rehabilitation principles for individuals presenting to physiotherapy for management of AD.

INITIAL EVALUATION PRINCIPLES

RANGE OF MOTION

Consensus Point: During an initial evaluation for an individual presenting for non-operative management of AD, hip flexion and hip IR and ER, in supine and prone, are the most important ranges of motion to measure.

Assessment of hip ROM is an important element of an initial physiotherapy evaluation. The panelists recommend a through side-to-side comparison of hip ROM, with a focus on hip flexion and hip IR and ER ROM. Individuals with AD have been shown to demonstrate normal or increased hip ROM. Careful attention should be paid the end of physiologic hip flexion ROM, ensuring that there are no compensatory movements of the lumbar spine during this measurement. Additionally, hip IR and ER ROM should be measured in both the supine with the hip and knee flexed to 90 degrees as well as in prone with the hip in neutral flexion/extension. Screening of hip rotation in the prone position reduces possibility of ROM restriction due to femoral head neck offset and therefore may allow for better assessment of the bony structure of the femoroacetabular articulation, specifically the presence of femoral version. Increased hip IR may indicate the presence of femoral anteversion, while increased hip ER may indicate the presence of femoral retroversion. Holm et al. reported hip rotation ROM has good reliability in screening for femoral version. Additionally, Uding et al. report a 20 degree difference between hip IR and ER ROM when measured prone may be suggestive of abnormal femoral version. Femoral anteversion in the presence of AD may further decrease the stability of the hip joint and progression of symptoms. Li et al. reported individuals with AD and concomitant femoral anteversion demonstrate a significantly greater incidence of OA.

STRENGTH

Consensus Point: During an initial evaluation for an individual presenting for non-operative management of AD, the hip abductors, hip extensors, deep rotators, and core musculature are the most important muscle groups to strength test.

Decreased strength of the lumbopelvic and posterolateral hip complex may lead to a reduction in hip stability. In the setting of osseous insufficiency secondary to AD, muscular strength may plan an even larger role by providing dynamic stability to the hip joint. The gluteus medius, gluteus maximus, deep rotators, and core musculature are key stabilizers of the hip joint and should be assessed during an initial physiotherapy evaluation in an individual with AD.

In conjunction with the gluteus maximus and deep rotators, the gluteus medius muscle controls transverse and frontal plane motion of the femur, preventing femoral adduction and internal rotation, while the core musculature assists with maintaining neutral pelvic and spinal alignment.

Given their role in lumbopelvic stability, the panelists recommend strength testing of the hip abductor, hip extensor, and deep rotator muscles through manual muscle testing or handheld dynamometry. Core musculature may be evaluated through performance of a plank and side plank, assessing for inability to maintain proper form over 45-seconds. The plank and side plank exercises were chosen as they are a widely utilized measure of isometric core strength. While the strength deficits associated with other non-arthritic hip disorders, such as femoroacetabular impingement, has been shown in the literature, there is little research assessing the strength deficits associated with AD. In a study of 46 men and 49 women with symptomatic AD, Wang et al. reported hip abductor muscle strength was decreased compared to the contralateral, asymptomatic hip during isokinetic strength testing.

SPECIAL TESTS

Consensus Point: During an initial evaluation for an individual presenting for non-operative management of AD, special tests including FADIR, FABER, log roll, and apprehension testing should be utilized.

While no single special test exists to evaluate for the presence of AD, a cluster of examination findings, along with the individuals subjective report, may indicate the presence of intra-articular hip pain and concomitant hip in-
stability associated with AD. The FADIR and FABER tests are commonly utilized to assess for the presence of intra-articular hip pain in this population. A systematic review by Caliesch et al.34 assessed the diagnostic accuracy of clinical tests for femoroacetabular impingement and found the FADIR test had a sensitivity of 0.96 (0.91-0.99) and a specificity of 0.11 (0.06-0.02) and the authors also reported a sensitivity of 0.6 (0.15 to 0.95) and a specificity of 0.2 (0.10 to 0.35). Therefore, these tests should be utilized to screen for the presence of intra-articular pain, not identify a specific pathology. Following identification of intra-articular hip pain, the use of apprehension testing may assist clinicians in identifying the presence of hip joint instability. Hoppe et al.35 analyzed three physical examination maneuvers to detect the presence of instability and found the abduction-hyperextension-external rotation test was the most accurate with a sensitivity and specificity of 80.6% and 89.4%, respectively. A systematic review by Cohen et al.36 found 65% of patients with a diagnosis of hip instability reported the presence of anterior apprehension in a position of combined hip extension and external rotation.

FUNCTIONAL CONTROL

Consensus Point: During an initial evaluation for an individual presenting for non-operative management of AD, SL activities such as a SL stance, SL squat, an/or step down should be utilized to assess functional control.

The relationship between lumbopelvic and posterolateral hip muscle function and lower extremity injury has been well documented in the literature.37-42 Frontal plane pelvic motion is controlled mainly by the gluteus medius muscle, providing not only dynamic stabilization of the hip joint, but also assists with control of knee adduction moment during SL activities.43,44 The deep hip external rotators and core musculature also play a role providing control of femoral internal rotation and dynamic stability of the trunk, respectively.45 Along with muscle activation, the presence of abnormal femoral version may impact an individual’s performance during functional testing. In order to appropriately assess functional control of these muscles, the panelists recommend evaluating an individual’s performance during SL tasks, including but not limited to a SL stance, SL squat, or/step down maneuvers. Observation of static SL stance can be useful to assess for gluteus medius dysfunction through the presence of a Trendelenburg sign, defined as a contralateral pelvic drop or a shift in the trunk to keep the pelvis level.46,47 McGovern et al.48 found the SL squat and the step-down test can help identify kinematic and biomechanical deficiencies and are useful in the evaluation of an individual with non-arthritis hip pain.

ACTIVITY MODIFICATIONS

Consensus Point: Recreational activities that do not increase pain should be permitted, however, activities that increase pain should be modified (ie. reduced intensity or frequency) as needed to remain symptom free.

Individuals presenting with AD are generally young and active, therefore, activity modifications while undergoing a trial of supervised physiotherapy may be indicated. The panelists recommend all recreational activities should be pain-free as a common short-term goal of non-operative physiotherapy is a reduction in pain. Continuing activities that are painful may hinder the individual’s ability to perform the necessary strength and control exercises which are crucial to improving dynamic joint stability in this population. These activities often include prolonged upright activities or activities incorporating large ranges of hip motion, especially into flexion and rotation. Therefore, activities that are painful should be modified as needed. Modifications may include discontinuation of the activity or simply a reduction in the intensity or frequency. Tolerance to these activities should be reassessed as strength and functional control improves and can be reinitiated when the individuals report improved tolerance to these activities.

THERAPEUTIC EXERCISE PROGRESSION

LOCAL TO GLOBAL EXERCISE PROGRESSION

Consensus Point: Progression from local to globally-focused exercise should be based upon quality of movement (ie. adequate muscle activation with minimal compensatory actions) and irritability of the hip joint.

Appropriate functional control relies on coordinated activation of muscles across multiple joints. To establish functional control, however, an individual needs to first demonstrate competency in local muscle control (deep rotators, etc) as activation of global muscles in the presence of local dysfunction may reduce the ability of the local musculature to assist with basic stability tasks. Local muscle control should be assessed through an individual’s ability to perform low-load isometric exercises in varying non-weight bearing positions without compensation. Examples of these activities include gluteal bridges, clamshells, and transverse abdominis firing (Figure 1). The importance of local muscular control has been well established in patients with low back pain as the local muscles promote segmental stabilization and are superior to controlling unwanted load through the spine.49 Once an individual demonstrates adequate muscle activation with minimal compensatory actions during local exercise, the panelists recommend progression to global exercise, which may include weight bearing tasks (Figure 2). Global exercises should challenge the control of multiple muscle groups across multiple joints and should mimic an individual’s activity goals.

ISOMETRIC TO ECCENTRIC EXERCISE PROGRESSION

Consensus Point: Progression from isometric to concentric exercise should be based on the individuals reported pain level during exercise. Progression from concentric to eccentric exercise should be based upon quality of movement (ie. adequate muscle activation with minimal compensatory actions).

Isometric muscle activation increases muscle tension without changing muscle length or joint range of motion and these types of contractions assist with dynamic joint stability.50 Not only do isometric contractions assist with
Figure 1. Examples of local muscle control exercises including a) supine transverse abdominis contraction with palpation, b) gluteal bridge, and c) sidelying hip abduction with resistance band.

Figure 2. Examples of global exercises including a) SL stance, b) SL squat, and c) lateral step down.

maintaining a stable posture during dynamic movements, but they have been shown to benefit both acute and chronic pain and allow for increased joint stability and strength in the presence of pain.\textsuperscript{50-54} The panelists recommend use of isometric exercise in the presence of acute pain in the hip joint to improve muscle activation and joint stability. When the individual demonstrates less irritability in the hip joint as well as adequate muscle activation during isometric exercise, clinicians should progress to concentric exercises to further assist with muscle strengthening.
LUMBOPELVIC AND LOWER EXTREMITY NEUROMUSCULAR CONTROL

**Consensus Point:** Exercises to facilitate lumbopelvic and lower extremity neuromuscular control should challenge both the pelvis and lower quarter with a focus on SL control when appropriate. Exercises should begin in low demand positions (ie. supine, quadruped, or tall kneeling) and progress to high demand positions (ie. double and SL) as tolerated. These tasks should include both static and multidirectional tasks and be progressed based on quality of movement.

The association between adequate lumbopelvic control and lower extremity injury has been well established in the literature.\textsuperscript{30,55} The lumbopelvic region serves as the foundation for the trunk and lower extremity and poor lumbopelvic neuromuscular control can result in uncontrolled trunk movement as well as lower extremity valgus.\textsuperscript{56,57} The gluteus medius, gluteus maximus, deep external rotator, and core musculature play an important role in lumbopelvic neuromuscular control and exercises should be prescribed to challenge functional control these muscles.\textsuperscript{58-60} The panelists recommend beginning lumbopelvic control exercises in low demand positions of supine, quadruped, and tall kneeling incorporating lower and upper extremity movement based on quality of movement (Figure 3). Once adequate lumbopelvic control has been established in low demand positions, exercises should be progressed to double and SL weight bearing activities. Weight bearing exercises should begin with static tasks, progressing to dynamic, multidirectional tasks based on quality of movement (Figure 4).

PROGRESSION FROM DOUBLE TO SL ACTIVITIES

**Consensus Point:** Progression from double to SL activities is appropriate when an individual exhibits no trunk or pelvic compensation during double leg activities and can maintain pelvic and lower extremity control during a basic SL stance.

Double leg activities, such as a squat, should be utilized to establish basic static and dynamic control of the pelvis in a weight bearing position. While Lubahn et al.\textsuperscript{61} found the double leg squat with a load may be effective strategy to activate the gluteus maximus, it has been well established that electromyographic (EMG) activity of the gluteus medius and gluteus maximus muscles are highest in a SL position.\textsuperscript{62} However, a study of 22 healthy females with a mean age of 22.6 ± 2.5 years found the magnitude of anticipatory gluteus medius activity before toe off of the contralateral limb during a SL squat was significantly correlated with the knee abduction moment (p < .001).\textsuperscript{63} This study highlights importance of establishing appropriate gluteus medius muscle recruitment in a double leg position before progressing to SL activities.\textsuperscript{64} Therefore, the panelists recommend progression from double to SL activities only when the individual can maintain appropriate pelvic and trunk control during double leg activities and can maintain pelvic and lower extremity control during a basic SL stance. Thorough attention should also be given to sagittal plane control, specifically pelvic tilt. Individuals with AD may increase their anterior pelvic tilt to improve functional acetabular retroversion, providing improved coverage anterior-superior femoral head.\textsuperscript{64,65} Therefore, creating increased anterior pelvic tilt may be a helpful compensatory motion to encourage in this population when transitioning from double to SL activities.

REHABILITATION OF THE HIP FLEXOR COMPLEX

**Consensus Point:** Therapeutic exercise directed at the hip flexor complex should begin only after the patient has demonstrated an improvement in posterosuperior hip strength and a reduction in hip joint irritability. These exercises should begin in a short lever position, when/if appropriate. Long lever hip flexion exercises may only be necessary based on sporting demands (i.e. dancers). They should be incorporated only when the patient has reduced hip joint irritability and is tolerating all short lever hip flexion exercises without an increase in pain.

The iliopsoas muscle complex sits anterior to the hip joint and may compensate for the lack of osseous stability associated with AD.\textsuperscript{66-68} As a result, the iliopsoas tendon is susceptible to inflammation, overload, and/or pain. Furthermore, Philippon et al.\textsuperscript{69} reported a link between gluteus medius muscle weakness and iliopsoas tendonitis. It has been shown that gluteal weakness is present in individuals with AD and therefore may increase the likelihood of developing iliopsoas tendinitis. More recently, Jacobsen et al.\textsuperscript{70} performed an ultrasound evaluation of the iliopsoas in 100 individuals with symptomatic AD. The authors reported that 50% of individuals demonstrated abnormalities in the iliopsoas tendon, hypothesizing that these abnormalities were a result of insufficient anterior acetabular coverage and the resulting increased load placed through the iliopsoas.\textsuperscript{70} Therefore, the expert panel recommends avoiding hip flexor muscle strengthening until improved dynamic hip joint stability has been established through increased posterosuperior hip strength. When appropriate, these exercises should begin in a short lever position to minimize the chance of further irritation to the iliopsoas tendon. If long lever hip flexion is a required sporting demand, strengthening of the iliopsoas in a long lever should be prescribed, but only after adequate tolerance to short lever strengthening has been established. Both short and long lever hip flexion exercises should be discontinued if the patient reports increased pain.

MUSCLE STRETCHING PRINCIPLES

**Consensus Point:** Muscular stretching should not be a focus of physiotherapy as AD is a diagnosis of instability. The focus of physiotherapy for patients with AD should be optimizing joint stability, not increasing mobility. As previously mentioned, the iliopsoas complex acts as a secondary stabilizer to the hip joint and may be hypertonic secondary to the lack of osseous coverage associated
Figure 3. Examples of low demand lumbopelvic control exercises including a) supine march, b) supine lower extremity isometric hold with alternating upper extremity flexion, c) alternating upper extremity flexion in supine, and d) bird dog.

Figure 4. High demand lumbopelvic exercise progression including a) quadruped hip extension with medial resistance, b) standing hip abduction with resistance band on unstable surface, c) lateral step down with medial resistance, and d) SL stance on unstable surface with upper extremity perturbations.

with AD.\textsuperscript{57,68} Other muscles, such as the hip adductors, which act to stabilize the pelvis and lower extremity during the stance phase of gait, may also exhibit hypertonicity. Evaluation of the flexibility of these muscles may indicate muscle tightness, the authors caution against restoring flexibility to these muscles in the early stages of the rehabilitation process as these muscles are providing anterior joint stability in the setting of osseous instability. Once adequate posterolateral hip strength has been established, providing increased dynamic hip joint stability, stretching...
can be initiated as tolerated. It should be noted, however, that the expert panel recommends a larger focus be placed on strength and neuromuscular control training to improve joint stability.

CARDIOVASCULAR EXERCISE

Consensus Point: Low impact activities such as cycling, the elliptical, and swimming (with a pool buoy if necessary) should be encouraged if pain-free. High impact cardiovascular activities such as running and plyometrics may be initiated as tolerated when strength and neuromuscular control improves and hip joint irritability and decreased.

The importance of cardiovascular exercise is well established. Maintenance of cardiovascular fitness during a trial of non-operative physiotherapy for the treatment of AD is crucial to allow for re-initiation of recreational activities as pain allows. Given individuals with AD often complain of pain with upright and high impact activities, low impact activities including cycling, the elliptical trainer, and swimming should be encouraged. Modifications may need to be made, such as adjusting seat position, stride length, and swim stroke, to allow these activities to be performed without increasing symptoms. These activities should be adjunct to strength and neuromuscular control exercises. As strength and functional control improves, individuals may report improved tolerance to higher impact activities. These high impact cardiovascular activities, including running and plyometrics, should be encouraged as pain allows.

RETURN TO RECREATIONAL ACTIVITIES/SPORTS

RETURN TO STRAIGHT LINE RUNNING

Consensus Point: Individuals may begin running when they demonstrate normalized strength, minimal hip joint irritability, appropriate pelvic and lower extremity neuromuscular control during SL activities, and a normal gait pattern during ambulation at faster paces.

Straight line running should be utilized as the first step in the return to sport progression as it introduces a dynamic, low load through the lower extremity and helps improve cardiovascular endurance. Utilizing objective criteria, including pain, ROM, and functional control, is crucial as running is the first sport-specific activity in the rehabilitation process. Despite the increased recognition of non-articular hip joint pathologies, there is a dearth of literature supporting return to run criteria for these individuals. The panelists recommend utilizing a combination of measures, including hip joint pain, lumbopelvic and lower extremity neuromuscular control during SL activities, and gait, to assess for readiness to return to straight line running. Running should be progressed in a gradual manner utilizing walk/jog intervals to allow for monitoring of hip joint irritability. If the patient demonstrates appropriate tolerance to a running progression, low-level agility drills, including ladder drills, should be initiated.

INITIATION OF PLYOMETRIC ACTIVITIES

Consensus Point: Plyometric activities should be initiated when an individual demonstrates normalized strength, minimal to no pain, and appropriate pelvic and lower extremity neuromuscular control during all running and low-level agility tasks.

Plyometrics exercises are crucial for return to sport progression as such activities improve power development during functional movement patterns, allowing the individual to prepare for their sporting demands. Along with increased power production, plyometrics increase peak force and velocity of acceleration movements and increase muscle activation. The panelists recommend progressing to plyometric activities when an individual is demonstrating minimal to no pain and appropriate pelvic and lower extremity neuromuscular control during straight line running and low-level agility tasks. Plyometric exercise should begin with double leg activities, progressing to SL activities when the patient demonstrates appropriate functional control with double leg tasks. Careful attention should be paid to dosing of plyometric activities, specifically contacts per session, and should be based on athletic ability or exercise volume.

FULL RETURN TO SPORT

Consensus Point: An individual should be cleared for full participation in sporting activities when they demonstrate normalized strength, adequate pelvic and lower extremity neuromuscular control during SL tasks, and tolerance to all sport specific activities including running and plyometrics.

Full return to activity is a common goal of individuals with symptomatic AD as these individuals tend to be young and athletic. Currently, there is no literature indicating return to sport rates or objective criteria that should be utilized to determine readiness to return to full participation in individuals with AD. The panelists recommend utilizing a combination of strength, lower extremity neuromuscular control, and tolerance to sport specific activities as criteria to determine readiness for full return to sport. Along with this objective criteria, psychological readiness should be taken into account as decreased psychological readiness may result in reinjury and/or decreased sport performance. In individuals with femoroacetabular impingement syndrome (FAIS), Jochimsen et al. reported low self-efficacy and high kinesiophobia resulted in worse function and increased pain. Given the long-standing nature of AD and similar activity limitations seen with FAIS, an assumption can be made that these individuals will exhibit signs consistent with low confidence and fear and clinicians should recognize the importance of these factors when considering full return to sport clearance.

REFERRAL TO A PHYSICIAN HIP SPECIALIST

Consensus Point: An individual should be referred for initial or return consultation to a physician specializing in hip preservation if they are exhibiting no decrease in symptoms...
Table I. Panelist recommendations for return to recreational activities/sports

<table>
<thead>
<tr>
<th>Return to Straight Line Running</th>
<th>Initiation of Plyometric Activities</th>
<th>Full Return to Sports</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Reduction in hip joint irritability</td>
<td>• Minimal to no pain and appropriate pelvic and lower extremity neuromuscular control during all running and low-level agility tasks</td>
<td>• Normalized, symmetrical strength</td>
</tr>
<tr>
<td>• Appropriate pelvic and lower extremity neuromuscular control during SL activities</td>
<td></td>
<td>• Adequate pelvic and lower extremity neuromuscular control during all SL tasks</td>
</tr>
<tr>
<td>• Normal gait pattern during ambulation at faster paces</td>
<td></td>
<td>• Tolerance to all sport specific activities including running and plyometrics</td>
</tr>
</tbody>
</table>

despite improved strength and neuromuscular control with completion of 4-8 weeks of physiotherapy.

After the initial diagnosis of AD, an individual may be referred for physiotherapy. If after 4-8 weeks of hip specific physiotherapy, the individual reports no decrease in symptoms despite improved strength and neuromuscular control, a referral to a physician specializing in hip preservation is indicated. It should also be noted that individuals with more severe disease may not be candidates for a trial of non-operative management due to the increased possibility of early onset arthritis. Severity of disease is often classified utilizing the lateral center edge angle (LCEA) on an anteroposterior radiograph, with an LCEA < 20 degrees considered pathologic and an LCEA between 20-25 degrees considered borderline dysplastic. While the LCEA is an oversimplification of the diagnosis, it may be a useful finding for physiotherapists to consider when determining timing of physician referral.

CONCLUSION

A trial of non-operative rehabilitation is often recommended in the setting of AD. However, no physiotherapy guidelines or description of therapeutic activity progression currently exist in the literature. This Delphi study established expert based recommendations regarding initial evaluation principles, activity modifications, therapeutic exercise progression, return to activity criteria, and indications for physician referral. This study will help reduce practice variation and is the first step in determining who is appropriate for a trial of non-operative rehabilitation. Future studies need to assess patient outcomes with utilization of this protocol and determine how many patients convert to surgery despite targeted rehabilitation.

CORRESPONDING AUTHOR
Ashley Disantis, DPT, OCS
Rangos School of Health Sciences, Department of Physical Therapy
Duquesne University
Pittsburgh, PA USA
disantisae@chp.edu
412-979-4733

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

ACKNOWLEDGEMENTS

We want to acknowledge all physiotherapists who put their time and effort into completion of the three survey rounds of this Delphi study. Their work was essential in creating this consensus statement.

Submitted: June 23, 2023 CST, Accepted: September 24, 2023 CST

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.

International Journal of Sports Physical Therapy
REFERENCES


72. American Heart Association. *Endurance Exercise (Aerobic).*


Original Research

Evaluating Functional Performance Tests in those with Non-arthritic Intra-articular Hip Pain: An International Consensus Statement

RobRoy L Martin¹, Amir Takla²,³, Ashely Disantis¹,⁴, David Kohlirieser⁶, Keelan Enseki⁷, Liran Lifshitz⁴, Louise Grant⁸, Mario Bizzini⁹, Mike Voight¹⁰,¹¹, Mark Ryan¹², Ryan McGovern¹³, Timothy Tyler¹⁵, Yael Steinfeld-Mass¹⁶, Ashley Campbell¹⁷, Yngni Zhang¹⁸

¹ Duquesne University, ² Swinburne University of Technology, ³ Australian Sports Physiotherapy, ⁴ Hip Arthroscopy Australia, ⁵ UPMC Children's Hospital of Pittsburgh, ⁶ Orthopedic One, ⁷ University of Pittsburgh Medical Center, ⁸ The Israel Football Association, ⁹ PhysioCure, ¹⁰ Human Performance Lab, Schulthess Klinik, ¹¹ Nashville Hip Institute at TOA, ¹² School of Physical Therapy, Belmont University, ¹³ The Steadman Clinic, Steadman Phillipsson Research Institute, ¹⁴ PatientIQ, ¹⁵ Pro Sports Physical Therapy, ¹⁶ Tel Aviv University, Israel, ¹⁷ School of Physical Therapy, Belmont University, ¹⁸ Duquesne - China Health Institute

Keywords: functional performance test, non-arthritic intra-articular hip pain, modified Delphi, consensus statement

https://doi.org/10.26603/001c.89269

International Journal of Sports Physical Therapy

Background
Non-arthritic intra-articular hip pain, caused by various pathologies, leads to impairments in range of motion, strength, balance, and neuromuscular control. Although functional performance tests offer valuable insights in evaluating these patients, no clear consensus exists regarding the optimal tests for this patient population.

Purpose
This study aimed to establish expert consensus on the application and selection of functional performance tests in individuals presenting with non-arthritic intra-articular hip pain.

Study Design
A modified Delphi technique was used with fourteen physical therapy experts, all members of the International Society for Hip Arthroscopy (ISHA). The panelists participated in three rounds of questions and related discussions to reach full consensus on the application and selection of functional performance tests.

Results
The panel agreed that functional performance tests should be utilized at initial evaluation, re-evaluations, and discharge, as well as criterion for assessing readiness for returning to sports. Tests should be as part of a multimodal assessment of neuromuscular control, strength, range of motion, and balance, applied in a graded fashion depending on the patient's characteristics. Clinicians should select functional performance tests with objective scoring criteria and prioritize the use of tests with supporting psychometric evidence. A list of recommended functional performance tests with varying intensity levels is provided. Low-intensity functional performance tests encompass controlled speed in a single plane with no impact. Medium-intensity functional performance tests involve controlled speed in multiple planes with low impact. High-intensity functional performance tests include higher speeds in multiple planes with higher impact and agility requirements. Sport-specific movement tests should mimic the patient's particular activity or sport.

a Corresponding author:
Yongni Zhang
111A Health Sciences Building 600 Forbes Ave Pittsburgh, PA 15282, US
Email zhzh19920903@163.com
Conclusion
This international consensus statement provides recommendations for clinicians regarding selection and utilization of functional performance tests for those with non-arthritic intra-articular hip pain. These recommendations will encourage greater consistency and standardization among clinicians during a physical therapy assessment.

INTRODUCTION
Non-arthritic intra-articular hip pain can result from multiple pathologies including femoroacetabular impingement syndrome (FAIS), acetabular dysplasia, and/or capsular/ligamentous laxity.1-3 These pathologies may lead to chondral/ labral damage with associated pain, abnormal hip range of motion (ROM), decreased hip and lumbopelvic strength, and impaired neuromuscular control.1,3,4 As a result, individuals with non-arthritic intra-articular hip pain report decreased function and quality of life.1 During an examination, functional tests are utilized to compliment patient reported outcome measures (PROMs) and assessments of strength and ROM.5-8 While a large number of functional performance tests have been proposed for the lower extremity,8-21 there is currently no agreement on which functional performance tests are optimal for use in individuals presenting with non-arthritic intra-articular hip pain.

Functional performance testing may allow for a simultaneous assessment of muscle flexibility, ROM, strength, balance, and neuromuscular control.22-24 These tests may provide clinicians with valuable information regarding the impact of the impairments and allow for assessing patient progress over the course of treatment. However, there is a lack of high-quality evidence and consensus supporting the use of specific functional performance tests during a physical therapy assessment of an individual presenting with non-arthritic intra-articular hip pain.

The purpose of this modified Delphi study was to present an international consensus statement that provides clinicians guidance regarding the use of functional performance tests in individuals presenting with non-arthritic intra-articular hip pain. It was hypothesized that consensus could be achieved on when to utilize functional performance tests, how to determine which functional performance tests should be implemented, and which functional performance tests may be most useful for an individual presenting with non-arthritic intra-articular hip pain.

METHODS
STUDY PARTICIPANTS
Panelists were identified as experts in physical therapy management of non-arthritic intra-articular hip pain by the senior author from the physiotherapy section of International Society for Hip Preservation (ISHA) membership. Panelists were chosen to represent five continents with representation from Asia, Australia, Europe, North America, and South America. Of the 14 identified individuals, 100% agreed to participate in the current study. The panelists were all specialists in sports/orthopedic physiotherapy and represented five countries with an average of 25 years (range: 9-40) experience. A summary of the panelist’s attributes can be found in Table 1.

STUDY DESIGN
This study utilized a modified Delphi technique to establish group consensus on use of functional performance tests for individuals with non-arthritic intra-articular hip pain.25,26 Methods for the current study are similar to those described in Disantis et al.27 Briefly, a list of relevant questions regarding the use of functional performance tests was determined and consensus was reached over three survey rounds. During round one, panelists were presented with list of potential topics via email. The senior author collected and organized all of the feedback to create an updated topic list. The second round included a face to face meeting with all the panelists where the updated topic list was presented with specific questions and responses being generated by the group. In the third and final round, the final question list and responses were emailed to all to panelists approval. A priori, consensus was defined as being ≥80%.

RESULTS
After the first two rounds the panelists agreed (14/14) that the following questions needed to be answered:

1. At what time points do you utilize functional performance tests in an individual presenting with non-arthritic intra-articular hip pain?
2. How and why do you determine which functional performance tests should be utilized?
3. Which functional performance tests are most useful for an individual presenting with non-arthritic intra-articular hip pain?

A consensus statement to each question was achieved by 14/14 panelists after the third round.

DISCUSSION
At what time points do you utilize functional performance tests in an individual presenting with non-arthritic intra-articular hip pain?

CONSENSUS STATEMENT
Physical therapists should utilize functional performance tests during the initial evaluation, subsequent re-evaluations, and discharge. Functional performance tests should also be utilized as criteria during return to sport testing in individuals presenting with non-arthritic intra-articular hip pain.
Currently, there is a paucity of high-quality literature supporting the utilization of functional performance tests in individuals with non-arthritic intra-articular hip pain. The Academy of Orthopedic Physical Therapy clinical practice guidelines (CPG) recommend using functional performance tests during examination to identify activity and participation limitations in those with musculoskeletal conditions, including non-arthritic hip pain.\(^1,28-34\) Based on limited evidence, the CPG recommendations include evaluation of sitting, ambulation on level surfaces, stair negotiation, and sit-to stand performance.\(^1\) However, these activities do not represent the full spectrum of functional activity. Specifically, these tests do not assess single leg control or sport specific activities, which are common pre-injury functional demands of this patient population.

Returning to sport is a common goal of individuals with non-arthritic intra-articular hip pain. Criteria to determine when an individual is ready to return to sport remains difficult. Determining readiness to return to sport should not be based solely on strength and ROM impairments.\(^35-38\) Measures of pain, strength, and ROM should be complemented with functional performance tests to help identify when individuals with non-arthritic intra-articular hip pain are ready to return to pre-injury activity.\(^39\)

**How and why do you determine which functional performance tests should be utilized?**

**CONSENSUS STATEMENT**

Physical therapists should utilize functional performance tests as part of a multimodal assessment of neuromuscular control, strength, and ROM. They should be progressed in a graded fashion, depending on the patient’s identified impairments, level of irritability, individual characteristics, and individual goals.

Functional performance tests are a valuable tool for simultaneously evaluating strength, ROM, balance, and neuromuscular control,\(^1\) and an essential component of physical therapy evaluations. In individuals with non-arthritic intra-articular hip pain, studies have specifically supported functional performance tests as assessments of muscle strength,\(^40-42\) ROM,\(^43,44\) balance,\(^44-48\) and neuromuscular control.\(^3,16,49\) The specific functional performance tests utilized by the clinician should be dependent on current level of activity, irritability of the hip joint, and individual patient goals.

Another important consideration when selecting appropriate functional performance tests are their associated psychometric properties, including reliability, validity, and responsiveness. Reliability refers to the consistency of the test over time, while validity refers to the ability of the test to measure what it intends to measure. Responsiveness refers to the ability to identify expected clinical changes over time.\(^50,51\) Selecting functional performance tests with psychometric evidence may allow for interpretation of patients’ improvement over time.

**Which functional performance tests are most useful for an individual presenting with non-arthritic intra-articular hip pain?**

**CONSENSUS STATEMENT**

Physical therapists should determine functional performance tests that challenge lumbopelvic and lower extremity neuromuscular control. Clinicians should choose functional performance tests based on intensity with low, medium, high, and sport specific tests that challenge limb support, speed, ROM, multiplanar control, and impact loading.

The panel recommends separating functional performance tests by level of intensity and classifying tests into

---

**Table 1. A Summary of Panelist Attributes**

<table>
<thead>
<tr>
<th>Name</th>
<th>Year of experience</th>
<th>No. of hip-specific consultations per week</th>
<th>Academic post</th>
<th>Actively involved in research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amir Takla</td>
<td>25</td>
<td>40</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Ashley Campbell</td>
<td>12</td>
<td>30</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Ashley Disantis</td>
<td>9</td>
<td>30</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>David Kohlrieser</td>
<td>15</td>
<td>35</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Keelan Enseki</td>
<td>21</td>
<td>10</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Liran Lifshitz</td>
<td>28</td>
<td>30</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Louise Grant</td>
<td>30</td>
<td>50</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Mario Bizzini</td>
<td>35</td>
<td>6</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Mike Voight</td>
<td>40</td>
<td>10</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Mark Ryan</td>
<td>30</td>
<td>20</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>RobRoy Martin</td>
<td>32</td>
<td>NA</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Ryan McGovern</td>
<td>13</td>
<td>NA</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Timothy Tyler</td>
<td>35</td>
<td>11</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Yael Steinfeld</td>
<td>25</td>
<td>30</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
categories of low, medium, high, and sport specific. Low intensity functional performance tests challenge neuromuscular control in a single plane, with no impact, and utilize a controlled speed. Specifically, low intensity tests should include single leg static tasks and those with double leg support and controlled ROM. Medium intensity functional performance tests should challenge neuromuscular control with multiplanar low impact movements at a controlled speed in a pain free ROM. High intensity functional performance tests progress to multiplanar, high-speed tests that incorporate greater impact and agility. Tests during this phase should mimic the activity or sport related goals of the patient. A summary of panelist recommend actions can be found in Table 2.

In addition to providing criteria to define low, medium, high, and sport specific functional performance tests, the panelists agreed upon examples of specific tests for each level of intensity. These example tests and available psychometric evidence are provided below. Note the function performance tests listed in Table 2 are meant to serve as example tests that meet the criteria at each intensity. Other tests that meet each criteria may be selected at a clinician’s discretion.

LOW INTENSITY FUNCTIONAL PERFORMANCE TESTS

SIT TO STAND TEST

The Sit to Stand Test (STS) is performed by having the individual standing up and sitting down five times as quickly as possible while keeping the arms crossed over the chest.52 Individuals with FAIS and acetabular dysplasia have been shown to demonstrate poor performance on sit-to-stand tests compared to asymptomatic controls.52,53 Deficits on the STS test are also strongly associated with scores on the Patient-Reported Outcomes Measurement System(PROMIS), Hip Disability and Osteoarthritis Outcome Score (HOOS), International Hip Outcome Tool (iHOT-33), and Modified Harris Hip Score (mHHS).53 The psychometric properties of the STS test in individuals with hip dysplasia have also been explored, with Scott et al.52 reporting excellent inter-rater (MDC=0.36 seconds) and intra-rater reliability (MDC=4.71 seconds).

TIMED SINGLE-LEG STANCE TEST

The Timed Single-Leg Stance Test requires individuals to place their hands on their hips and stand on one leg for a duration of up to 30 seconds.47 In individuals with FAIS, hip abductor strength has been shown to be reduced in those who perform the timed single-leg stance test with poor pelvic control compared to those who performed the activity with good pelvic control.40 Additionally, those who perform poorly also scored lower on the Hip Outcome Score-Activities of Daily Living (HOS-ADL) subscale.40 The timed single-leg stance test demonstrated good inter-rater and intra-rater reliability in individuals presenting with hip osteoarthritis and FAIS.40

MEDIUM INTENSITY FUNCTIONAL PERFORMANCE TESTS

STAR EXCURSION BALANCE TEST AND Y-BALANCE TEST

The SEBT requires subjects to maintain a single-leg stance on the test leg while reaching the opposite leg in eight directions. The star excursion balance test (SEBT) and the Y-Balance test (YBT) are utilized to assess dynamic control of the lower extremity.45 Individuals with FAIS demonstrate lower reach distances in the posteromedial and posterolateral directions of the SEBT on the symptomatic lower extremity when compared the asymptomatic lower extremity.46 Additionally, reach distance in the posteromedial and posterolateral direction highly correlate with Hip and Groin Outcome Score (HAGOS) symptom and pain intensity subscale scores.46 Similarly, Palsson et al.47 found patients with hip-related pain demonstrate decreased reach distance on the SEBT in the anterior, posteromedial, and posterolateral directions compared to healthy controls. The YBT was found to have high intra-rater reliability in all three directions in individuals with non-arthritic hip re-
lated groin pain. Furthermore, hip strength as well as hip internal rotation and flexion ROM contributed to reach distance in all directions on the YBT. SINGLE LEG SQUAT TEST AND STEP-DOWN TEST

The single-leg squat and step-down tests assess an individual’s ability to squat and step down on one leg, respectively, with the rater monitoring for lower extremity deviations. The single leg squat test (SLST) and step-down test (SDT) are utilized to assess single leg lumbopelvic and lower extremity neuromuscular control. A literature review by McGovern et al. found moderate-to-excellent inter-rater reliability for both tests in assessing neuromuscular control for the trunk, pelvis, hip and knee. Crossley et al. reported individuals who passed the SLST and SDT exhibited strong hip abduction strength and earlier onset timing activation than those who fail the SLST and SDT. Furthermore, a study by McGovern et al. found the tests to be reliable and valid, as there were significant differences in pain VAS, HOS-ADL, and HOS-sport scores between those that passed and failed the SLST and SDT on initial assessment. Also, patients with non-arthritis hip pain who demonstrate improvements on the SLST and SDT after undergoing a rehabilitation program demonstrated lower pain VAS scores and higher scores on the HOS-ADL and HOS-Sport than those who did not improve on the SLST and SDT.

THE TIMED STAIRS ASCENT TEST

The Timed Stairs Ascent Test (TSA) measures the time for the individual to ascend 12 of stairs as quickly as possible. Individuals with FAIS and acetabular dysplasia demonstrated poorer performance on the TSA test compared to asymptomatic controls. Performance on the TSA test has been shown to have a strong correlation with the PROMIS, HOOS, iHOT-53, and mHSS and a moderate correlation with the iHOT-12. Scott et al. found excellent inter-rater reliability with MDC value of 0.87 seconds and intra-rater reliability with MDC value of 1.81 seconds for the TSA test, when used to assess individuals with acetabular dysplasia.

TIMED WALKING TEST

In the Timed Walking Test, individuals walk a 20-meter distance at a comfortable speed, and the time taken to cover the central 10 meters is recorded. Individuals with FAIS and acetabular dysplasia performed worse speed on the timed walking test compared to asymptomatic controls. In individuals with acetabular dysplasia, Scott et al. found excellent inter-rater reliability (MDC=0.09 m/s) and intra-rater reliability (MDC=0.35 m/s)

DEEP SQUAT TEST

Deep squat test requires individual to squat down as deeply as possible. The deep squat test is a measure of both lumbopelvic and lower extremity neuromuscular control. Ayeni et al. found a sensitivity and specificity of 75% and 41%, respectively, in identifying individuals with a CAM-type deformity using the deep squat test. Those with FAIS display altered biomechanics during the deep squat test, including reduced hip internal rotation ROM, a posterior pelvic tilt, and hip extensor muscle activity during descent. Additionally, individuals with FAIS demonstrated reduced squat depth and altered lumbopelvic kinematics compared to healthy controls.

HIGH LEVEL FUNCTIONAL PERFORMANCE TESTS

HOP TESTS

The hop lunge test assesses lower body strength, power, and control by requiring participants to hop forward and lunge deeply. The hop lunge test has demonstrated good inter and intra-rater reliability when used to assess individuals with FAIS, based on visual assessment. Poor performance on this test has been associated with reduced hip abductor strength in patients with FAIS. The medial and lateral triple hop tests evaluate the individual’s ability to consecutively perform three hops on a single leg, with the total distance covered being recorded. A systematic review has shown good reliability of hop tests including the medial triple hop and lateral triple hop tests performed on dancers with FAIS. Another study found dancers with FAIS perform worse during medial and lateral hop triple tests compared to healthy dancers. Additionally, healthy women with weak hip muscles have been found to have altered coordination between the hip, knee, trunk and pelvis during hopping when compared to individuals with strong hip muscles.

MODIFIED AGILITY T-TEST

The modified agility T-test assesses an individual’s capacity for rapid change in direction and may be an important assessment tool for those returning to sports requiring agility, quickness, and speed. Males with FAIS demonstrated significantly lower speeds during the modified agility T-test compared to healthy controls. Sassi et al. found excellent test-retest reliability of the modified agility T-test in healthy athletes.

SPORT SPECIFIC TESTING

Sport specific testing should be individualized to the patient’s goals and required demands of their chosen sport(s). Specifically, sport specific testing should be tailored to mimic movements that pertain to the patient’s activity or sport. Sport-specific retraining represents a crucial final phase in the rehabilitation process to determine an athlete’s readiness for return to sport. Sport specific tests can have a positive impact on the athlete’s psychological readiness for return to their sport. Psychological readiness has become increasingly recognized as an important component of optimal performance and timely return to pre-injury performance levels. Jochimsen et al. found low self-efficacy and high kinesiophobia were associated with increased pain and decreased function in individuals with...
The panel in this current study recommended utilization of 3-4 sport specific activities coupled with a PROM to assess fear of physical activity and fear avoidance, such as the Tampa Scale of Kinesiophobia and Hip-Return to Sport after Injury Scale, when assessing for readiness for return to sport.68,69

LIMITATIONS

There are several limitations to this study. First, there is a paucity of high-quality literature supporting the use of functional performance tests in individuals with non-arthritic intra-articular hip pain. Initial study questions may be biased as they were generated by the panel of selected experts. To minimize bias, the senior author selected an international panel of experts in the management of these disorders. This panel of experts may not encompass all international opinions.

CONCLUSION

This international consensus statement provides recommendations for clinicians regarding selection and utilization of functional performance tests for use in this population. These recommendations will encourage greater consistency and standardization among clinicians during a physical therapy evaluation of an individual presenting with non-arthritic intra-articular hip pain. Further research is needed to validate the categorization of tests and offer psychometric evidence to allow better interpretation of test results in subjects with non-arthritic intraarticular hip pathology.

CONFLICTS OF INTEREST

The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article.

The authors declare no conflict of interest.

FUNDING

There is no financial support for the research.

Submitted: June 24, 2023 CST, Accepted: September 25, 2023 CST

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


International Journal of Sports Physical Therapy


Original Research

Safety Considerations When Dry Needling the Multifidi in the Thoracolumbar Region: A Cadaveric Study

Christi L. Williams1, Christian R. Falyar2, Ryan C. McConnell, Stacey Lindsley

1 Physical Therapy, Belmont University, 2 Middle Tennessee School of Anesthesia

Keywords: multifidus, ultrasound, cadaver, dry needling, safety considerations

Original Research

International Journal of Sports Physical Therapy

Background
Dry needling the lumbar multifidi is a technique used by physical therapists to effectively treat low back pain. While studies have examined the safety considerations in the upper lumbar spine related to the kidneys and lungs, none have investigated the possibility of entering the spinal canal in this region.

Purpose
The purpose of this cadaveric ultrasound-guided dry needling exploration was to determine if a dry needle can penetrate the ligamentum flavum at the T12/L1 interspace and enter the spinal canal using a paramedian approach in a fresh-frozen, lightly fixed cadaver in the prone position.

Study Design
Cadaveric study.

Methods
The procedure was performed on a cadaver in the prone position. The needle was advanced under ultrasound guidance to determine if a 0.50 x 50 mm dry needle inserted 1.0 cm lateral to the spinous process of T12 and directed medially at a 22-degree angle could penetrate the ligamentum flavum and enter the spinal canal.

Results
As determined via ultrasound, a dry needle can penetrate the ligamentum flavum and enter the spinal canal at the thoracolumbar junction using this technique.

Conclusion
This interprofessional collaboration demonstrates that a dry needle can penetrate the ligamentum flavum to enter the spinal canal at T12/L1 using a documented technique for dry needling the multifidi. A thorough understanding of human anatomy along with the incorporation of available technology, such as ultrasound, may decrease the risk of adverse events when dry needling the multifidi at the thoracolumbar junction.

Level of Evidence
Level IV.

INTRODUCTION

Dry needling is a common technique used by physical therapists to treat musculoskeletal pain,1 and needling the muscles around the lumbar spine has been shown to decrease low back pain in patients post-intervention.2-4 Significant and serious adverse events with dry needling have been published5-7; however, they are likely underreported.8

1 Corresponding Author:
Christi L. Williams
School of Physical Therapy, Belmont University, Nashville 37212, USA
615-260-0940, christi.williams@belmont.edu
Documented adverse events from needling interventions in areas around the spine include: acute epidural hematoma, post-dural puncture headache, infection, lower extremity weakness, and numbness into an extremity. Other documented adverse events include bleeding, bruising, pain, aggravation of symptoms, nausea, feeling faint, and headaches. Currently, no national or international system is available for tracking data on adverse events related to dry needling. While significant and serious events from dry needling are not common, therapists should be aware of all potential risks to improve procedures, safety for the individual patients, and the overall standard of practice.

One potential factor that may contribute to the occurrence of adverse events with dry needling is the lack of a universally accepted intervention methodology. Multiple approaches are used in research and instruction of dry needling techniques, which leads to variability in practice and difficulty determining if adverse events are tied to a specific approach. For example, there are a variety of methods described to dry needle the lumbar multifidi, which include variations in both the location of needle placement as well as the angulation of the needle as it is directed toward the targeted tissue.

When targeting the lumbar multifidi, Rainey describes a needle placement within one finger breadth lateral to the spinous process and a needle direction that is just medial to the vertical axis. Wang-Price et al. used a needle placement 2.0 cm lateral to the spinous process and angled 20° medially toward the spinous process, as well as a needle placement 4.0 cm lateral to the spinous process with a 45° medial angulation, with both techniques resulting in successful placement of the needle in the lumbar multifidi confirmed on ultrasound imaging.

Other authors report an intermedial needle angulation when targeting the lumbar multifidi but are not consistent with all parameters. Variations in parameters include needle placements at 1.0 cm lateral to the spinous process with a 15° intermedial angulation as well as 1.0 cm, or 1 finger breadth lateral placement with an intermedial angulation without specific information related to the degree of angulation, thereby leaving the technique open to interpretation. Hannah et al. describe a 1.5 cm needle placement lateral to the spinous process with a 45° inferior and 45° medial angulation of the needle. In addition to the medial and intermedial needle angulation techniques, other techniques include placing the needle 1.0-1.5 cm lateral to the spinous process with no angulation, but rather a straight posterior to anterior direction. Table 1 outlines the variability that exists related to needle position, needle length, needle angulation, depth of penetration, and patient position for dry needling the lumbar multifidi.

Despite the variability that exists in needle technique, dry needling of the multifidi has been considered a safe technique due to the ability of the vertebral lamina to serve as a protective barrier for the spinal canal, preventing inadvertent needling into the spinal canal. Several studies have examined the accuracy of needle placement in the lumbar multifidi at L4-5 and the safety considerations related to nearby structures, such as the kidneys and lungs, but none have investigated the possibility of entering the spinal canal in the upper lumbar region. Spinal canal perforation is a risk and has been demonstrated in the upper cervical spine. Additionally, acute cervical epidural hematoma has occurred following dry needling and may occur in other areas as well. The cadaveric dry needling technique described in this commentary highlights one of the multiple, documented approaches for the lumbar multifidi and sought to determine if a significant safety vulnerability exists.

The idea for this collaboration between physical therapy and certified registered nurse anesthetist (CRNA) faculty originated during a discussion on the distinctions between lumbar punctures performed by anesthesia providers and dry needling techniques executed by physical therapists on the multifidi. While the classic approaches and needle types for these two procedures differ, it raises the question of whether a dry needling procedure, when conducted in a manner described as safe and effective, can potentially breach the spinal canal. Table 2 compares a lumbar puncture technique and dry needling techniques targeting the lumbar multifidi.

The purpose of this collaborative cadaveric ultrasound-guided examination of dry needling was to determine if a dry needle can penetrate the ligamentum flavum at T12/L1 interspace and enter the spinal canal using a paramedian approach in a fresh-frozen, lightly fixed cadaver in the prone position.

METHODS

The procedure was performed at Middle Tennessee School of Anesthesia on an 88 y/o female donor by a certified registered nurse anesthetist with over 20 years of diagnostic ultrasound imaging experience and 15 years performing and teaching regional anesthesia. The fresh/lightly embalmed donor was received via the Willed Body Program at The University of North Texas Health Science Center. Exemption from Institutional Review Board approval was granted by Advarra IRB (Pro00070509).

The cadaver was placed in a prone position. A Sonosite Edge II ultrasound system with an rC60xi 5-2 MHz curvilinear array transducer (Bothell, WA) was placed in a parasagittal orientation with the orientation indicator facing cephalad. The sacrum, L5-S1 interspace, and L5 spinous process were identified. The transducer was slid cephalad until the interspace between T12 and L1 was identified. An AGUPUNT APS 0.30 x 50 mm dry needle was inserted approximately 1.0 cm lateral to the spinous process of T12 (Figure 1) and was directed medially at a 22-degree angle (Figure 2). The needle was advanced under ultrasound guidance to determine if it could penetrate the ligamentum flavum to enter the spinal canal.

RESULTS

As Figure 3 and Figure 4 illustrate, a 0.30 x 50 mm dry needle inserted approximately 1.0 cm lateral to the spinous
Table 1. Variability of Techniques used by Physical Therapists when Dry Needling the Lumbar Multifidus

<table>
<thead>
<tr>
<th>Reference</th>
<th>Target Muscle</th>
<th>Needle diameter</th>
<th>Needle length</th>
<th>Insertion Depth</th>
<th>Pt position</th>
<th>Needle approach</th>
<th>Needle angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loizidis et al., 20202</td>
<td>L2-5 Para-vertebral muscles(^a)</td>
<td>0.30 mm</td>
<td>50-75 mm</td>
<td>To lamina</td>
<td>Prone over pillow(^b)</td>
<td>2 cm lateral to SP(^c)</td>
<td>Inferomedial (~20°)</td>
</tr>
<tr>
<td>Wang-Price et al., 2020(^16)</td>
<td>L4-52 multifidi</td>
<td>0.30 mm</td>
<td>60-100 mm</td>
<td>To lamina(^d)</td>
<td>Prone over pillow(^b)</td>
<td>On or near tender point</td>
<td>Inferomedial (~20-30°)</td>
</tr>
<tr>
<td>Hannah et al., 2016(^23)</td>
<td>L4 multifidi</td>
<td>0.25-0.30 mm(^f)</td>
<td>N/A</td>
<td>To lamina</td>
<td>Prone</td>
<td>1.5 cm lateral to SP</td>
<td>45° inferior &amp; 45° medial</td>
</tr>
<tr>
<td>Clark et al., 2021(^22)</td>
<td>T12-L1 multifidi</td>
<td>0.30 mm</td>
<td>60 mm</td>
<td>To lamina</td>
<td>Not stated</td>
<td>1 cm lateral to SP</td>
<td>0°</td>
</tr>
<tr>
<td>Koppenhaver et al., 2015(^25)</td>
<td>L3-L5 multifidi</td>
<td>0.30 mm</td>
<td>50-60 mm</td>
<td>To lamina</td>
<td>Prone</td>
<td>1.5 cm lateral to SP</td>
<td>Inferomedial (~20°)</td>
</tr>
<tr>
<td>Puantedura et al., 2017(^26)</td>
<td>L4 multifidi</td>
<td>0.30 mm</td>
<td>40-50 mm</td>
<td>To lamina</td>
<td>Prone</td>
<td>1.5 cm lateral to SP</td>
<td>Inferomedial (~20°)</td>
</tr>
<tr>
<td>Wang-Price et al., 2022(^20)</td>
<td>L4-L5 multifidi</td>
<td>0.30 mm</td>
<td>100 mm</td>
<td>Bony backdrop(^g)</td>
<td>Prone over pillow(^b)</td>
<td>2.0 cm lateral to SP</td>
<td>20° medial</td>
</tr>
<tr>
<td>Rainey 2013(^19)</td>
<td>L3 &amp; L5 multifidi</td>
<td>0.25 mm</td>
<td>60 mm</td>
<td>To lamina</td>
<td>Prone over pillow(^b)</td>
<td>Within 1 finger breadth from midline</td>
<td>45° medial</td>
</tr>
<tr>
<td>Koppenhaver 2015(^21)</td>
<td>L3-L5 multifidi</td>
<td>.30 mm</td>
<td>50-60 mm</td>
<td>To multifidus</td>
<td>Prone</td>
<td>1 cm lateral to SP</td>
<td>Inferomedial 15°</td>
</tr>
</tbody>
</table>

\(^a\)Paravertebral muscles included: multifidus, erector spinae, iliocostalis lumborum, thoracolumbar fascia

\(^b\)The pillow is under the patient's abdomen

\(^c\)SP = Spinous Process

\(^d\)Not specified but mentioned standardizing depth by stopping at bony lamina of vertebrae

\(^e\)Not specifically stated in dry needling procedure, but was the position for other testing procedures

\(^f\)Researchers used craft needle for dissection purposes but stated the typical dry needling procedure would be with 0.25-0.30mm

\(^g\)To bony backdrop or until entire shaft of needle is completely subcutaneous
Table 2. Comparison of Techniques Used in a Lumbar Puncture Performed by an Anesthesia Provider and Dry Needling the Lumbar Multifidi Performed by a Physical Therapist

<table>
<thead>
<tr>
<th></th>
<th>Lumbar Puncture</th>
<th>Dry Needling Multifidi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Needle diameter (gauge)</td>
<td>20-22 gauge</td>
<td>0.25-0.30 mm</td>
</tr>
<tr>
<td>Needle length</td>
<td>9 cm</td>
<td>40-100 mm</td>
</tr>
<tr>
<td>Patient position</td>
<td>Sitting or side-lying with flexion of the spine</td>
<td>Prone or prone over pillow</td>
</tr>
<tr>
<td>Needle approach</td>
<td>Midline (in the interspinous space)</td>
<td>1-4 cm lateral to spinous process</td>
</tr>
<tr>
<td></td>
<td>In some cases, a paramedian (off midline) approach is used(^a)</td>
<td></td>
</tr>
<tr>
<td>Needle angle</td>
<td>Slightly cephalad.</td>
<td>0-45 degrees</td>
</tr>
<tr>
<td></td>
<td>In some cases, medially and superiorly(^a)</td>
<td>Medial or inferomedial</td>
</tr>
<tr>
<td>Use of imaging to ensure proper placement</td>
<td>Ultrasound-assisted techniques(^b)</td>
<td>Not a standard practice</td>
</tr>
</tbody>
</table>

\(^a\) In certain instances, such as increased age and spinal deformity, providers may employ a paramedian approach in which the spinal needle is placed off midline and directed medially and superiorly to avoid the interspinous space.

\(^b\) Authors have also described ultrasound-assisted techniques to determine the interspinous level, midline, and depth to the ligamentum flavum.\(^{28}\)

Figure 1. Needle inclination demonstrates ~22-degree medial angle

Process of T12 and directed medially at a 22-degree angle can pass between adjacent vertebral laminae and penetrate the ligamentum flavum to enter the spinal canal. Please reference Supplemental File 1 for video evidence.

CONCLUSION

While adverse effects resulting from entering the spinal canal during a dry needling procedure are rare, this interprofessional collaboration demonstrates some important considerations for the clinician when performing dry needling. First, there is significant variability in the techniques described for dry needling the multifidi with no clear consensus regarding which technique is most effective and safe. Many techniques described also lack specific information regarding needle angulation, thereby leaving the exact technique open to interpretation, and this ambiguity has the potential to lead to variations in clinician needling technique and a resulting decrease in the certainty of a safe needle path and placement. This cadaveric study demonstrates that a 0.30 x 50 mm dry needle is able to penetrate the ligamentum flavum and enter the spinal canal at T12/L1 using a dry needling technique described for the multifidi, and therefore, either purposeful or inadvertent deviations in needle placement in this area of the spine have the potential to cause neurologic injury. While a comprehensive understanding of human anatomy is crucial for dry needling, the utilization of ultrasound has the potential to enhance the precision of dry needleing techniques in vulnerable areas, such as the thoracolumbar junction, and may contribute to further risk reduction. The authors recommend that future studies explore various needle lengths and positions, as well as other regions of the spine and patient positions to explore the risk of a dry needle entering the spinal canal under these conditions.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.
Figure 3. Ultrasound image of the spine in parasagittal orientation; SP - spinous process, PLL – posterior longitudinal ligament

Submitted: July 13, 2023 CST, Accepted: October 10, 2023 CST
REFERENCES


17. Mirzaei H, Pourahmadi MR, Ayoubpour MR, Firouze B. The effect of dry needling compared to lumbar spine mobilization on pain, functional disability, quadratus lumbarum and lumbar multifidus function, lumbar range of motion and pain pressure threshold in patients with non-specific chronic low back pain: Study protocol for a randomized controlled trial. Research Square. Published online December 5, 2022. doi:10.21205/r s.s.3.rs-2153991/v1


Supplemental Video
Abstract
Musculoskeletal (MSK) ultrasound has emerged as a valuable tool for sports physical therapists in the assessment and treatment of various knee pathologies. Its ability to provide high-resolution images of soft tissue and superficial bone surfaces makes it especially useful for sports physical therapists and orthopedic clinicians. Specifically, MSK-ultrasound is increasingly recognized as a potent tool for the assessment of the femoral trochlea. Its non-invasive nature and dynamic imaging capabilities make it particularly suited for visualizing the femoral trochlea, a critical component in knee function and biomechanics. The use of MSK ultrasound in the evaluating the femoral trochlea provides sports medicine professionals with a dynamic, non-invasive, and cost-effective means to diagnose, and monitor knee-related injuries. This article delves into the utility of MSK ultrasound in the anatomical and functional assessment of the femoral trochlea, elucidating its benefits, limitations, and clinical implications for athletes.

Keywords: MSK Ultrasound, Femoral Trochlea, Knee Injuries, Dynamic Assessment, Rehabilitation.

Introduction
Over three decades ago, ultrasound emerged as a promising technique for assessing the thickness and pathologies of cartilage. Cartilage pathology is a hallmark of degenerative joint diseases, notably osteoarthritis, which is of paramount concern to physical therapists due to its impact on an athletes pain, mobility and function. The femoral trochlea is an integral component of the knee joint mechanism, and its pathologies are often implicated in anterior knee pain and dysfunction among athletes. The trochlear cartilage serves dual functions as a lubricant and a shock absorber, mitigating the transfer of load to the subchondral bone. Cartilage irregularities frequently underlie anterior knee pain. Abnormalities in the trochlea, such as dysplasia, can lead to patellar instability, maltracking, pain, and degenerative changes that impact an athlete’s performance and quality of life. Prompt and accurate assessment of the femoral trochlea is essential for the early detection and management of these conditions. Accurate visualization of the femoral trochlea is essential for diagnosis, treatment planning, and monitoring the healing process in athletes presenting with anterior knee pain or suspected patellofemoral dysfunction.

Historically, the assessment of the femoral trochlea has relied on magnetic resonance imaging (MRI) and computed tomography (CT). These traditional imaging modalities have only offered static views that sometimes fall short in replicating the stresses and movements an athlete’s knee undergoes during dynamic activity. Despite MRI becoming the preferred modality for articular cartilage evaluation due to its superior contrast resolution, there is a resurgence of interest in leveraging MSK ultrasound as an adjunctive tool alongside MRI. Over two decades ago, it was recognized that ultrasonography could be a viable technique for assessing knee articular cartilage thickness as well as alterations in the surface and subsurface of the cartilage. A substantial corpus of research validates the effectiveness of ultrasound in diagnosing cartilage pathologies. Recent investigations into ultrasonography have yielded reasonably accurate results for the identification of chondral lesions and the measurement of cartilage thickness in animal models.

In contemporary clinical practice, the application of knee MSK ultrasonography is gaining traction as an adjunctive diagnostic tool alongside MRI. In vitro studies have confirmed ultrasonography’s precision in identifying and detailing cartilage defects in both animal and cadaver models, including the accurate grading of induced defects as per the International Cartilage Repair Society’s criteria. As the condition progresses, the cartilage may exhibit asymmetrical thinning, accompanied by changes in the underlying subchondral bone.

Technical Overview
The assessment of the femoral trochlea via MSK ultrasound involves a systematic approach to imaging. The patient is typically positioned supine with the knee extended or slightly flexed. A high-frequency linear transducer is preferred to visualize the superficial structures of the knee in high definition. The advancements in high-frequency linear transducers have significantly improved the resolution of MSK ultrasound, allowing for exceptional
visualization of superficial structures like the femoral trochlea. Sonographically, normal cartilage presents as hypoechoic with a generally uniform thickness. \(^1\) Initial chondral lesion stages are marked by changes in the ultrasound echotexture, progressing to irregular thinning and evident chondral lesions, with advanced cases involving the subcortical bone. \(^1\) In visualizing the femoral trochlea, the patient is typically positioned supine with the knee in various degrees of flexion. The physical therapist places a linear ultrasound probe on the anterior aspect of the knee, adjusting the orientation to optimize the view of the trochlear groove. Care should be taken to ensure probe is perpendicular to desired cartilage to decrease risk of anisotropy.

**MSK Ultrasound: Technique and Application**

Performing an ultrasound examination of the femoral trochlea requires a systematic approach:

1. **Patient Positioning:** The patient is positioned supine with the knee in various degrees of flexion (Figure 1).

2. **Transducer Selection:** A high-frequency linear transducer is typically used to optimize the resolution of superficial structures like the femoral trochlea.

3. **Scanning Technique:** The transducer is placed in a transverse/SAX orientation over the distal quadriceps tendon and is then moved distally to the superior pole of the patella, visualizing the trochlear groove (Figure 2). The capability to conduct sonopalpation (applying pressure with the probe) further assists in assessing the trochlea's structural integrity and identifying areas of pain or injury.

4. **Dynamic Assessment:** MSK ultrasound provides immediate feedback on the condition of the trochlear cartilage, subchondral bone, and surrounding soft tissues. It can detect subtle changes in the trochlear surface, synovial tissue, and early signs of patellar maltracking or instability that might be missed during a static examination or with other imaging modalities.

Unlike static imaging, MSK ultrasound allows for the observation of the patella's articulation with the femoral trochlea during dynamic movements. The patient is asked to flex and extend the knee to assess the trochlear tracking and patellar alignment dynamically. This dynamic assessment can be critical for understanding the biomechanical contributions to conditions such as patellofemoral pain syndrome caused by either patellar hyper or hypomobility, and can guide targeted therapeutic interventions.

**Advantages of MSK Ultrasound in Visualizing the Femoral Trochlea**

MSK ultrasound offers several advantages over traditional imaging modalities like MRI and CT scans, including:

1. **Dynamic Assessment/Real-time Imaging:** MSK ultrasound allows for the observation of the patellar tracking over the trochlea in real time. The movement of the patella through the trochlear groove can be observed in real time, providing insights into the functional aspects of the patellofemoral joint that static imaging cannot. High-resolution ultrasound probes can visualize cartilage quality, detecting early signs of breakdown or cartilage wear before they become more significant issues. Therefore, subtle changes in movement can be identified that might contribute to a patient's symptoms, which static images from MRI cannot capture.

2. **Accessibility and Convenience:** MSK ultrasound is portable and can be used in various settings, including clinics, sporting events, and on the field. This accessibility allows for immediate assessment and informed decision-making regarding athlete care.

3. **Cost-effectiveness:** MSK ultrasound is significantly less expensive than MRI and CT, reducing the financial burden on healthcare systems and patients.

4. **Safety:** The absence of ionizing radiation makes MSK ultrasound a safer choice for repetitive use, particularly in younger populations. It is also non-invasive and generally well-tolerated by patients, with minimal discomfort.

**Clinical Implications and Rehabilitation**

Visualization of the femoral trochlea through MSK ultrasound has significant clinical implications for sports physical therapy.

1. **Diagnosis:** Early and accurate diagnosis of trochlear dysplasia, cartilage wear, subchondral bone changes, or maltracking can lead to timely and targeted interventions (Figure 3).

2. **Treatment Planning:** Real-time imaging helps in guiding interventions such as therapeutic exercises, patellar taping, or ultrasound-guided injections.

3. **Rehabilitation Monitoring:** Sequential ultrasound examinations can monitor the healing process, assess the efficacy of interventions, and guide the progression of rehabilitation protocols.

4. **Injury Prevention:** Regular screenings with MSK ultrasound can potentially identify early changes in the trochlear groove, guiding preventive strategies for athletes at risk of patellofemoral disorders.

**Limitations and Considerations**

While MSK ultrasound has numerous advantages, there are considerations to keep in mind:

1. **Operator Dependency:** The quality of the assessment is highly dependent on the skill and experience of the operator. Proper training and practice is essential to ensure accurate and reliable imaging. Proficiency requires significant skill and experience to both acquire and interpret images correctly. A thorough understanding of knee anatomy and proficiency in ultrasound technique are essential for operators.
2. **Limited Penetration:** Ultrasound may not adequately visualize deeper structures of the knee or those obscured by calcifications. Deep structures and certain pathologies may be better visualized with MRI or CT, necessitating a combined approach for comprehensive evaluation.

3. **Patient Factors:** Variations in anatomy and the presence of significant soft tissue can affect the quality of ultrasound images.

4. **Interpretation Variability:** There may be variability in interpretation among clinicians, underscoring the need for standardized training and certification.

**Conclusions**

Looking ahead, the future of MSK ultrasound, particularly in visualizing the femoral trochlea, appears promising. Advances in technology are expected to overcome some of the current limitations, enhancing the accuracy and ease of interpretation. The increasing interest in femoral trochlear cartilage sonography is attributed to its relevance in the etiology of anterior knee pain and the reality that some patients are either contraindicated for MRI or may prefer ultrasound as a preliminary investigative procedure. MSK ultrasound represents a paradigm shift by offering real-time dynamic imaging, enhancing the evaluation of the trochlear groove and patellar tracking in various states of knee flexion. MSK ultrasound has significantly advanced the assessment and treatment of femoral trochlea pathologies in sports medicine. It enhances the understanding of the patellofemoral joint’s dynamics in real-time, informs clinical decision-making, and augments patient education and engagement. While there are limitations, ongoing advancements in ultrasound technology and clinician education are expected to enhance its application further, solidifying its role in musculoskeletal assessment. As technology advances and proficiency in ultrasound techniques grow, the utilization of MSK ultrasound is poised to become a standard in the assessment of the femoral trochlea, paving the way for more accurate diagnoses and more effective, personalized treatments for athletes.

**Future Directions**

Ongoing research and technological advancements will likely increase the resolution and capabilities of MSK ultrasound, potentially expanding its applications. One of the exciting developments is the advent of 3D ultrasound. This technology can generate three-dimensional volumetric images, offering a more comprehensive view of the knee joint and its structures, including the femoral trochlea. Furthermore, it can enable a more precise measurement of cartilage thickness and other important parameters, potentially improving the diagnosis and monitoring of disorders like osteoarthritis.

Another promising advancement is the integration of artificial intelligence (AI) and machine learning (ML) into MSK ultrasound. These technologies can assist in image interpretation, reducing the operator dependency and variability in diagnosis. Moreover, they can potentially automate some of the complex tasks, such as identifying abnormalities or measuring anatomical structures, making the procedure faster and more efficient.

Further research and systematic evaluations are warranted to fully establish ultrasonography’s role in the diagnostic algorithm for knee pathologies. This can help to standardized protocols for trochlea ultrasound assessment, evaluate the efficacy of ultrasound-guided interventions, and help integrate ultrasound findings with other clinical assessments.

**References**


**FEMORAL TROCHLEA**

*Figure 1: Patient position and transducer placement.*
The patient is supine with knee flexed from 90 degrees to end of available range. Patient’s foot is planted on exam table. The transducer is placed supra-patellar in a transverse/SAX orientation. Toggling maneuvers will be necessary to visualize the central concavity and width of the medial and lateral trochlear bony facets.

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

*Figures 2A and 2B Short Axis View:* The femoral trochlea is the initial interface to produce on the image. Anechoic/black hyaline cartilage following the hyperechoic bony reflection is the anticipated normal finding. Mixed echoes superficial to the anechoic cartilage are the supra-patellar synovial membrane/fluid interface.
Figure 3: Cartilage echogenicity is classified in 3 grades: (a) grade 0 (normal cartilage), a monotonous anechoic band with a sharp hyperechoic anterior and posterior interfaces; (b) grade I, degenerative changes (mild) where loss of the normal sharpness of the cartilage interfaces and/or increased echogenicity of the cartilage; (c) grade II, degenerative changes (moderate) in addition to the aforementioned changes with clear local thinning; and (d) grade III, degenerative change (severe) with 100% local loss of the cartilage tissue. (Abbasi, B., Pezeshki-Rad, M., Amini, M., Foroughian, M., Sahebari, M., Nekooee, S., & Akhvan, R. (2019). Evaluation of clinical symptoms and sonographic characteristics of femoral trochlear cartilage in primary knee osteoarthritis).