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# TABLE OF CONTENTS

## VOLUME 12, NUMBER 7

<table>
<thead>
<tr>
<th>Page Number</th>
<th>Article Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1023</td>
<td>Gait Deficits Under Dual–Task Conditions in the Concussed Adolescent and Young Athlete Population: A Systematic Review</td>
<td>Grants L, Powell B, Gessel C, Hiser F, Hassen A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1023</td>
<td>The Influence of Extrinsic Factors on Knee Biomechanics during Cycling: A Systematic Review of the Literature</td>
<td>Johnston TE, Baskins TA, Koppel RV, Oliver SA, Steiber DJ, Hogland LT</td>
</tr>
<tr>
<td>1034</td>
<td>Spinal and Peripheral Dry Needling Versus Peripheral Dry Needling Alone Among Individuals with a History of Lateral Ankle Sprain: A Randomized Controlled Trial</td>
<td>Rossi A, Blaustein S, Brown J, Diefenderfer K, Ervin E, Griffen S</td>
</tr>
<tr>
<td>1048</td>
<td>Transversus Abdominis Activation and Timing Improves Following Core Stability Training: A Randomized Trial</td>
<td>Selkow NM, Eck MR, Rivas S</td>
</tr>
<tr>
<td>1057</td>
<td>The Diagnostic Accuracy of the Lever Sign for Detecting Anterior Cruciate Ligament Injury</td>
<td>Mulligan EP, Anderson A, Watson S, Domeff RJ</td>
</tr>
<tr>
<td>1078</td>
<td>Clinical Measures of Hip Range of Motion Do Not Correlate With the Degree of Cam Morphology In Semi-Elite Australian Footballers: A Cross-Sectional Study.</td>
<td>Murphy M, Kemp J, Smith A, Charlesworth J, Briffa K</td>
</tr>
<tr>
<td>1103</td>
<td>Isokinetic Knee Muscle Strength Profile in Brazilian Male Soccer, Futsal, and Beach Soccer Players: A Cross-Sectional Study.</td>
<td>deLira CAB, Mascarin NC, Vargas VZ, Vancini RL, Andrade MS</td>
</tr>
<tr>
<td>1111</td>
<td>Postural Alterations in Patients with Subacromial Impingement Syndrome.</td>
<td>Alizadehkhaiyat O, Roehuck MM, Makki AT, Frostick SP</td>
</tr>
<tr>
<td>1134</td>
<td>Effect of Reliability of Ankle-Foot Morphology, Mobility, Strength, and Motor Performance Measures.</td>
<td>Fraser JJ, Koldenhoven RM, Saiba SA, Hertel J</td>
</tr>
<tr>
<td>1150</td>
<td>The Rehabilitation of a Runner with Iliopsoas Tendinopathy using an Eccentric-biased Exercise: A Case Report</td>
<td>Rauseo C</td>
</tr>
</tbody>
</table>
ABSTRACT

Background: There are no current sport concussion assessments that capture the effects of dual-task conditions on gait. Multiple studies have evaluated changes, but none have comprehensively examined literature related to the adolescent and young adult population.

Purpose: The purpose of this systematic review is to synthesize documented changes in gait under dual-task conditions in adolescents and young adults after sustaining a concussion.

Study Design: Systematic Review

Methods: The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was consulted to guide this systematic review. Six databases were searched: Cinahl, ProQuest, PubMed, Scopus, SPORTdiscus, and Web of Science. Concussion, gait, and dual-task, along with their synonymous terms were the search terms used. Inclusion criteria consisted of adolescent and young adult age groups, acute concussion, dual-tasking, and matched controls. Quality assessment was performed using The Joanna Briggs Institute Critical Appraisal Checklist for Case Control Studies.

Results: Ten full-text articles were selected for inclusion. Concussed individuals demonstrated longer stride times with shorter stride lengths, increased mediolateral displacement with corresponding increases in sagittal and frontal plane peak velocity, and decreased sagittal plane Center of Mass (COM) and Center of Pressure (COP) displacement. The majority of included studies demonstrated moderate to large effect sizes in these gait characteristics.

Conclusion: Concussed individuals demonstrated decreased gait stability while ambulating with a dual-task condition. Though statistically significant differences between concussed individuals and matched controls lasted only 72 hours, concussed individuals demonstrated continued improvements in gait for up to two months post-injury, which has the potential to affect an athlete’s ability to perform. Further research is needed to determine if a gait examination with a dual-task condition is a realistic, reliable, and valid measure to be included in return to sport testing.

Level of Evidence: 2a

Key words: Adolescent, concussion, dual-task, gait
INTRODUCTION
The Centers for Disease Control and Prevention report 300,000 traumatic brain injuries per year. However, this number does not reflect the incidence of mild traumatic brain injuries, like concussions, that do not always cause a loss of consciousness. This number may be even higher if accounting for the lack of reporting and limitations in concussion detection.\(^1\) Due to the fact that large numbers of adolescents and young adults participate in sports, particularly football, this population has an increased risk for sustaining a concussion, as well as an increased susceptibility to damage because of brain immaturity.\(^4\) Additionally, the potential risk for brain re-injury and its resulting long term damage caused by premature return to sport play indicates the need for careful detection of injury before resuming play.

Some standard tools used to detect concussion include symptom checklists and neuropsychological (NP) performance measurements.\(^6\) Other common measurements include those related to balance and sway which are assessed by detecting alterations in motoric measures such as center of mass and center of pressure. Despite multiple functional components being examined during a concussion assessment, there have been few objective measures that combine these components. Register-Mihalik et al. suggested the importance of testing cognitive and motor performances together.\(^7\) For this reason, testing for gait deficits under dual-task conditions has been developed and is being used to examine the effect of cognitive and motor tasks performed together.\(^7\)

Dual-tasking is necessary for performing activities within daily life such as obstacle avoidance or maintaining a conversation while walking.\(^5\) The necessity for performance in dual-tasking may be even greater with athletes who are competing in higher level activities than walking. A common way the effects of dual-tasking are measured is by evaluating gait combined with a cognitive task. The Stroop test and [modified] Mental Status Exam (MSE) are two examples of commonly used cognitive dual tasks.\(^7\) The Stroop test presents a sequence of congruent or incongruent stimuli to be discriminated between\(^9\) and the MSE asks a series of questions.\(^10\) Both are meant to simulate the type of thinking required for decision making because they utilize the executive functioning areas in the frontal and prefrontal brain regions.\(^8\) An individual who has sustained a concussion may have increased difficulty with dual-task activities because the tasks compete for limited resources in the healing brain.\(^12\) Fait et al. report that alterations in locomotor tasks were still present during dual-task activity, even in the absence of other concussion symptoms and normal NP testing.\(^13\) Often, NP testing results demonstrate normality after as little as one week.\(^13\) Dual-tasking, therefore, may be able to detect more residual effects of a concussion.\(^7,13\)

Currently, it is not standard practice to measure gait deficits under dual-task conditions after injury or for use in return to play decision making following a concussion in adolescents and young adults. The types of gait deficits under dual-task conditions must be identified and described in order to develop a tool that captures the effects which may occur or become apparent during concurrent motor-cognitive activities. There have been some studies about these changes,\(^7,8,12,17-26\) but no systematic review of the literature exists which focuses exclusively on this population. The purpose of this systematic review is to synthesize documented changes in gait under dual-task conditions in adolescents and young adults after sustaining a concussion.

METHODS
Registration and protocol
This study was registered in the International Prospective Register of Systematic Reviews (PROSPERO) database under the ID: CRD42016053813.

Search strategy, databases utilized, and study selection
The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist was consulted to guide this systematic review. The PRISMA checklist is a 27-item list designed with the intent of improving reporting for authors of both systematic reviews and meta-analyses.\(^12\) The following databases were searched: Cinahl, ProQuest, PubMed, Scopus, SPORTdiscus, and Web of Science. Gray literature was not intentionally excluded during the systematic search process, however, none was found to include in this review. A hand search was also performed by
two reviewers who read the reference list of each included study in search of relevant additional titles. The original search was not restricted with any limiters such as year of publication or language. The search strategy included three main categories (concussion, gait, and dual-task) and synonymous terms were defined and used along with the main category terms to define the search. Similar terms were used across all databases, and specific database terms such as Medical Subject Heading (MESH) terms were used when applicable. A full list of search strategies used can be found in Appendix 1. The final initial search was performed on November 30, 2016.

Duplicates between the six databases were eliminated using EndNote duplication system and then manually to ensure all duplicates were removed. The remaining titles were reviewed independently by two authors and then discussed if there was disagreement to determine a final list for abstract review. The same process was performed to screen abstracts to determine a list for full text review and to screen full texts to determine the final included studies. A third reviewer was available to settle any disagreements. A Cohen's unweighted Kappa was calculated for agreement during title, abstract, and full-text selection. A Kappa of less than 0.2 is considered poor agreement; 0.21 to 0.4, fair; 0.41 to 0.6, moderate; 0.61 to 0.8, strong; and more than 0.8, near complete agreement.16

Eligibility criteria
Adolescents and young adults were the primary populations of interest. Adolescents were defined as ages 14 to 18 and young adults as ages 18 through 26. Injury qualifying as a “concussion” was determined by examination and diagnosis by a health care professional. Concussion was defined using either the American Academy of Neurology Practice Parameter or the 3rd International Consensus Statement.17-28 Studies must have included a dual-task defined as the performance of two tasks simultaneously.17-26 The primary task of interest was gait and the secondary task was a cognitive task.

Studies that included a matched control group of non-concussed individuals were included. To ensure the concussion was acute, the concussed groups must have been tested initially within 72 hours post-injury. If a study did not specify the timeline of the concussion in the article, it was excluded. Traumatic brain injuries were also excluded because they suggest a greater severity of brain injury than a concussion. Studies with redundant information were excluded.

Data extraction and synthesis
Data from the final text articles were extracted by two authors and cross checked. For any disagreements about data, a third author was consulted to make the final decision. Sample data extracted included the number of participants, sex, age, mass, and height of participants. Data extracted from the articles included the following outcome measures: center of mass (COM), center of pressure (COP), peak velocities, displacement measures, gait speed, step width, stride length, and max separation distance between COM/COP. Gait variables were analyzed using 3D motion analysis with a range of 25 to 31 retro-reflective markers placed on bony landmarks of the subjects. As the subjects walked along a 10-meter walkway, body movement was recorded using a six, eight, or ten camera motion analysis system developed by Motion Analysis Corporation.17-26

Two types of tasks were used as the secondary task to gait. One task was an audio variation of the Stroop test and the other task was a collection of cognitive tasks described within the modified Mental State Exam (MSE). The Single Auditory Stroop (SAS) task required the subject to listen to the words “high” or “low” played in a high or low pitch and then asked to identify the pitch of the word, regardless of whether the pitch was congruent with the meaning.17,21-23 The Multiple Auditory Stroop task was similar to the SAS, except the words were played multiple times per trial rather than once. The Stroop Test has been previously shown to have good test re-test reliability in assessing gait deficits.9 The modified MSE included tasks such as spelling a common five-letter word in reverse, serial subtraction of 7’s, and reciting the months of the year in reverse.18-20,23-26 Reliability and validity of the modified MSE has not been previously explored in the existing literature, however it has been used in multiple studies.18-20,23-26

Center of Mass (COM) and Center of Pressure (COP) are two outcome measures that were analyzed within the selected studies. COP can be defined as the point
on the ground in which it can be assumed that a resultant ground reaction force is acting upon. To compute COP, ground reaction forces were collected by two force plates. External markers and estimated joint centers were used to calculate the three-dimensional motion for individual body segments and locations of segmental COM. Measurement was taken of the maximum separation between the COM and COP of the supporting foot in the anterior (COM/COP ANTmax) and mediolateral (COM/COP MLmax) directions.24

Quality Assessment
The Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Case Control Studies was used by two authors to assess quality of the included studies. The JBI Critical Appraisal Checklists were collaboratively developed and subsequently reviewed and approved by the JBI International Scientific Committee. The case control checklist in particular consists of ten items regarding study quality plus an additional question at the end referring to the overall opinion of appraisal.29 The opinion of appraisal was subjectively determined based on the number of criteria ranked as “yes” versus “no” for each study. Kohen’s unweighted Kappa was calculated between the two authors to determine level of agreement of the quality of the studies between raters.

RESULTS
Study Selection
The results of the search criteria produced 1,333 titles which were reviewed for applicability. After title assessment, 74 abstracts were screened; and 30 were deemed appropriate for full-text review. Ten full-text articles were selected after full evaluation and included in the systematic review.

The agreement between authors throughout the multiple stages of selecting articles varied at each stage of the process: $\kappa = -0.22$ (poor agreement) for the abstract screen; $\kappa = 0.51$ (medium agreement) for the full text review screen; and $\kappa = 1.0$ (complete agreement) for which full text articles were selected for inclusion. Detailed characteristics of the study selection process are presented in Figure 1.

Seven of the ten included studies involved young university aged participants reported as having a Grade 2 concussive brain injury as defined by the American Academy of Neurology Practice Parameter.17-20, 24-26 In three of the studies that studied young university22,23 and adolescent participants21 the definition of concussion was consistent with that of the 3rd International Consensus Statement on Concussion in Sport.21-23 The control groups of all studies were matched by age, sex, mass, and height to non-concussed individuals as indicated in Table 1.

Quality Assessment
There are currently no studies establishing reliability or validity for the JBI Critical Appraisal Checklists, however, the Cohen’s unweighted Kappa agreement between two independent reviewers was $\kappa = 0.713$ (substantial agreement). The ten included studies all received at least 8 out of 10 affirmative scores as indicated in Table 2. JBI category seven was the most missed as four studies failed to state strategies used to deal with confounding factors. While the JBI was a useful guide to measure quality, it did not detect the lack of data reporting throughout the majority of included studies. Most studies did not report the group mean for each measured variable which led to an inability to calculate effect sizes. The calculated effect sizes that are available are indicated in Table 3.

GAIT VARIABLES
Gait Velocity/Walking Speed/Average Walking Speed
Four of the six studies that measured gait velocity/walking speed found a significant decrease in velocity/speed when compared to the control group.17,20, 24,26 Three of those studies reported on gait velocity showed a large effect size.18,20,26 In the two studies reporting on walking speed, effect size of only one of the studies could be calculated and was trivial.22

Stride Time
Three studies measured stride time; one study showed an increased stride time in concussed versus control with a large effect size,18 whereas the two studies that did not find a significant difference had small effect sizes.24,26

Step Length/Stride Length
One study found that step length significantly decreased in subjects with concussion as compared
Step Width

Four studies measured step width during gait with dual-task conditions and none reported a significant difference compared to control.\textsuperscript{18,20,24,26} The results of these studies demonstrate conflicting trends and varied effect sizes.\textsuperscript{18,26}

with control and had a large effect size.\textsuperscript{22} Four studies looked at stride length in the concussed group, and two showed a significant decrease versus control and had large effect sizes,\textsuperscript{24,26} while two showed no significant difference between groups but still revealed moderate effect sizes.\textsuperscript{18,20}
Three of the included studies measured peak velocity in the sagittal plane and all showed a significant decrease versus the control.21,22,23 Not enough information from the three studies was reported on peak velocity to calculate effect size.

COM ANTERIOR TO POSTERIOR (A/P) PLANE VARIABLES

A/P COM Velocity, Peak Velocity
Four studies measured COM velocity in the sagittal plane and all four showed that subjects with concussion had a decreased A/P COM velocity compared to the control subjects.17,18,19,26 Only three studies reported enough information to calculate effect size; two were large,18,26 while one was considered small.19 Three of the included studies measured peak velocity in the sagittal plane and all showed a significant decrease versus the control.21,22,23 Not enough information from the three studies was reported on peak velocity to calculate effect size.

Table 1. Included study demographics, measurement timing, and concussion definition

<table>
<thead>
<tr>
<th>Study</th>
<th>Concussed Participants</th>
<th>Non-Concussed Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N (Gender)</td>
<td>Mean Age (SD)</td>
</tr>
<tr>
<td>Catena (2011)</td>
<td>10 (5M, 5F)</td>
<td>21.0 (3.1)</td>
</tr>
<tr>
<td>Catena (2006)</td>
<td>14 (8M, 6F)</td>
<td>22.29 (4.46)</td>
</tr>
<tr>
<td>Catena (2009)</td>
<td>30 (16M, 14F)</td>
<td>21.5 (3.3)</td>
</tr>
<tr>
<td>Howell (2014)</td>
<td>23 (20M, 3F)</td>
<td>15.4 (1.3)</td>
</tr>
<tr>
<td>Howell (2015)</td>
<td>YA: 19 (9M, 10F) AD: 19 (17M, 2F)</td>
<td>YA: 23 (2.4) AD: 15.1 (1.1)</td>
</tr>
<tr>
<td>Howell (2013)</td>
<td>20 (18M, 2F)</td>
<td>15.3 (1.3)</td>
</tr>
<tr>
<td>Parker (2006)</td>
<td>15 (9M, 6F)</td>
<td>20.6 (1.55)</td>
</tr>
<tr>
<td>Parker (2007)</td>
<td>21.6 (3.26)</td>
<td>29 (15M, 14W)</td>
</tr>
<tr>
<td>Parker (2005)</td>
<td>10 (4M, 6F)</td>
<td>20.2 (1.7)</td>
</tr>
<tr>
<td>Chen (2015)</td>
<td>15 (9M, 6F)</td>
<td>21.3 (3.3)</td>
</tr>
</tbody>
</table>

NOTE: Mass is reported in kg, and age is reported in years.
SD= Standard deviation, D= days post injury, YA= Young Adult, AD= Adolescent, AAN= American Academy of Neurology, ICSC3= 3rd International Consensus Statement on Concussion

Table 2. Joanna-Briggs Institute Checklist Results for included studies

<table>
<thead>
<tr>
<th>Title</th>
<th>JBI criterion number</th>
</tr>
</thead>
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</tr>
<tr>
<td>Catena 2006</td>
<td>Yes</td>
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<td>Catena 2009</td>
<td>Yes</td>
</tr>
<tr>
<td>Catena 2011</td>
<td>Yes</td>
</tr>
<tr>
<td>Chen 2015</td>
<td>Yes</td>
</tr>
<tr>
<td>Howell 2014</td>
<td>Yes</td>
</tr>
<tr>
<td>Howell 2015</td>
<td>Yes</td>
</tr>
<tr>
<td>Howell 2013</td>
<td>Yes</td>
</tr>
<tr>
<td>Parker 2006</td>
<td>Yes</td>
</tr>
<tr>
<td>Parker 2007</td>
<td>Yes</td>
</tr>
<tr>
<td>Parker 2005</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Notes: JBI= Joanna-Briggs Institute Critical Appraisal Checklist for Case Control Studies, Criterion numbers 1-10 represent the corresponding criterion listed in the JBI Appraisal Checklist.
Table 3. Statistical outcomes between gait parameters and cognitive dual-task, including effect sizes when available

<table>
<thead>
<tr>
<th>Study</th>
<th>Cognitive dual-task used</th>
<th>Gait parameter (Change vs Control)</th>
<th>Interaction</th>
<th>p-value</th>
<th>Cohens D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catena 2011</td>
<td>Auditory Stroop Task (high/low pitch)</td>
<td>1. COM-AV (DEC)</td>
<td>1. G*G</td>
<td>1. p = 0.015*</td>
<td>NC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Sagittal COM/COP Separation</td>
<td>2. G*G,</td>
<td>2. p = 0.411*/0.001*</td>
<td>NC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(DEC)</td>
<td>G*D</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Day 14 COM M/L ROM (INC)</td>
<td>3. G*G</td>
<td>3. p = 0.00625*</td>
<td>NC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Peak M/L COM V</td>
<td>4. NS</td>
<td>4. NR</td>
<td></td>
</tr>
<tr>
<td>Howell 2014</td>
<td>3. MSE (5word reverse, -7s, month reverse)</td>
<td>1. M/L COM Disp. (INC)</td>
<td>1. G*G</td>
<td>1. p = 0.004*</td>
<td>1.4-NC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. M/L COM Peak V</td>
<td>2. NS</td>
<td>2. P = 0.125</td>
<td>NC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Peak COM Ant V</td>
<td>3. G*G</td>
<td>3. p = 0.008*</td>
<td>NC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. AVG Walking Speed (DEC)</td>
<td>4. G*D</td>
<td>4. p = 0.015*</td>
<td>NC</td>
</tr>
<tr>
<td>Howell 2015</td>
<td>Auditory Stroop 4stim (high vs. low pitch)</td>
<td>1. Adolescent M/L COM disp. (INC)</td>
<td>1. G*G</td>
<td>1. p = 0.001*</td>
<td>1-5-NC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Peak M/L COM V (INC)</td>
<td>2. G*G</td>
<td>2. p = 0.001*</td>
<td>NC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Peak COM ANT V (DEC)</td>
<td>3. G*G</td>
<td>3. p = 0.01*</td>
<td>NC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Young Adult M/L COM Displacement</td>
<td>4. NS</td>
<td>4. p = 0.149</td>
<td>NC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. Young Adult Peak M/L COM V</td>
<td>5. NS</td>
<td>5. NR</td>
<td>NC</td>
</tr>
<tr>
<td>Howell 2013</td>
<td>Auditory Stroop 4stim (high vs. low pitch)</td>
<td>1. Peak Ant COM V (DEC)</td>
<td>1. G*G</td>
<td>1. p = 0.001*</td>
<td>1-3-NC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Peak M/L COM V (INC)</td>
<td>2. G*G</td>
<td>2. p = 0.027*</td>
<td>NC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. M/L COM DISP. (INC)</td>
<td>3. G*G</td>
<td>3. p = 0.014*</td>
<td>NC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Average Walking speed (m/s)</td>
<td>4. NS</td>
<td>4. NR</td>
<td>NC</td>
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<td></td>
<td></td>
<td>5. Step Length (m) (INC)</td>
<td>5. G*D</td>
<td>5. p = 0.012*</td>
<td>NC</td>
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<tr>
<td>Catena 2006</td>
<td>1. MSE (5word reverse, Sub X 7, months reverse)</td>
<td>1. Gait V (DEC)</td>
<td>1. G*G</td>
<td>1. p = 0.007*</td>
<td>1. -1.19 (large)</td>
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<td>2. Stride Time (INC)</td>
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<td>5. NR</td>
<td>5. - 0.517 (Mod)</td>
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<td>6. p = 0.007*</td>
<td>6. - 1.197 (large)</td>
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<td></td>
<td>7. COM/COP SMAX (DEC)</td>
<td>7. NS</td>
<td>7. NR</td>
<td>7. - 0.712 (Mod)</td>
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<td></td>
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<td>8. COM M/L DISP (INC)</td>
<td>8. G*G</td>
<td>8. p = 0.41*</td>
<td>8. 0.899 (Mod)</td>
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<td></td>
<td></td>
<td>9. COM Peak M/L V</td>
<td>9. G*G</td>
<td>9. p = 0.46*</td>
<td>9. 0.871 (Mod)</td>
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<tr>
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<td>10. COM M/L Max</td>
<td>10. NS</td>
<td>10. NR</td>
<td>10. 0.200 (Small)</td>
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<tr>
<td>Catena 2009</td>
<td>1. MSE (5word reverse, Sub X 7, months reverse)</td>
<td>1. Day 2 COM AP Disp. (DEC)</td>
<td>1. G*G</td>
<td>1. p = 0.0143*</td>
<td>1. NC</td>
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<td>2. COM A/P V (DEC)</td>
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<td>2. p = 0.0135*</td>
<td>2. -0.483 (Small)</td>
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<td>3. COM/COP M/L SMAX</td>
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<td>3. NR</td>
<td>3. 0.017 (Trivial)</td>
</tr>
<tr>
<td></td>
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<td>4. COM M/L V</td>
<td>4. NS</td>
<td>4. NR</td>
<td>4. -0.029 (Trivial)</td>
</tr>
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<td>Parker 2006</td>
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<td>1. G*G</td>
<td>1. p = 0.012*</td>
<td>1. NC</td>
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<td></td>
<td>2. Day 2 Stride Length (DEC)</td>
<td>2. G*G</td>
<td>2. p = 0.016*</td>
<td>2. -0.990 (large)</td>
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<td>3. Stride Time (s)</td>
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<td>3. NR</td>
<td>3. 0.40 (Small)</td>
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<td>4. Step Width (m)</td>
<td>4. NS</td>
<td>4. NR</td>
<td>4. 0.848 (trivial)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. COM ANT DISP (m)</td>
<td>5. NS</td>
<td>5. NR</td>
<td>5. -0.845 (large)</td>
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<td>6. COM ANT Inst. V</td>
<td>6. NS</td>
<td>6. NR</td>
<td>6. -0.907 (large)</td>
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<td></td>
<td>7. COM/COP SMAX (DEC)</td>
<td>7. G*G</td>
<td>7. p = 0.005*</td>
<td>7. NC</td>
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<tr>
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<td>8. COM M/L Inst. V</td>
<td>8. NS</td>
<td>8. NR</td>
<td>8. 0.030 (trivial)</td>
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<tr>
<td></td>
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<td>10. COM/COP M/L SMAX</td>
<td>10. NS</td>
<td>10. NR</td>
<td>10. -0.038 (trivial)</td>
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<tr>
<td>Parker 2007</td>
<td>MSE (5word reverse, Sub X 7, months reverse)</td>
<td>1. COM M/L DISP (INC)</td>
<td>1. G*D</td>
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<td>2. G*D</td>
<td>2. p = 0.040*</td>
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group but not in the young adult group.21 One study reported no significant relationship between groups for M/L velocity at separation maximum26 while the two remaining studies reported the M/L velocity relationship between groups to have no significance and trivial19 to small effect sizes.26

M/L Displacement, COM

Seven studies measured M/L COM displacement. Six showed a significant increase in displacement between concussion and control groups,18,21-25 but of the six, only one effect size could be calculated and was reported as moderate.18 The study completed by Howell et al in 2015 showed the concussion group exhibited a significant increase versus control in the adolescent group, but not in the young adult group.21 One study reported no significant relationship between groups for M/L velocity at separation maximum26 while the two remaining studies reported the M/L velocity relationship between groups to have no significance and trivial to small effect sizes.26

COM MEDIOLATERAL (M/L) VARIABLES

M/L Velocity, Peak Velocity, Velocity at Separation Max

Nine total studies measured a form of mediolateral COM velocity; however, they measured the variable in three different ways. Six studies reported on peak M/L velocity, and they were evenly split; three reported a significant increase in M/L velocity in the concussion group compared to control18,21,22 with a large calculated effect size,18 while the other three reported no significant difference between groups17,23,24 and no effect sizes could be calculated. The study completed by Howell et al in 2015 reported a significant increase versus control in the adolescent age group but not in the young adult group.21

COM/COP SEPARATION VARIABLES

A/P COM/COP Separation

Five studies measured sagittal plane COM/COP separation. Three reported a significant decrease in separation in the concussion group (effect sizes could not be calculated)17,24,25 while two studies found no significant relationship between groups for A/P COM/COP separation. One study reported a significant decrease in A/P COM/COP separation in the concussion group when compared to the control group17 (effect size could not be calculated) while two did not find a significant difference between groups and showed moderate and large effect sizes.18,24 Parker et al in 2005 did not find a significant difference in sagittal plane COM range of motion between concussion and control groups; however, the calculated effect size was large.26

Table 3. (Continued) Statistical outcomes between gait parameters and cognitive dual-task, including effect sizes when available

<table>
<thead>
<tr>
<th>Year</th>
<th>Study</th>
<th>Task</th>
<th>Measures</th>
<th>Concussion</th>
<th>Control</th>
<th>Effect Size</th>
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<td>2005</td>
<td>Parker</td>
<td>MSE (5-srd reverse, Sub X 7, months reverse)</td>
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<td>Gait Velocity (m/s)</td>
<td>1. NS</td>
<td>1. NR</td>
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<td></td>
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<tr>
<td>2015</td>
<td>Chen</td>
<td>MSE (5-srd reverse, Sub X 7, months reverse)</td>
<td></td>
<td>Gait V (m/s)</td>
<td>1. G*G</td>
<td>1. p=0.04*</td>
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</table>

Cognitive task: MSE= Mental state exam 3 task Q/A.
Gait Parameters: COM= Center of Mass, COP= Center of Pressure, Anterior, V= Velocity (m/s), A/P= Anterior/Posterior, M/L= Medial/Lateral, Disp= Displacement, SMAx= Separation Maximum (m), SEP= Separation (m), Inc= Increased compared to control, Dec= Decreased compared to control
Significance: * = p < 0.05, NR= Value Not Reported
Interaction: G*D= Between Group Interaction (Concussion vs control), G*O= Between testing day interaction within the concussion group, NS= No Significant Interaction
Cohen’s: Not calculated due to a lack of study reporting (NC)
significant difference between groups, but showed moderate effect size.\(^{18,26}\)

**M/L COM/COP Separation**

Two studies compared the mediolateral separation between COM and COP, but neither showed a significant difference.\(^{19,24}\) The calculated effect sizes were trivial.\(^{19,24}\)

**CONCUSSION SYMPTOMS OVER TIME**

The majority of significant gait deviations in the concussed group were observed during the first two days post-injury, however, all included studies showed a trend that concussed patients continued to show improvement in gait abnormalities over the course of two months. Of the seven studies that took measurements up to the 28 days post injury, four studies noted significant differences between concussed and control past the day two measurement mark. Howell et al noted concussed individuals had increased M/L COM displacement (2 months post-injury\(^{23}\)), increased step length (1 week post-injury; large effect size\(^{22}\)), decreased peak sagittal plane COM velocity (2 weeks post-injury\(^{23}\)) and walking speed (1 week post-injury\(^{23}\)). Catena et al noted COM/COP separation decreases up to a week post-injury.\(^{17}\) Parker et al reported significant differences between single and dual-task COM/COP separation and COM M/L displacement up to 28 days post-injury.\(^{26}\)

**DISCUSSION**

The purpose of this systematic review is to synthesize documented changes in gait under dual-task conditions in adolescents and young adults after sustaining a concussion. When tested under two distinct dual-task conditions (Stroop, MSE), subjects who experienced a concussion exhibited a variety of gait deficits within four main categories: gait characteristics, sagittal COM, medial/lateral (M/L) COM, and COM/COP changes. These variables combined suggest that individuals who have sustained a concussion exhibit poorer outcomes while dual-tasking compared to matched controls, specifically in the adolescent and young adult population.

One possible explanation for the deviations in gait is the disrupted attention allocation in concussed adolescents and young adults.\(^{7,8,12}\) Kahneman's (1973) theory about divided attention suggests that there is a limited capacity available for processing information, with different tasks taking up different amounts of space. This capacity can be influenced by external variables. Due to the nature of a concussion, an individual who has sustained a concussion must devote more attention to what are typically automatic processes in the uninjured population. Cognitive deficits are typically associated with sustaining a concussion, which may make proper allocation of attentional resources more difficult, and explain why dual-task performance is typically decreased in concussed individuals.\(^{7,12}\)

A second potential explanation for the deviations in gait is postural instability caused by concussion deficits. Previously, postural instability has been demonstrated in individuals with a concussion as deviations in M/L and A/P COP time series in static balance, postural sway, and COM deficits.\(^{30,31,32}\) This is consistent with the current findings. Additionally, this instability is thought to decrease gait velocity to serve as a protective mechanism.\(^{31}\) A contributing factor to decreased gait velocity is the increased time in double stance phase to compromise for instability, adopting a more conservative gait strategy post-concussion.\(^{7,8,31}\) The combination of all of the deviations seen, suggest that sport performance could be compromised. Because performing in a sporting event requires a higher level of stability and cognitive function compared to basic daily tasks, deficits in performance may be amplified. The potential amplified deficits could negatively impact an athlete's ability to compete at their previous level or at a level consistent with non-concussed peers.\(^{34,35}\)

Adolescents and young adults have a heightened risk for increased susceptibility to damage because of brain immaturity.\(^{4,5}\) Greatest deficits were seen 48-72 hours post-injury, however these deficits may not have fully resolved until two months post-injury, suggesting this brain immaturity may play a role in the healing time. The prolonged recovery, though currently not clinically significant in the adolescent and young adult population, is consistent with healing times in the brain, specifically in the regions where dual-tasking is processed.\(^{12}\) This discrepancy in healing times may indicate that healing is still occurring even though it is not detected
in current testing measures. This increase in healing time could potentially affect an athlete if they return to play too early putting them at a higher risk for re-injury.

**LIMITATIONS**

One potential limitation of this systematic review was poor initial agreement between authors when selecting articles for inclusion based on title. This may have led to exclusion of articles that may have been appropriate for this systematic review. The two subsequent levels of agreement showed much higher agreement, once both authors had re-discussed and clarified in further detail the study’s inclusion and exclusion criteria.

The nature of concussion limits the studies in the review to only case control studies; as using a randomized control trial research design would not be feasible or ethical. Therefore, causation cannot be inferred, only correlated with the findings.

The studies selected focused on the adolescent and young adult age group of both athletes and non-athletes. Because of this, the information presented within this study cannot be generalized to other populations outside of the population parameters. The methods used in attaining the information on gait parameters requires an extensive use of equipment that may not be feasible to keep within the general clinic due to costs.

**CONCLUSION AND IMPLICATIONS FOR FURTHER RESEARCH**

The majority of current standard concussion tests only test motor or neurophysiological performance, but often not together. Performing baseline gait examination during dual-task conditions is suggested to provide another outcome measurement for rehabilitation deficits not captured with separate motor or neurophysiological tests. Further research is needed to discover if examining gait deficits during a dual-task condition is a realistic, reliable, and valid measure that can be included in return to sport test batteries and clinical settings.

**REFERENCES**


### Appendix 1. Search Strategy

<table>
<thead>
<tr>
<th>Database</th>
<th>Search Strategy</th>
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<td>CINAHL</td>
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</tr>
<tr>
<td>ProQuest</td>
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<tr>
<td>PubMed</td>
<td>(((Concuss*[Text Word]) OR &quot;Mild Traumatic Brain Injury&quot;[Text Word]) OR mTBI[Text Word]) AND (((gait[MeSH Terms]) OR gait disorder, neurologic[MeSH Terms]) OR gait[Text Word]) OR ambulat*[Text Word]) OR walk*[Text Word]) OR walk*[Text Word]) OR walking[MeSH Terms]) AND (((((&quot;Dual Task&quot;[Text Word]) OR &quot;Dual-Task&quot;[Text Word]) OR multitask[Text Word]) OR &quot;multi-task&quot;[Text Word]) OR &quot;Simultaneous Task&quot;[Text Word]) OR &quot;divided attention&quot;[Text Word]) OR &quot;split attention&quot;[Text Word]) OR distract*[Text Word]) OR motor activity[MeSH Terms]) OR performance, task[MeSH Terms]).</td>
</tr>
<tr>
<td>Scopus</td>
<td>( TITLE-ABS-KEY ( concuss* ) OR TITLE-ABS-KEY ( &quot;mild traumatic brain injury&quot; ) OR TITLE-ABS-KEY ( mtbi ) ) AND ( TITLE-ABS-KEY ( gait ) OR TITLE-ABS-KEY ( ambulat* ) OR TITLE-ABS-KEY ( walk* ) ) AND ( ( TITLE-ABS-KEY ( &quot;dual task&quot; ) OR &quot;dual-task&quot; ) OR TITLE-ABS-KEY ( multitask* ) OR &quot;multi-task&quot; ) OR TITLE-ABS-KEY ( &quot;divided attention&quot; ) OR TITLE-ABS-KEY ( distract* ) OR TITLE-ABS-KEY ( &quot;split attention&quot; ) OR TITLE-ABS-KEY ( &quot;simultaneous task&quot; ) OR TITLE-ABS-KEY ( &quot;secondary task&quot; ) OR TITLE-ABS-KEY ( &quot;task perform*&quot; ) )</td>
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ABSTRACT

**Background:** The knee is susceptible to injury during cycling due to the repetitive nature of the activity while generating torque on the pedal. Knee pain is the most common overuse related injury reported by cyclists, and intrinsic and extrinsic factors can contribute to the development of knee pain.

**Purpose:** Due to the potential for various knee injuries, this purpose of this systematic review of the literature was to determine the association between biomechanical factors and knee injury risk in cyclists.

**Study Design:** Systematic review of the literature

**Methods:** Literature searches were performed using CINAHL, Ovid, PubMed, Scopus and SPORTDiscus. Quality of studies was assessed using the Downs and Black Scale for non-randomized trials.

**Results:** Fourteen papers were identified that met inclusion and exclusion criteria. Only four studies included cyclists with knee pain. Studies were small with sample sizes ranging from 9-24 participants, and were of low to moderate quality. Biomechanical factors that may impact knee pain include cadence, power output, crank length, saddle fore/aft position, saddle height, and foot position. Changing these factors may lead to differing effects for cyclists who experience knee pain based on specific anatomical location.

**Conclusion:** Changes in cycling parameters or positioning on the bicycle can impact movement, forces, and muscle activity around the knee. While studies show differences across some of the extrinsic factors included in this review, there is a lack of direct association between parameters/positioning on the cycle and knee injury risk due to the limited studies examining cyclists with and without pain or injury. The results of this review can provide guidance to professionals treating cyclists with knee pain, but more research is needed.

**Level of Evidence:** 3a

**Key Words:** Biomechanics, cycling, knee injury, knee pain, overuse
INTRODUCTION

With the increase in recreational and competitive cycling, cyclists are experiencing more overuse injuries related to repetitive loading.1 Both intrinsic and extrinsic factors contribute to injury.1 Intrinsic factors are inherent to the cyclist and include fitness level as well as anatomical alignment of the lower extremities.1 Extrinsic factors are generally associated with factors external to the cyclist such as equipment, riding technique, and training.1

The knee is the most common joint impacted by cycling overuse injuries in recreational and professional cyclists.1,2 Knee pain is reported to affect 40-60% of recreational cyclists and 36-62% of professional cyclists.1,3 Anterior knee pain is the most common, which is likely due to patellofemoral pain, patellar tendinopathy, or quadriceps tendinopathy.1,3,4 Factors that may cause anterior knee pain include increased pressure due to hill climbing, heavy workloads, increased training, altered patellar tracking, or by a combination of factors.1,3,4 Many risk factors can contribute to the problem such as altered patellar position, decreased flexibility, increased quadriceps (Q) angle, muscle imbalances, and various limb torsional and foot deformities.1,6 In a review article, Johnston reported that cycling cadence and workload impact moments around the knee, which may contribute to knee injury at higher effort levels.7 Increasing knee flexion angle can increase forces impacting the knee8 while co-contraction of the knee flexors and extensors can decrease them.9 Thus the interaction of these variables as well as power output and cycling duration may be important in understanding cyclists who are at greater risk of injury due to loading.

Several knee structures are potentially at risk for overuse injury with cycling due to intrinsic and extrinsic factors. Patellofemoral pain (PFP) is one of the most common causes of knee pain in cyclists, resulting in anterior knee pain.5 Female gender is a risk factor for PFP,10 and PFP is more common in female cyclists.11 An additional risk factor is reduced quadriceps strength,10 which may cause the greatest prevalence of PFP during preseason training in cyclists.4 Additional associated factors with PFP in cyclists include excessive varus knee moments during the power stroke,12 excessive valgus knee alignment,5 repetitive loading of the patella,13 weak gluteal muscles,5 increased Q angles,11 excessive patellar lateral tilt,4 and excessive foot pronation.5 Patellar and quadriceps tendinopathies are additional causes of anterior knee pain in cyclists,8 which are caused by chronic repetitive overload of tendons during quadriceps contractions.14,15 Iliotibial band (ITB) syndrome is the most common cause of lateral knee pain in cyclists.2 Proposed mechanisms for ITB syndrome are compression of fat beneath the ITB at the lateral femoral epicondyle or friction of the ITB as it moves across the lateral femoral epicondyle during repetitive knee flexion and extension.2,11,16 When the knee reaches 20-30° of flexion, the ITB passes over the lateral femoral epicondyle,17,18 creating an impingement zone for fat and an adventitial bursa.2,5,11 ITB syndrome is likely caused by increased tibial internal rotation, ITB tightness, inward pointing of toes on the pedals, increased hip adduction, a bicycle saddle position that is too high, and rapid increase in mileage.1,2,5,16,19 Medial knee injuries seen in cyclists include medial collateral ligament bursitis, plica syndrome, pes anserine syndrome and medial meniscus tear.2 Plica syndrome is characterized by pain, snapping or clicking sensations as inflamed remnants of synovial tissue impinge against the anterior medial femoral condyle as the knee flexes and extends.2,20 Medial meniscus tear is least likely to occur in cyclists, but can be symptomatic when rotating the leg to release the shoe from the pedal.2 The posterior knee is the least commonly injured and may be attributed to biceps femoris tendinopathy presenting posterolaterally.2 The etiology of biceps femoris tendinopathy is chronic overload of the hamstring muscles and tendons, and may be due to tight hamstrings or an excessively high saddle.21

Due to the potential for various knee injuries, this purpose of this systematic review of the literature was to determine the association between biomechanical factors and knee injury risk in cyclists. To accomplish this goal, biomechanical studies that examined extrinsic factors including kinematics, kinetics, and/or muscle activity under various cycling conditions and cycle component settings were included.

METHODS

Search Strategy: An initial literature search was performed in August of 2015 using CINAHL, Ovid,
PubMed, Scopus & SPORTDiscus databases. Key terms used in the search included knee injuries, knee pain, cycling, cyclist, biomechanics, and overuse. All keywords were compiled and searched using AND/OR to further refine the search. Key words were used to screen titles that best addressed the research question. A second search using the same search terms and databases was performed in March of 2017 to locate additional articles published between August of 2015 and March of 2017.

Selection Criteria: Of the 46 articles selected, abstracts were screened based on the inclusion criteria of evaluating extrinsic biomechanical factors associated with the knee in cyclists. Studies were required to include measurement of one or more of the following at the knee during cycling: kinematics, kinetics, and muscle activity. Studies were excluded if they were not published in English, focused on injury in other areas of the body, or evaluated traumatic injury. The studies included were comparison or cross sectional.

Data Collection: Five reviewers evaluated the final studies after applying inclusion/exclusion criteria from full text articles. Each study was read and evaluated by two reviewers. Articles were graded using the Downs & Black scale for assessment of methodological quality and risk of bias. The Downs & Black scale is considered a valid and reliable checklist for non-randomized studies and was deemed appropriate due to the observational nature of the studies. Data extracted from articles included population, variables measured, results, and conclusions (Table 1).

RESULTS
Study Selection: Of the 72 studies found across the two searches, 14 were deemed eligible based on inclusion criteria (Figure 1). Studies were overall small with sample sizes ranging from 9-24 participants, with a total of 239 participants across studies.

Study Characteristics: Studies that reported gender included more male than female participants. Studies included adults aged 19 to over 50 years. Eleven studies were within-participant designs with one study including participants with knee pain and 10 including participants without injury. Three studies compared participants with and without pain. Participants were described as competitive cyclists, amateur cyclists, experienced trained cyclists, recreational cyclists, non-cyclists, or cyclists without further description.

Assessment of Included Studies: Ten of the 14 studies had sample sizes of less than 20 participants. Downs and Black scores ranged from 3 to 13 (out of 27) with a median score of 10 (Table 1). Study quality was categorized according to percentage of the possible Downs and Black score as follows: low (≤33.3%), moderate (33.4% - 66.7%), and high quality (≥66.8%). Therefore, the included studies were of low to moderate quality using this scale. No blinding of assessors occurred in any comparison studies.

Methodology and Outcomes Measured: Methodology and outcomes measured varied across studies (Table 1). Knee kinematics with or without assessment of other joints were main outcomes assessed in 10 studies using 2D or 3D motion capture. Knee kinematics were primarily measured in the sagittal plane, but three studies also measured kinematics in the coronal plane. Knee kinetics with or without assessment of other joints were main outcome measures in 12 studies with different measures examined, including joint power, muscle/joint moments, patellofemoral compressive forces, tibiofemoral compressive and shear forces, pedal forces/pedal force effectiveness, and crank torque. Moments around the knee were primarily measured in the sagittal plane, but four studies also examined moments in the coronal plane. Two studies measured muscle activity around the knee using electromyography (EMG) and one study assessed pain.

Experimental Conditions: Studies manipulated several conditions to examine effects at the knee, including cadence, power output, crank length, saddle fore/aft position, saddle height, and foot position. Participants used their own cycles mounted on a trainer or a standard cycle on a trainer. Increased cadence led to increased knee range of motion (ROM), increased anterior and vertical pedal reaction forces, and increased knee flexion moments. As cycling power output increased, greater knee extension and
<table>
<thead>
<tr>
<th>Author, Year</th>
<th>DB Score</th>
<th>Subjects</th>
<th>Primary Variable(s)</th>
<th>Experimental Protocol</th>
<th>Results</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bailey et al., 2003</td>
<td>13</td>
<td>24 male cyclists, 10 with knee pain history, Experienced, 28.0±8.4 yrs</td>
<td>Kinematics: coronal/sagittal hip, knee, ankle</td>
<td>Conditions: 90 rpm, 200±10W</td>
<td>Cyclists with knee pain had ↑ dorsiflexion &amp; knee valgus. No differences in knee flexion angle with &amp; without knee pain. Anterior knee pain seen when knee extensors active.</td>
<td>More medial knee position (valgus) may disrupt knee extensor mechanism, leading to pain. ↑ dorsiflexion with knee injury history possibly unrelated to pain as difference seen along with knee flexor moment.</td>
</tr>
<tr>
<td>Barrett et al., 2011</td>
<td>10</td>
<td>15 cyclists (12 male), No injury, Experienced, 19-44 yrs</td>
<td>Kinetics: 2D joint powers at hip, knee, ankle</td>
<td>Conditions: 5 different crank lengths, 2 cadences (“optimized” &amp; 120 rpm), 3sec maximal efforts.</td>
<td>Crank length had no effects on power at optimized cadence.</td>
<td>When cadence is accounted for, crank length does not impact joint powers.</td>
</tr>
<tr>
<td>Barrett et al., 2016</td>
<td>10</td>
<td>15 cyclists (12 male), No injury, Trained, 19-44 yrs</td>
<td>Kinetics: Sagittal plane forces, 2D muscle moments, joint powers at hip, knee, ankle</td>
<td>Conditions: 5 different crank lengths, 2 cadences (“optimized” &amp; 120 rpm), 3sec maximal efforts.</td>
<td>↑ Knee &amp; hip ROM with ↑ cadence &amp; crank length. ↓ Knee extension moments &amp; power and ↓ hip extension power with ↑ crank length.</td>
<td>Powers most impacted by crank length.</td>
</tr>
<tr>
<td>Bini et al., 2013</td>
<td>9</td>
<td>21 male cyclists, No injury, Competitive, 28±7 yrs</td>
<td>Kinematics: knee flexion, Kinetics (2D): Patellofemoral compressive &amp; tibiofemoral compressive/ shear forces</td>
<td>Conditions: 1 min; 90 rpm; max power output; preferred, forward and backward saddle positions (self-selected to simulate time trial or hill climbing).</td>
<td>↓ Tibiofemoral anterior shear forces in forward saddle position. ↑ Knee flexion angle comparing forward to backward saddle positions. Neither position affected patellofemoral &amp; tibiofemoral compressive forces.</td>
<td>Tibiofemoral anterior shear forces more sensitive to knee angle. Larger differences in knee flexion angle across conditions may be needed to affect compressive forces.</td>
</tr>
<tr>
<td>Bini et al., 2014</td>
<td>9</td>
<td>24 cyclists (12 road, 12 triathlon), No injury, Competitive, 36±14 yrs (road), 42±8 yrs (tri)</td>
<td>Kinematics: sagittal hip, knee, ankle, Kinetics (2D): pedal forces, net joint moments (hip, knee, ankle), pedal force effectiveness</td>
<td>Conditions: Four 2min trials, submax effort, 4 saddle heights: 1 preferred, 2) low (−10° change in knee flexion angle at bottom dead center), 3) high (10° change) 4) “optimal saddle height” (25° knee flexion).</td>
<td>↑ Force effectiveness optimal saddle height (road cyclists). ↓ Ankle ROM &amp; work at low saddle height (triathletes) ↑ Mean knee angles &amp; ↓ mean hip angles at low &amp; preferred compared to high &amp; optimal saddle heights (all cyclists)</td>
<td>Road cyclists ↑effectiveness with saddle at optimal compared to preferred height; triathletes ↑ ankle work &amp; ROM with saddle at optimal compared to low. Optimal saddle position was up to 5% (road) -7% (triathlete) different from current saddle height.</td>
</tr>
<tr>
<td>Bini and Hume, 2014</td>
<td>12</td>
<td>24 cyclists (16 with knee pain), Recreational, 40±11 yrs (pain group), 43±9 yrs (no pain group)</td>
<td>Kinematics: sagittal hip, knee, ankle, Kinetics (2D): pedal forces, net joint moments (hip, knee, ankle), patellofemoral compressive &amp; tibiofemoral compressive/ shear forces</td>
<td>Conditions: Four 2min trials, submax effort, 4 saddle heights: 1 preferred, 2) low (−10° change in knee flexion angle at bottom dead center), 3) high (10° change) 4) “optimal saddle height” (25° knee flexion).</td>
<td>↑ Anterior tibiofemoral peak forces at high and optimal compared to low saddle height No differences in peak with and without knee pain across saddle conditions. Large differences in knee angle with changing saddle heights.</td>
<td>No differences seen in forces or kinematics with and without knee pain across saddle conditions. Small sample size led to large within group variability.</td>
</tr>
<tr>
<td>Study</td>
<td>10 cyclists</td>
<td>10 without pain (4 male), 7 with PPFS (6 male)</td>
<td>Kinematics: knee flexion</td>
<td>Conditions: 30s at the end of each of 10 mins, 90 rpm, RPE score 14.</td>
<td>No significant difference seen in onset of quadriceps muscles between groups. Vastus medialis turned off sooner with pain.</td>
<td>Onset of quadriceps activity not correlated to pain. Differences in offset of quadriceps may not contribute to altered joint mechanics but may contribute to pain.</td>
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<tr>
<td>Dieter et al., 2014</td>
<td>11 male cyclists</td>
<td>No injury</td>
<td>Experienced</td>
<td>19-44 yrs</td>
<td>Kinetics: 2D joint powers at hip, knee, ankle</td>
<td>Conditions: 5 power outputs (250-850W), 90 rpm, 3sec submax efforts plus 2 max effort at 90 and 110 rpm</td>
</tr>
<tr>
<td>Elmer et al., 2011</td>
<td>18 cyclists</td>
<td>No injury</td>
<td>Recreational</td>
<td>55.8±11.0 yrs</td>
<td>Kinetics: sagittal/coronal plane</td>
<td>Conditions: 2 mins, 8 conditions: 60 rpm, 5 workloads (0.5-2.5kg); 70, 80, 90 rpm at 1kg.</td>
</tr>
<tr>
<td>Fang et al., 2016</td>
<td>10 cyclists (6 male)</td>
<td>No injury</td>
<td>Recreational</td>
<td>30.6±5.5 yrs</td>
<td>Kinematics: knee flexion, crank angle</td>
<td>Conditions: 80-90 rpm, 280W, five 4s trials of 5 min ride, saddle height to obtain 25-30° knee flexion at bottom dead center.</td>
</tr>
<tr>
<td>Farrell et al., 2003</td>
<td>12 road cyclists</td>
<td>No injury</td>
<td>Amateur</td>
<td>20.8±2.8 yrs</td>
<td>Kinematics: 2D hip, knee, ankle</td>
<td>Conditions: 3 submax efforts; 150, 200, 250 W; 3 crank lengths (preferred ±5mm).</td>
</tr>
<tr>
<td>Ferrer-Roca et al., 2016</td>
<td>24 non-cyclists</td>
<td>13 with knee OA, 11 without OA</td>
<td>Kinematics (3D): knee and ankle sagittal/coronal</td>
<td>Conditions: Last 30s of a 2 min effort; 60 rpm; 80W; foot in neutral rotation plus 2 toe-in positions</td>
<td>5° and 10° wedges↓ knee adduction angles</td>
<td>Results mixed as knee adduction angles↓ without change in abduction moment or pain, while vertical loading↑.</td>
</tr>
</tbody>
</table>
Table 1. Study characteristics, results, and Downs and Black scores. (continued)

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Setting</th>
<th>Results</th>
<th>Conditions</th>
<th>Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gregersen et al, 2006</td>
<td>15 cyclists</td>
<td>Kinetics: Knee sagittal/coronal moments</td>
<td>Peak varus &amp; average varus/varus moments with inversion and with eversion.</td>
<td>90 rpm, 225W, 5 positions of ankle eversion/inversion</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>No injury</td>
<td>Conditions: 5 min effort, EMG: quadriceps, tensor fascia latae</td>
<td>Activation ratio of the vastus medialis to vastus lateralis with inversion</td>
<td>Cycle: Stationery ergometer</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Competitive</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18-30 yrs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tamborindey et al, 2011</td>
<td>9 male non-cyclists</td>
<td>Kinematics: knee sagittal plane</td>
<td>No difference in peak tibiofemoral compressive/anterior shear components across heights.</td>
<td>Conditions: 1 minute, 70 rpm, 70W, 3 saddle heights (100, 103, 97% trochanteric height).</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>No injury</td>
<td>Kinetics (2D): pedal forces, tibiofemoral compressive/shear forces, &amp; patellofemoral compressive force.</td>
<td>( \uparrow ) knee flexion angle at lowest saddle height compared to other heights.</td>
<td>Cycle: Stationery ergometer</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>22-36 yrs</td>
<td></td>
<td></td>
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</tbody>
</table>

DB score = Downs and Black score; EMG = electromyography; ITB = iliotibial band; ITBS = iliotibial band syndrome; OA = osteoarthritis; PFPS = patellofemoral pain syndrome; ROM = range of motion; RPE = Rating of Perceived Exertion

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abduction moments were seen.\(^{30}\) Related to these increases, relative knee flexion power increased while extension decreased with increasing power output.\(^{28}\) Interestingly, hip extension power was reported to be dominant in power production, but relative hip extension power did not change with increased power output.\(^{26}\) Increased knee vertical and medial pedal reaction forces were seen with increasing power output.\(^{30}\)

**Bicycle Setting Effects:** In two studies, Barratt et al. examined power\(^{25,27}\) and muscle moments\(^{27}\) at five different crank lengths at a cadence of 120 rpm and a cadence optimized to provide maximum power. They reported that crank length had no effect on power at joints, except for greater power at the shortest crank length of 150mm compared to the longest of 190mm at 120 rpm;\(^{25}\) thus showing a combined effect of crank and cadence.\(^{25}\) In another study, knee extension moments and power decreased, and hip extension power increased as crank length increased.\(^{27}\) In contrast, Ferrer-Roca et al.\(^ {32}\) reported increased crank length led to increased torque around joints; however the range of crank lengths used was much smaller (10 mm)\(^ {32}\) than in Barratt et al. (40 mm).\(^ {25,27}\)

Bini et al.\(^ {28}\) manipulated saddle fore/aft position and reported increased knee flexion angles of 22-36% and decreased tibiofemoral anterior shear forces of 26% with the saddle at the most forward position compared to the most backward position. No differences were seen across positions in patellofemoral
and tibiofemoral compressive forces. \(90\) Three studies examined various saddle heights, \(99,93,94\) one of which being a height considered optimal, which was defined as the position that achieved 25-30° of knee flexion at bottom dead center. \(99\) Bini et al. \(94\) examined four different saddle heights and found increased tibiofemoral anterior shear forces at high and optimal compared to low saddle height \(94\) and large differences in knee angle across conditions in recreational cyclists. There were no differences for patellofemoral or tibiofemoral compressive forces across seat heights and no differences seen between cyclists with and without knee pain. \(94\) In competitive cyclists, they found increased force effectiveness for road cyclists at optimal saddle height, and increased mean knee flexion angles at low and preferred compared to high and optimal saddle heights for road cyclists and triathletes. \(99\) Interestingly, Farrell et al. \(91\) reported that while saddle height was set in the optimal position statically, knee flexion seen while cycling was greater due to lateral movement of the pelvis in recreational cyclists, which may decrease risk of ITB impingement. \(91\) Finally, Tamborindeugy and Bini \(93\) set saddle height based on cyclists’ anthropometrics and found no differences in peak tibiofemoral compressive/anterior shear components across three slightly different saddle heights based on percentages of floor-greater trochanter heights of 97%, 100%, and 103%.

Two studies examined effects of foot position on knee forces. For participants with osteoarthritis (OA) with and without pain, decreased knee abduction angles of 2.7° and 3.2° were seen with wedges placed to increase the toe-in angle by 5° and 10°, respectively; yet no changes were seen in knee abduction moments and vertical pedal reaction forces increased. \(96\) Ankle eversion of 10° was found to decrease knee peak varus moments by 55% and peak internal axial moments by 53% and to increase activation ratio of the vastus medialis to vastus lateralis \((r = -0.23)\). \(91\) Thus eversion of the foot may decrease risks for PFP. \(91\)

Muscle Temporal Activation and Kinematics: Two studies compared temporal muscle activation patterns and kinematics between cyclists with and without pain without manipulating cycling conditions. Dieter et al. \(95\) reported differences in muscle activity patterns for cyclists with and without PFP. In cyclists with PFP, offset of the vastus medialis occurred 22 ± 23 ms sooner than the vastus lateralis, onset of the biceps femoris occurred 111 ± 78 ms sooner than the semitendinosus, and the semitendinosus had overall decreased activation compared to cyclists without pain. \(95\) Bailey et al. \(92\) reported differences in knee and ankle angular positions between cyclists with a history of anterior knee pain or patellar tendinitis and uninjured cyclists. The previously injured group had lower peak knee adduction angles and increased ankle dorsiflexion angles. No differences were found for peak knee flexion angles. \(92\)

**DISCUSSION**

Cycling parameters (i.e., cadence and power output) and bicycle fit settings have differing effects on kinematics, kinetics, and muscle activity around the knee. Few studies compared cyclists with and without knee pain, so injury risk can only be surmised based on the results of biomechanical studies that examine cyclists without injury or pain. There is also a lack of longitudinal studies to assess the effects of altering parameters on knee injury and pain. Thus, causation cannot be determined.

Studies examining cycling kinetics indicate that various stresses are imparted on the knee based on a variety of kinetic variables. Vertical and anterior pedal reaction forces increase at higher cadences, \(90\) and vertical and medial pedal reaction forces increase at higher power outputs. \(90\) Tibiofemoral peak anterior shear forces were found to be increased at higher saddle heights, \(94\) and ankle inversion increased peak vertical forces. \(91\) These findings are in partial agreement with an earlier study by Ericson and Nisell, \(97\) which reported that higher saddle heights significantly increased tibiofemoral anterior shear forces, but decreased tibiofemoral compressive forces. The findings of the studies in this systematic review and earlier studies have implications for loading of the knee joint during cycling and suggest that lower cadences, lower workloads, a higher saddle height, and foot eversion might be preferred for cyclists with knee pain due to tibiofemoral compressive joint loading, such as with medial tibiofemoral OA. In contrast, cyclists with anterior cruciate ligament injury or reconstruction may benefit from a
lower saddle height and lower cadences.\textsuperscript{30,34,37} However, force effectiveness, a measure of force output in relation to angle of force application, may be decreased with these settings,\textsuperscript{29} and thus the effects of combining these conditions is unknown. The effect of crank length due to loading is more difficult to interpret as a shorter crank length at a higher cadence increases power output,\textsuperscript{25} yet increased crank lengths may shift more of the power production from the knee extensors to the hip extensors.\textsuperscript{27} When comparing the moments around the knee to other activities such as walking, jogging, and stair climbing, the extension and flexion moments are generally smaller when cycling at 120 Watts. At 240 Watts, the loads were similar to the other activities.\textsuperscript{35} Knee injuries are the most commonly reported injuries in cyclists, thus it may be the combined effects of workload, cadence, and positioning on the cycle that contribute to injury.

Shear forces are another concern in cyclists, particularly possible injury to the anterior cruciate ligament (ACL) or after an ACL reconstruction. Tibiofemoral anterior shear forces may decrease with a more forward\textsuperscript{28} or lower saddle position,\textsuperscript{34} decreasing potential strain on the ACL. However, studies reported low in vivo ACL strain\textsuperscript{39} and low anterior tibiofemoral shear force\textsuperscript{37} during cycling. Fleming et al.\textsuperscript{39} reported that strain on the ACL during cycling was approximately 1.7\%, and did not change significantly with alteration of cadence or power level. Strain on the ACL during cycling was low compared to 3.6\% while squatting and 2.8\% while extending the knee from flexion.\textsuperscript{39} Strong contraction of the hamstrings during the second half of the power phase may minimize ACL strain.\textsuperscript{40} Posterior pull of the hamstrings on the tibia when the crank angle is 180° from top dead center may limit ACL strain as the knee approaches its least flexed position of 37°,\textsuperscript{41} an angle which is within the range of greatest ACL strain during activities, 0° - 50° flexion.\textsuperscript{42} While shear forces on the ACL during cycling appear to be low, more research is needed to examine shear forces on the posterior cruciate ligament and patella during cycling. Thus, cyclists with anterior cruciate ligament injury or reconstruction may benefit from a lower saddle height or more forward saddle position.\textsuperscript{28,34} as well as a lower cadence.\textsuperscript{30} Medial and lateral regions of the knee are also susceptible to injury. Coronal plane forces are affected by foot position, with eversion lowering peak varus and internal axial moments and increasing vastus medialis activation compared to inversion.\textsuperscript{12} For people with medial knee OA, rotating the shank to increase toe-in angle reduced peak knee adduction angles, with no impact on peak knee abduction moments.\textsuperscript{36} Gardner et al.\textsuperscript{36} hypothesized that an alignment change with increased toe-in foot position would decrease the frontal plane moment arm of the pedal reaction force, which would decrease knee abduction moments. As competitive cyclists and people with knee OA differ in knee alignment, findings may be specific to these populations. One study examined the impact of saddle height on ITB syndrome and reported that a lower saddle height that increased minimum knee flexion angle to greater than 30° kept the ITB out of the impingement zone.\textsuperscript{31} For cyclists at risk for ITB pain, a lower seat height may also be desirable by reducing compensatory lateral pelvic motion\textsuperscript{43} that can increase stress to the ITB. Overall, more research is needed to better understand the effects of cycling on the medial and lateral regions of the knee.

Few studies have examined PFP in cyclists specifically, which is surprising due to the prevalence of anterior knee pain in cyclists.\textsuperscript{2} One study reported differences in muscle activation between cyclists with and without PFP.\textsuperscript{35} Although no differences were found between groups for vastus medialis onset times, the slower contraction offset time of vastus lateralis relative to vastus medialis in the PFP cyclist group may be associated with lateral patellar maltracking.\textsuperscript{35} These findings are consistent with a systematic review that did not find a difference in vastus medialis and vastus lateralis contraction onset in persons with PFP, but reported significant variability in muscle activation ratio.\textsuperscript{43} Dieter et al.\textsuperscript{35} also reported earlier contraction onset and later offset time of the biceps femoris relative to the semitendinosus in the PFP group compared to controls.\textsuperscript{35} These changes may result in increased tibial external rotation, with a resultant increase in the dynamic Q angle and potentially increased lateral patellofemoral joint stress.\textsuperscript{44,45} As the hamstrings are active longer than the quadriceps during cycling,\textsuperscript{21} altered hamstring
activation may be more critical to development of PFP in cyclists compared to vasti activation. However, it is unknown if altered muscle activation is compensatory to or a cause of PFP. Altered coronal plane knee position may be associated with PFP as reduced knee adduction angles, that is, a more valgus position, are seen in cyclists with anterior knee pain or patellar tendonitis. Studies in this systematic review that examined the impact of saddle position on patellofemoral compressive forces did not find significant differences. In contrast, an earlier study by Ericson and Nisell reported that a lower saddle increased patellofemoral joint compressive forces. Although increased knee flexion from a lower saddle position would increase patellofemoral joint reaction force, patellofemoral joint cartilage stress does not increase linearly with increasing knee flexion from 0° to 90°. Patellofemoral joint stress increases to a lesser degree than patellofemoral joint reaction force with increasing knee flexion due to increased patellofemoral joint contact surface area. Tamborindeguy and Bini found the highest patellofemoral compressive force occurred with the knee at approximately 75°-80°. Thus, patellofemoral joint stress may be minimized during cycling by greater patellofemoral joint contact area at knee joint positions which have high patellofemoral joint reaction forces. PFP in cyclists may not be related to high joint stress, but rather secondary to frequent patellofemoral joint loading from repetitive knee extension. This repetitive loading could cause supraphysiologic loading of osseous and non-osseous structures potentially causing loss of tissue homeostasis and PFP.

There are several limitations of this systematic review. Studies differed considerably in methodology, making qualitative or quantitative comparisons challenging. It is also difficult to make strong recommendations as far as the amount of change needed to decrease injury risk as studies vary in the magnitude of changes in cycling parameters and bicycle settings. Bini et al. reported that even a 5% difference in saddle height can affect knee joint kinematics by 35% and joint moments by 16%; yet it is unknown how these differences then translate into injury risk. There is also the lack of direct association between parameters/positioning on the cycle and injury due to limited studies examining cyclists with and without pain or injury and a lack of longitudinal studies. More research is needed to establish clear links and recommendations by manipulating parameters based on the available literature and knowledge of biomechanics impacting specific areas of the knee. Longer term effects on pain, performance, and participation should then be assessed. Another limitation is the inclusion of 2D measurements in some studies. 2D data capture can be misleading as movement outside of the sagittal plane impacts how each joint is visualized on a 2D image. In addition, 3D kinetic measurements are needed to fully understand the effects on the knee in all three planes.

**CONCLUSIONS**

The results of this systematic review indicate that changes in cycling parameters or positioning on the bicycle can impact movement, forces, and muscle activity around the knee. While studies showed differences across some of the extrinsic factors, there is a lack of direct association between parameters/positioning on the cycle and knee injury. Despite the lack of this clear association, the results of this systematic review can provide guidance to professionals treating cyclists with knee pain. The literature provides important information about how biomechanical factors and positioning on the bicycle can increase or decrease stress in specific areas of the knee joint. Further research is needed with larger samples of cyclists with including those without knee pain to better understand direct relationships between these variables and knee pain during cycling.
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44. Salsich GB, Perman WH. Patellofemoral joint contact area is influenced by tibiofemoral rotation alignment in individuals who have patellofemoral pain. *J Orthop Sports Phys Ther*. 2007;37:521-528.


ABSTRACT

Background: In addition to established interventions, dry needling may reduce impairments leading to greater functional abilities for individuals following ankle sprain.

Hypothesis/Purpose: The purpose of this study was to compare effects of spinal and peripheral dry needling (DN) with peripheral DN alone on impairments and functional performance among individuals with a history of lateral ankle sprain.

Study Design: Randomized controlled trial.

Methods: Twenty individuals with a history of lateral ankle sprain (18 bilateral, 2 unilateral) participated in this study (4 males, 16 females; mean age 28.9 +/- 9.2 years). During the first of two sessions, participants completed the Foot and Ankle Disability Index (FADI) and the Cumberland Ankle Instability Tool (CAIT) and their strength, unilateral balance, and unilateral hop test performance was assessed. Participants were randomly assigned to a spinal and peripheral DN group (SPDN), or a peripheral only DN group (PDN). Participants in the SPDN site group received DN to bilateral L5 multifidi and fibularis longus and brevis muscles on the involved lower extremity. Participants in the PDN group received DN to the fibularis muscles alone. Participants' strength, balance and hop test performance were reassessed immediately following the intervention, and at follow-up 6-7 days later, all outcome measures were reassessed. Three-way mixed model ANOVAs and Mann-Whitney U tests assessed between group differences for outcome variables with normal distributions and non-normal distributions, respectively.

Results: ANOVAs showed significant group by time interaction (p<0.05) for invertor strength, significant side by group and time by group interactions (p<0.05) for plantarflexor-evertor strength, no significant findings for dorsiflexor-invertor strength, significant side by time interaction (p<0.05) for unilateral balance, significant main effect of time (p<0.05) for triple hop for distance test, and significant main effect of side (p<0.05) for the CAIT. Mann-Whitney U tests showed no significance (p>0.05) for the side hop test or FADI.

Conclusion: The results suggest that DN of the multifidi in addition to fibularis muscles does not result in improvements in strength, unilateral balance or unilateral hop test performance, compared to DN the fibularis muscles alone among individuals with a history of ankle sprain.

Key Words: Dry needling, functional performance tests, lateral ankle sprain
INTRODUCTION

Ankle sprains are one of the most common injuries encountered during sporting and recreational activities. Lateral ankle sprains may lead to functional ankle instability with patients reporting a feeling of the ankle joint “giving way” and experiencing recurrent sprains. It has been estimated that 40% of ankle sprain cases will result in chronic ankle instability (CAI). Impaired muscle function is common among individuals with CAI and may explain the joint’s vulnerability to recurrent injury. Previous investigators have shown abnormalities of the fibularis muscles in persons with CAI, including reduced reaction time, diminished postural control and corticomotor excitability, and the presence of myofascial trigger points (MTrPs). MTrPs are areas of increased irritability in palpable taut bands of skeletal muscle tissue that are clinically associated with both local and referred pain, muscle dysfunction, and autonomic phenomena.

In addition to other intervention strategies, the use of dry needling as a treatment for MTrPs is gaining attention as investigations on its effectiveness emerge. Dry needling is the insertion of a monofilament needle with the intent of treating a MTrP by disrupting the physiological milieu that causes the abnormal contraction, leading to restoration of proper muscular function. While theories regarding the precise etiology and pathophysiology of MTrPs continue to evolve, three main theories have emerged to explain this phenomenon: the integrated hypothesis, expanded trigger point hypothesis, and intra-muscular stimulation (IMS). These theories originate from the research performed by Simons and Travell, Gerwin, Shah, and Dommerholt. Based on the IMS theory, Gunn proposes that the pain from MTrPs is a result of neuropathic pain from the irritation of the spinal nerve root caused by the shortening of the corresponding segmental paravertebral muscles. Hypersensitivity then develops in skeletal muscles innervated with the nerve root, leading to the development of MTrPs. Treatment approaches utilizing Gunns’ IMS theory suggest that performing dry needling to the muscles of the spine normalizes the resting length of paraspinal muscles, reduces spinal nerve compression and muscle dysfunction along the corresponding myotomes to produce long-lasting pain reduction.

While the physiological mechanism of dry needling is still a topic of debate, numerous studies support the efficacy of dry needling as an intervention with reported improvements in range of motion, muscle activation patterns, reduction in both local and referred pain, and decreased end plate dysfunction related to trigger points. Individuals with and without low back pain have demonstrated varied responses in muscle activation following a dry needling intervention to the lumbar multifidi muscles. Studies investigating the physiological effects of dry needling of the lumbar multifidi muscles in individuals with and without low back pain demonstrate changes in nociceptive sensitivity, segmental mobility and motor function following the interventions. In a study by Koppenhaver et al., individuals with mechanical low back pain received a dry needling intervention to bilateral L4-5 and L5-S1 multifidi. Ultrasonography was used to visualize the thickness of the multifidus muscles pre and post-intervention and one week following the dry needling intervention. The results of the study indicated that the participants with improved scores on the Oswestry Disability Index (ODI) had an improvement in the thickness of the multifidi contraction one week following the intervention. An increase in muscle thickness implies that dry needling may have an effect on selective activation of motor nerve fibers and a facilitory effect within the multifidus muscles. Conversely, participants with continued pain and no improvement in the ODI scores at one week demonstrated a decrease in the lumbar multifidi muscle contraction following the needling intervention suggesting that pain inhibition may continue to produce an inhibitory effect within the multifidi muscles.

To date, a significant portion of dry needling research has focused on treatment of the upper quarter and several studies have shown that dry needling to muscles in the upper quarter has significant effects on pain reduction, increased range of motion, and improved quality of life. Fewer studies have focused on the effects of dry needling on conditions of the lower extremity in general, or specifically, the foot and ankle. The efficacy of dry needling in the treatment of plantar fasciitis demonstrated a beneficial effect when paired with traditional therapeutic procedures, with two studies authors’ reporting
statistically significant reduction in plantar heel pain. With regard to chronic ankle instability, a randomized clinical trial compared the effects of combined MTrP dry needling of the fibularis muscle and therapeutic exercises to therapeutic exercises alone for pain and function in subjects with chronic ankle instability. The authors concluded that subjects who received the combined therapy approach demonstrated superior outcomes in pain and function one month after ceasing treatment. Few studies are available that compare the efficacy of different dry needling treatment sites. Based on the IMS theory, one approach proposed by Gunn suggests that the clinician dry needle the site of the peripheral trigger point and proximal multifidi of the corresponding segmental level. While Gunn’s approach has been adopted by some clinicians the authors are aware of only one study comparing this dual site method to treatment of the distal trigger point alone. Ga et al, 2007 investigated the effects of dry needling at the C3-C5 spinal levels and the upper trapezius versus the upper trapezius alone among aging adults with chronic myofascial pain syndrome. At a 4-week follow-up, these authors reported that the subjects who received spinal and peripheral dry needling had decreased pain and depression and increased cervical ROM compared to the patients who received only peripheral needling.

The purpose of this study was to compare the effects of spinal and peripheral dry needling (DN) with peripheral DN alone on impairments and functional performance among individuals with a history of lateral ankle sprain.

METHODS

Study Design
This study was a single-blinded randomized controlled trial. Participants were randomly assigned to one of two intervention groups: 1) a peripheral dry needling (PDN) group receiving dry needling to the fibularis longus and brevis muscles of the involved lower extremity, or 2) a spinal and peripheral dry needling (SPDN) group, receiving needling of the L5 multifidi bilaterally and the fibularis longus and brevis muscles of the involved lower extremity. Investigators assessing outcome measures were blinded to participants’ group allocation and the physical therapists administering the dry needling intervention were blinded to results of outcome assessments. Participants were not blinded to group assignment. A sham procedure was not included, as based on previously published work, using a blunt needle (sham) does not successfully blind subjects to dry needling versus sham dry needling groups. The study was approved by the institution’s Institutional Review Board and informed consent was obtained from participants prior to data collection.

Participants
Thirty-eight prospective participants were screened for inclusion in this study. Twenty subjects with unilateral or bilateral history of ankle sprain satisfied the eligibility criteria, agreed to participate, and were enrolled in the study (4 males and 16 females; 2 unilateral and 18 bilateral; average age 28.9 years, SD 9.2 years). Among those subjects with bilateral involvement, the side that performed less well on the strength, balance and hop tests was the side that received the DN to the fibularis muscles and the side that performed better on the strength, balance and hop tests did not receive DN to the fibularis muscles. For the purposes of this study, the side that did or did not receive DN of the fibularis muscles will be identified as the “involved side” or “uninvolved side”, respectively. The flow of subjects through the study is summarized in Figure 1, and subject characteristics are summarized in Table 1.

Eligibility criteria included: 1) age between 18 and 65 years, 2) sustained at least one self-reported lateral ankle sprain within 12 months prior to enrolling in the study, 3) inflammatory symptoms present at the time of initial injury (pain, swelling, warmth or redness), and 4) the previous ankle sprain(s) interrupted normal physical activity for at least one day. Additionally, participants’ were required to have the ability to perform specific functional activities at the time of the study, including walking at a self-selected pace over an even surface without pain and performing single leg hops (with or without pain).

Participants were excluded from the study if they: 1) had a history of a knee or hip injury to either lower extremity within 12 months of enrolling in the study, 2) had a history of fracture of either lower extremity, 3) had a history of other chronic lower extremity injuries, and 4) had a history of other musculoskeletal conditions that would affect the outcome measures.
extremity requiring surgical reduction, 3) had previous surgery to either lower extremity, 4) exhibited neurological symptoms resulting from a traumatic brain injury, spinal cord injury, stroke, or peripheral nerve injury, 5) received physical therapy interventions or dry needling to the spine and/or the affected lower extremity within six months of enrolling in this study, 6) were taking prescription blood thinners at the time of the study or non-prescription NSAIDs within 24 hours of the dry needling intervention, 7) were pregnant at the time of the study, 8) had systemic infection or immunosuppression at

Table 1. Participant Characteristics (n = 20).

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</table>

SPDN = Spinal and Peripheral Dry Needling
PDN = Peripheral Dry Needling

*n=10 for this value, as one subject declined to provide weight
the time of the study, and 9) had been diagnosed with osteoarthritis in the lumbar spine or either lower extremity.

**Procedures**
Participants were seen during two onsite visits one week apart. During the initial visit, participants’ baseline self-reported functional status, strength, balance, and single leg hop tests were assessed in order of right leg followed by left leg and this order was maintained throughout the study. Following obtainment of baseline outcome measures, based on allocation previously determined by use of a random number table with group assignment identified in concealed envelopes, participants were randomly assigned to the PDN or SPDN group. Following randomization into groups, the dry needling intervention was performed by one of three physical therapists, each of whom had completed over 50 hours of supervised training and had a minimum of three years of dry needling experience. Immediately following the intervention, investigators blinded to participants’ group, re-assessed participants’ strength, balance, and single leg hop tests. Pain was monitored at four separate times: 1) pre-assessment, pre-needling, 2) post-assessment, pre-needling, 3) post-needling, pre-reassessment, and 4) post-needling, post-reassessment. One week after the initial visit, investigators again assessed participants’ self-reported functional status, strength, balance, and single leg hop tests. Pain level was monitored again pre-assessment and post-assessment during the second visit. Participants in the study were monitored throughout the study for adverse reactions to the needling procedure such as a sympathetic response (fainting, profuse sweating, dizziness), excessive bruising or bleeding, and signs of infection by investigator observation and verbally cuing the participants to report their current status during the dry needling procedure.

**Outcome Measures**

**Self-Reported Functional Status**
Functional status was assessed with the Foot and Ankle Disability Index (FADI) and the Cumberland Ankle Instability Tool (CAIT). The FADI is a self-reported functional questionnaire that includes a 26-item ADL subscale and an 8-item sports specific subscale. There is evidence for reliability and validity with a test-retest intraclass correlation coefficient (ICC) of 0.89 for the ADL subscale and 0.84 for the sports subscale.29,30 The CAIT is a 9-item questionnaire used to classify severity of functional ankle instability. Test-retest reliability for the CAIT has been reported with an ICC of 0.96. An assessment of the CAIT’s validity showed a score of 28 or higher had a sensitivity and specificity of 86% and 83%, respectively, in differentiating between those who had experienced an ankle sprain or not.

**Strength**
Strength testing was performed bilaterally for three ankle muscle groups: 1) invertors, 2) dorsiflexor/invertors, and 3) plantarflexors/evertors. Examiners measured strength with the MicroFET2 handheld dynamometer (Hoggan Scientific LLC; Salt Lake City, UT). Testing positions for each movement were standardized to maintain consistency throughout the study. Each muscle group was measured three times on each side to assess intra-examiner reliability. Additionally, all strength measurements were repeated by a second examiner for every other participant to assess inter-examiner reliability. The participant was positioned sitting on the edge of a treatment table for all strength tests with the contralateral lower extremity supported on a footstool. To test the invertors and plantarflexors/evertors, the examiner was seated in a chair with the elbow flexed approximately 90 degrees and braced against the knee. When testing the invertors, the examiner placed the dynamometer directly on the medial aspect of the first metatarsal head perpendicular to the foot. When testing the plantarflexors/evertors, the examiner placed the dynamometer on the inferior-lateral aspect of the fifth metatarsal head, about 45 degrees from parallel with the foot. To test dorsiflexors/invertors, the examiner was standing with the elbow locked; the examiner placed the dynamometer on the superior-medial aspect of the first metatarsal head, about 45 degrees from parallel with the foot.

The participant was instructed to push into the dynamometer with maximal force and hold the contraction for five seconds. The average of the three trials for each muscle group was calculated and used for data analysis.
Balance

Balance was assessed using a unilateral version of the Modified Clinical Test of Sensory Integration and Balance (MCTSIB). The MCTSIB has been shown to be a simple and inexpensive measure to assess generalized balance deficits and effectiveness of physical therapy interventions on balance deficits. The MCTSIB assesses duration of standing balance with eyes open and eyes closed on both noncompliant and compliant surfaces. Despite the participants’ history of ankle sprain(s), a more challenging, unilateral single limb balance testing method was selected with the expectation that a bilateral lower extremity balance assessment would result in a ceiling effect.

Each participant performed the unilateral single leg balance assessment, testing the right lower extremity first followed by the left lower extremity, without footwear and the components of the test were performed on each limb in the following order: 1) single leg stance on a noncompliant surface with eyes open, 2) single leg stance on a noncompliant surface with eyes closed, 3) single leg stance on a compliant surface (foam cushion) with eyes open, and 4) single leg stance on a compliant surface with eyes closed. Participants were instructed to hold their position during each component for as long as possible up to 30 seconds. A two and a half inch thick AIREX Balance Pad (Power Systems, LLC; Knoxville, TN) was used to provide the compliant surface.

Single Leg Hop Tests

Following the balance test, subjects were given standardized instructions to perform hop tests. Two single leg hop tests, the side hop and triple hop, were utilized because both demonstrate good test-retest properties. Participants performed three trials bilaterally for each test and were allotted one minute of rest between each trial.

The side hop test requires participants to laterally hop on one foot over a gap of 30 cm separated by two pieces of tape. One repetition was counted as successful clearance over the tape and back to the starting position. Participants were instructed to perform ten repetitions as quickly as possible. The examiner measured the time taken to perform the 10 repetitions with a stopwatch.

The triple hop test required participants to forward hop three times on a single leg and attain maximum distance. Following a successful landing on the third hop, the examiner marked the location of the posterior heel and recorded the total distance travelled in centimeters. Any errors required the participant to restart the trial. Participants performed the test until three successful trials were completed for both extremities. For both the side hop and triple hop tests, the average of the three trials was calculated and used for data analysis.

Other Measured Variables

Pain

Pain was monitored using the Visual Analogue Scale (VAS). The VAS has been shown to be a valid and reliable pain assessment tool and is more sensitive to small changes in pain than verbal pain scales. A standard VAS consisting of a horizontal line 100 mm in length anchored with the descriptors “no pain” on the left and “very severe pain” on the right was utilized, and participants were asked to mark the point on the line between the two anchors that best represented where they perceived their pain. The participant’s mark was then measured in millimeters and transformed into a pain rating, with each 10 mm increment assigned the value of 1 point. Participants were blinded to their previous answers to the VAS in order to minimize bias.

Dry Needling Intervention

One of three physical therapists, all with at least ten years of clinical experience and a minimum of three years dry needling experience, performed the dry needling interventions. First, the physical therapist identified trigger points in the fibularis longus and brevis muscles. Trigger points were identified using the approach described in Gerwin et al., as it has been shown to exhibit good intra-examiner reliability when applied by experienced clinicians. This method defines trigger points as those meeting all the following criteria: 1) hypersensitive spot in a palpable taut band, 2) palpable or visible local twitch on palpation, and 3) reproduction of referred pain elicited by palpation of the sensitive spot. All participants fulfilled the first criteria outlined by Gerwin et al., a hypersensitive spot within a palpable taut
band, which by the author’s description was indicative of a latent trigger point. Participants in this study were self-reporting a history of a lateral ankle sprain and were able to perform strength and balance tests with minimal pain, so it was not anticipated that active trigger points as noted by a local twitch response or reproduction of referred pain would be present in all participants. All subjects meeting the inclusion criteria for the study had a locally tender and palpable taut band within both fibularis longus and brevis, as noted by cross-muscle fiber palpation.

Participants in the SPDN group received dry needling in the following muscles: 1) the ipsilateral L5 multifidus of the involved side, 2) the contralateral L5 multifidus, 3) a trigger point identified in the proximal fibularis longus muscle of the involved side, and 4) a trigger point identified in the distal fibularis brevis muscle of the involved side. The L5 segmental level was chosen for two reasons: 1) the expectation of the most consistent anatomical innervation pattern of the fibularis muscles, and 2) the L5 multifidi are more readily identified through palpation than the multifidi at the S1 level. Participants in the PDN group received dry needling to trigger points in the fibularis longus and brevis muscles only.

Prior to insertion of a needle, the skin over the area to be treated was cleaned with an alcohol wipe. Disposable single use Seirin® brand stainless steel needles (.30 x 60 mm for multifidus muscles, .30 x 40 mm for fibularis muscles) were used in this study. With the participant in the prone position, the physical therapist first administered needling bilaterally to the multifidi at the L5 segment, in the order of more involved side followed by the contralateral side. The needling procedure was performed at the bilateral multifidi with the patient prone to facilitate patient relaxation and accurate location of the L5 multifidus muscle. The therapist utilized a pistoning technique (up and down movement of the needle) for 30 seconds at approximately 1 Hz, then left the needle in each multifidus muscle for an additional five minutes. The patient was then moved to the sidelying position in order to facilitate accurate and reproducible location of palpable taut bands in the fibularis longus and brevis, and to ensure a consistent and safe needling technique using the fibula as a bony backdrop to the procedure. With the participant in the contralateral side-lying position, the physical therapist identified a trigger point in the proximal fibularis longus and a trigger point in the distal fibularis brevis using the method previously described. The physical therapist then administered trigger point dry needling to the proximal trigger point using a pistoning and fanning method (changing the inclination angle of the needle) for at least 30 seconds at approximately 1 Hz. If after 30 seconds the trigger point had not yet cleared, the pistoning and fanning technique was continued until the physical therapist no longer observed any visible or palpable muscle twitches. The authors describe the clearing technique as the continuation of the dry needling technique until local muscle twitches are no longer visible or palpable by the therapist during the dry needling intervention. The same technique was then applied to the distal fibularis brevis muscle, (during the five minute “in situ” time on the fibularis longus). The needle was left in the fibularis longus and the fibularis brevis for an additional five minutes at each site.

Data Analysis
Participants’ baseline characteristics were summarized as means and standard deviations for continuous variables and as frequencies for categorical variables. The balance tests are reported and analyzed as composite scores (each of the four tests were summed for the treated and untreated sides). Normality of distribution and homogeneity of variance of baseline characteristics and outcome variable were assessed with Shapiro-Wilk and Levene’s test, respectively. Between group differences in baseline characteristics were analyzed using independent t-tests for continuous variables with normal distribution, Mann-Whitney U tests for continuous variables with non-normal distribution, and chi-square analysis for categorical variables. The intra-examiner and inter-examiner reliability of strength tests were assessed using intra-class correlation coefficients (ICC). Three-way mixed model ANOVAs were utilized to assess between group differences for outcome variables measured on an interval or ratio scale and normal distribution (time and side were the repeated measures). When an overall ANOVA was statistically significant, post-hoc analyses were performed to determine pairwise differences.
Mann-Whitney U tests were used to assess between group differences for outcome variables with non-normal distributions.

RESULTS
There were no significant between group differences in baseline characteristics (p > 0.05), summarized in Table 1. ICCs (3,3) assessing intra-examiner reliability of strength tests ranged from .84-.98 and ICCs (2,3) assessing inter-examiner reliability of strength tests ranged from .64-.93. Descriptive summaries of all outcome measures are presented in Table 2. Graphs of the strength and balance outcome measures are provided in Figures 2-5. As presented in Table 3, there was: 1) a significant group by time interaction (p = 0.02) for invertor strength with the peripheral dry needling group (PDN) improving more at the one-week follow-up than the spinal and peripheral (SPDN) group and post-hoc tests showed greater improvement on the treated side of the PDN group than the untreated side or either side of the SPDN group (p < 0.05) (Figure 2), 2) a significant group by time (p = 0.02) and group by side (p = 0.02) interaction for plantarflexor-evertor strength (Figure 3), with the PDN group showing more of an increase at the one week follow up than the SPDN group and the uninvolved side increasing between baseline and 1 week follow up for the PDN group, but decreasing between baseline and 1 week follow up for the SPDN group, and, 3) no significant findings (Figure 4) for dorsiflexor-invertor strength (p = 0.75). There was a significant time by side interaction (p = 0.04) for unilateral balance with the involved side of the PDN group showing a larger improvement at the one-week follow up than the uninvolved side of the PDN group or either side of the SPDN group (Figure 5). There was a significant main effect of time (p < 0.01) for triple hop for distance test, with both groups improving at follow-up and a significant main effect of side for the CAIT, with the uninvolved side consistently showing a better score than the involved side (p < 0.01). There were no significant differences between the groups (p > 0.05) for the side hop test and the Foot and Ankle Disability Index.

DISCUSSION
The results of the current study are contradictory to one other published study that compared the effects of spinal and peripheral dry needling alone for muscles in the upper extremity and outcomes measures related to pain, cervical ROM and depression scores in older adults. However, there are substantial differences between the two studies in terms of patient demographics, patient condition and outcome measures. Ga et al, 2007 investigated the effects of dry needling at the C3-C5 spinal levels and the upper trapezius versus the upper trapezius alone among aging adults with chronic myofascial pain syndrome and used pain, depression score, and cervical ROM as outcome measures. At the four-week follow-up, these authors reported that patients who received spinal and peripheral dry needling had decreased pain and depression and increased cervical ROM than subjects who received only peripheral needling. Due to differences in patient demographics and recorded pain levels between these studies, a direct comparison of study results is difficult. The outcome variables of range of motion and mental functions reported in Ga et al are also difficult to compare with the recorded outcome measures of strength, balance, hop tests and functional ability in this study. Finally, and perhaps most importantly, the participants in the study performed by Ga et al were much more likely to have spinal pathology; this may explain why their subjects showed more improvements with inclusion of spinal dry needling than participants in this study. Future investigations using combined spinal and peripheral dry needling for individuals with and without spinal involvement may provide insight into ideal dry needling sites for subjects with and without spinal involvement.

Strength
The PDN group demonstrated statistically significant improvements in strength of the invertors on the treated side and of the plantarflexor-evertors on both the treated and untreated sides. Improvement of invertors on the treated side suggests a peripheral mechanism of effect whereas improvement of the plantarflexor-evertors on both sides suggests a central mechanism of effect. Both peripheral and central mechanisms have been proposed as potential mechanisms of effect for dry needling. Despite the challenge of reliably identifying active myofascial trigger points, much previous research on the
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<tr>
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<tr>
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<td>77.32 (20.72)</td>
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<td>80.66 (13.71)</td>
<td>84.15 (18.08)</td>
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<tr>
<td>One Week Follow-up</td>
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<tr>
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<tr>
<td>80.58 (12.35)</td>
<td>96.29 (10.61)</td>
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<td>86.67 (11.14)</td>
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<td>Side Hop Test (s)</td>
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<tr>
<td>Involved side</td>
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<tr>
<td>16.94 (7.3)</td>
<td>12.40 (4.7)</td>
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<tr>
<td>Involved side</td>
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<td>16.05 (7.8)</td>
<td>11.33 (4.3)</td>
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<tr>
<td>15.84 (7.6)</td>
<td>12.40 (5.6)</td>
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<td>14.73 (6.6)</td>
<td>10.76 (2.9)</td>
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<td>Triple Hop for Distance (cm)</td>
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<tr>
<td>368.1 (78.8)</td>
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<tr>
<td>380.6 (78.9)</td>
<td>398.8 (91.4)</td>
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<td></td>
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<tr>
<td>378.0 (89.2)</td>
<td>424.7 (86.1)</td>
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<td>Uninvolved side</td>
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<tr>
<td>378.2 (84.1)</td>
<td>419.8 (93.8)</td>
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<tr>
<td>One Week Follow-Up</td>
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<tr>
<td>Involved side</td>
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<tr>
<td>393.1 (85.5)</td>
<td>446.5 (86.6)</td>
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<tr>
<td>395.7 (86.9)</td>
<td>436.5 (95.4)</td>
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</table>

SPDN= Spinal and Peripheral Dry Needling
PDN= Peripheral Dry Needling
αModi/gied Clinical Test of Sensory Integration and Balance
effects of dry needling has focused on individuals with active myofascial trigger points.\textsuperscript{20} Because dry needling of active trigger points results in local twitch responses on the contralateral,\textsuperscript{40} as well as the treated side (as measured by electromyography), some authors suggest that active trigger points are centrally-maintained tissue states rather than a peripheral phenomenon.\textsuperscript{40} Interestingly, dry needling of latent trigger points appears to result in local twitch responses on the treated side only.\textsuperscript{40} Participants in

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig2.png}
\caption{Strength of invertors, measured in newtons. \textit{PDN Group} = Peripheral Dry Needling Group; \textit{SPDN} = Spinal and Peripheral Dry Needling Group}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig3.png}
\caption{Strength of plantarflexors-evertors, measured in newtons. \textit{PDN Group} = Peripheral Dry Needling Group; \textit{SPDN} = Spinal and Peripheral Dry Needling Group}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig4.png}
\caption{Strength of dorsiflexors-invertors, measured in newtons. \textit{DN Group} = Peripheral Dry Needling Group; \textit{SPDN} = Spinal and Peripheral Dry Needling Group}
\end{figure}
external trunk support was provided during testing. Therefore, trunk stability could have affected performance on these tests. Participants in both groups had low initial pain scores with low variability across time, so the strength increases and decreases in the PDN and SPDN groups, respectively, may not stem from any central or peripheral pain-related mechanism. Rather, it may be changes within the muscle spindles (facilitatory or inhibitory) that explain the differences in strength at the ankle between the two groups.

**Balance**

Composite scores of the single limb balance tests showed that the treated side of the PDN group demonstrated a statistically significant improvement in single leg balance compared to the untreated side or either side of the SPDN group. Previous investigators have shown reduced reaction time and postural...
control of the fibularis longus muscle during a perturbation task among basketball players with chronic ankle instability as compared with healthy basketball players. Other investigators have reported reduced corticomotor excitability of the fibularis muscles among individuals with unilateral chronic ankle instability compared to healthy individuals. Should dry needling of the fibularis muscles have any effect on their corticomotor excitability or reaction time, this may explain an increase in performance on unilateral balance tests and are future areas of investigation. If dry needling the multifidi has any inhibitory effect on the fibularis muscles, then the effects of needling spinally may negate the facilitatory effects of dry needling the fibularis muscles. Alternatively, inhibition of the multifidi may decrease core stability affecting the SPDN participants' performance on these tests.

Other Outcome Measures

Though there were some increases in strength and balance on the treated side of the PDN group at the one week follow-up, there were not similar findings for the single limb hop tests, as performance on the triple hop increased on both sides of both groups and there were no differences in performance of the side hop test. It is likely that the increases on the triple hop test were due to a motor learning effect. Previous research has shown test-retest improvements on unilateral hop tests one to two days following baseline (on both the operative and non-operative sides) among individuals 16 weeks following ACL reconstruction when no expected improvements in impairments would explain the better performance. Nor were the increases in strength and balance on the treated side of the PDN group at the one week follow-up mirrored by improvements on the CAIT or FADI; as would be expected, the CAIT showed the uninvolved side consistently scoring higher than the involved side across groups and time points and there was no between groups difference on the FADI. The changes in strength and balance may not be large enough for any reflection in higher demand activities or overall functional level. A previous investigation of the effects of dry needling of the fibularis longus and brevis muscles in addition to proprioception exercises for individuals with chronic ankle instability and a history of lateral ankle sprain showed improvements in pain level and scores on the Functional Ankle Ability Measure (FAAM) compared to proprioceptive exercises alone. These participants received four needling interventions as compared to the single treatment provided in this study, so it is possible that multiple needling treatments are needed to gain enough improvement to be reflected in a functional assessment tool.

Limitations

There was no control group in this study so no conclusions can be drawn that any changes in outcomes measures for the two dry needling groups are different from a group receiving no treatment. The small sample size limits statistical power and the intervention was limited to a single session with short-term follow-up, whereas typically in clinical care, patients receive needling interventions across multiple visits. Though participants' baseline CAIT scores are indicative of individuals who have experienced an ankle sprain, participants' history of lateral ankle sprains were self-reported, so we cannot be certain their injuries would have been medically diagnosed as lateral ankle sprain at the time they occurred. Finally, participants were unable to be successfully blinded to their intervention group, and this may have introduced bias.

CONCLUSION

The results of this study suggest that in individuals with a history of ankle sprain, DN to the corresponding multifidi segments in addition to MTrPs in the fibularis longus and brevis muscles does not result in short-term improvements in strength, unilateral balance, unilateral hop test performance or self-reported functional ability as compared to DN in the fibularis muscles alone. Based on these findings, it appears that DN of the fibularis muscles in individuals with a history of ankle sprain may provide some short-term improvements in strength and unilateral balance, though additional studies with larger sample sizes are needed to substantiate these findings.

REFERENCES


ABSTRACT

Background: Patients with non-specific low back pain (LBP) often present with a decrease in transversus abdominis (TrA) muscle activation and delayed onset of contraction with extremity movements, potentially contributing to recurrent LBP. Core stability is required for extremity movement and if the timing of when the TrA contracts is not corrected patients may continue to experience LBP.

Hypothesis/Purpose: The purpose of this study was to assess the effects of a four-week core stability rehabilitation program on TrA activation ratio and when the TrA initiates contraction during upper extremity movements in subjects with and without LBP. It was hypothesized that those with LBP would experience greater changes in TrA activation and onset of contraction by the TrA compared to the healthy group.

Study Design: Randomized Clinical Trial

Methods: Forty-two participants volunteered (21 healthy and 21 LBP). Ultrasound imaging measured the TrA activation ratio and time of initial contraction of the TrA during upper extremity movement into flexion. Half of the healthy and LBP participants were assigned to the exercise group. Participants reported twice a week to the athletic training facility to complete an exercise progression of three exercises. After four weeks, all participants returned to have TrA activation and timing measured again.

Results: Pertaining to demographics, there were no differences between the healthy and LBP participants. There was a group interaction for both TrA activation ratio (p = .049) and onset of initial contraction (p = .008). Those in the exercise group showed an increase in TrA activation ratio (1.85 ± 0.09) compared to the control group (1.79 ± 0.08), as well as an improvement in the onset of contraction (2.07 ± 0.08 seconds) compared to the control group (2.23 ± 0.09 seconds) after the four-week rehabilitation program. Strong effect sizes for TrA activation ratio (0.71 [0.06-1.35]) and initial onset of TrA contraction (-1.88 [-2.63 - -1.11]) were found indicating clinical differences related to the interventions.

Conclusion: TrA activation and timing were altered following a four-week core stability program in people with and without LBP. Clinicians should consider incorporating these exercises for improving the function of the TrA.

Level of Evidence: Therapy, level 2b

Key words: core stabilization exercises, low back pain, ultrasound imaging

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The Institutional Review Board approved at Illinois State University approved this study.
INTRODUCTION
Low back pain (LBP) is one of the leading reasons people seek medical advice in the United States. With a high recurrence rate of over 60%, the cause of LBP, as well as effective treatment practices, need to be at the forefront of clinical practice. Clinical spinal instability has been considered to be an important cause for recurrent LBP. It is believed to be caused by the loss of spinal motion leading to pain and neurologic dysfunction, such as that of weak or delayed activation of core musculature.

Stability of the spine involves three subsystems: active, passive, and neural control. The active system incorporates the muscles surrounding the spine that produce the forces necessary for stability. The passive system incorporates non-contractile tissues, such as ligaments, that provide stability at the end ranges of motion. The neural system receives afferent information from the trunk and extremities and sends efferent signals for muscle activation and motor patterns for spinal stability. As muscle tone and motor patterns improve, spinal stability should also be enhanced, decreasing LBP.

One of the core muscles addressed during rehabilitation that addresses spinal stability is the transversus abdominis (TrA), as it has been shown to atrophy following an episode of LBP. This muscle acts as a corset and is activated prior to extremity movement in order to increase stiffness of the spine for stability. Individuals with LBP have a decrease in TrA activation measured via real-time ultrasound, as well as delayed muscle activation. It has been proposed that patients with LBP be screened using clinical prediction rules for LBP. Of the four classifications, patients that fall in the stabilization category are believed to have altered motor patterns resulting in excessive segmental movements of the spine. The treatment for people in this category is isolated contraction and co-contraction of the deep stabilizing muscles (TrA and multifidus) and strengthening the large spinal stabilizers (erector spinae and obliques). Exercises that have been shown to activate the TrA the best are the abdominal drawing in maneuver (ADIM), the side-bridge, and quadruped exercises. While these exercises have been shown to increase TrA activation, it is unknown if changes in muscle activation affect when the TrA “turns on” or becomes activated with movement.

To measure TrA activation and timing, diagnostic ultrasound imaging can be used to view the muscle in real time. Ultrasound imaging (USI) has been shown to be as reliable as MRI in measuring muscle activation. Most ultrasound machines also have a movie feature that allows an examiner to capture muscle activation during movement. Therefore, the purpose of this study was to assess the effects of a four-week core stability rehabilitation program on TrA activation ratio and when the TrA initiates contraction during upper extremity movements in subjects with and without LBP. It was hypothesized that those with LBP would experience greater changes in TrA activation and onset of contraction by the TrA compared to the healthy group.

METHODS
Subjects
Forty-two participants volunteered to be in the study, with 21 participants reporting LBP. The other half were healthy, never having experienced LBP. Demographics are presented in Table 1. Exclusion criteria for the LBP group included any injury to the body in the prior six weeks, except low back pain; previous abdominal or lumbar surgery; pregnancy; balance disorders; or an Oswestry Disability Index (ODI) score greater than 40%. To be in the healthy group, exclusion criteria was the same except participants could not have any injury to the body in the prior six weeks or an ODI score higher than 0%. The study was approved by the Institutional Review Board and all subjects signed informed consent and the rights of subjects were protected.

Ultrasound Imaging
A Terason t3000 M-series portable ultrasound system (Teratech, Burlington, MA) with an 8-15MHz linear array measured TrA activation and onset of contraction by the TrA during upper extremity movement into flexion. Prior to exercise assignment, all participants met with the lead investigator who was blinded to group allocation. The lead investigator performed all the ultrasound imaging and has utilized these techniques for seven years. The patient was supine in the hook lying position with the abdomen exposed. Ultrasound gel was applied to the transducer and placed over the right abdomen superior to the iliac crest, in the midaxillary line, in
a transverse position.\textsuperscript{11,27,28} To standardize position of the TrA on the ultrasound screen, the medial edge of the TrA was visualized on the far right of the screen. Three resting images were captured at the end of exhalation to limit the effect of respiration on muscle thickness.\textsuperscript{29} Next, the participant was instructed to perform an ADIM. The instructions were to “breathe in, breathe out, and when near maximal exhalation, draw your belly button to your spine”. During the contraction, an image was recorded. This was repeated two more times.

For the movie portion, the participant and transducer was positioned in the same location as above. Using a stop watch, a three second count down was given before the participant started moving the left arm overhead for a two second count. As the arm was returning to the starting position, the right arm was moving overhead for a two second count. The pattern continued until the movie finished recording. The movie began to be captured at the beginning of the three second count down and a 10 second clip was recorded.

**Exercise Protocol**

Half of the LBP and half of the healthy participants were randomly assigned to the exercise protocol using a random number generator. The four-week rehabilitation protocol consisted of the participants meeting with one of the other investigators twice a week in the athletic training facility. If the participant was in the control group, they were instructed to maintain their daily activities of living and return four weeks later.

Three exercises were chosen (ADIM, side-bridge, and quadruped) and the level of difficulty increased each week, pain permitting. For the ADIM, 3 sets of 10 contractions, with a 10 second hold and 15 second rest, was used. The cue to the patient was “breathe in, breathe out, and when near maximal exhalation, draw your belly button to your spine”. During week 1, the patient was in the hook-lying position and only performed the ADIM. During week 2, the arms were moved overhead in an alternating pattern, every two seconds during the contraction phase. During week 3, the legs lifted off the table in an alternating pattern, every two seconds during the contraction phase. During week 4, the opposite arm and leg moved overhead/lifted off the table in an alternating pattern, every two seconds during the contraction phase, (Figure 1).

For the side-bridge exercise, the patient started by lying on their right side, with the weight-bearing elbow flexed and both knees flexed. The patient was instructed to perform an ADIM, then lift into a

<table>
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<th>Table 1. Demographics</th>
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<td>Healthy (n=20)</td>
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<td>LBP (n=19)</td>
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<td>Exercise (n=19)</td>
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<td>Control (n=20)</td>
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LBP= low back pain; ODI= Oswestry Disability Index

![Figure 1. Weekly progression of the abdominal drawing-in maneuver (ADIM) exercises. A = Week 1: Hooklying with ADIM B = Week 2: Hooklying with ADIM and alternating arms, C = Week 3: Hooklying with ADIM and alternating legs and D = Week 4: Hooklying with ADIM and alternating opposite arm and leg.](image-url)
The patient performed the side plank position with the elbow and knees flexed, keeping the hip and shoulder in line. The position was held for 10 seconds, with a 15-second rest. Then the patient switched to the left side and performed the same half version of the side-bridge. This was repeated three times. During week 2, the elbow remained bent, but the knees were extended. During week 3, the elbow was straight and the knees bent. During week 4, both the elbow and knees were extended (Figure 2).

Lastly, for the quadruped exercise, the patient began in quadruped. Keeping a flat back, the patient performed the ADIM, holding the contraction for 10 seconds. This was repeated two more times, with 15 seconds rest between contractions. During week 2, the arms were extended out front in an alternating pattern every two seconds during the contraction phase. During week 3, the legs were extended behind the patient in an alternating pattern every two seconds, during the contraction phase. During week 4, the opposite arm and leg were extended at the same time in an alternating pattern, every two seconds (Figure 3).

For all exercises, the number of repetitions stayed the same, but the difficulty increased if the patient was ready to progress to the advanced level.

**Procedures**

Participants entered the athletic training facility wearing athletic clothing. After signing informed consent, inclusion/exclusion criteria were reviewed. If the subject met the LBP group qualification, the ODI was completed. Healthy subjects also completed the ODI to make sure the score was 0. Next, ultrasound imaging was completed. The lead investigator left the room and the subject was assigned to either the exercise or control group. Those in the exercise group began with the exercises that day. Those in the control group did not report back until four weeks later. A home exercise program was not prescribed and the participants were asked not to do exercises outside of the study. At the end of the four weeks, those in the exercise group reported to the athletic training facility 24 hours after the last rehabilitation session. The same ultrasound images were recorded again by the lead investigator.

**Figure 2.** Weekly progression of the side-bridge exercise. A = Week 1: half side plank with elbows and knees flexed, B = Week 2: full side plank with elbow flexed, C = Week 3: half side plank with elbow straight and D = Week 4: Fill side plank with elbow straight.

**Figure 3.** Weekly progression of the quadruped exercise. A = Week 1: Quadruped with ADIM, B = Week 2: Quadruped with ADIM and alternating arms, C = Week 3: Quadruped with ADIM and alternating legs and D = Week 4: Quadruped with ADIM and alternating opposite arm and leg.
DATA REDUCTION

**TrA Activation**
TrA activation was measured using a ratio from the following equation as it has been well documented in the literature.\textsuperscript{12,34,35,49,52}

\[
\text{Thickness of TrA during ADIM} = \frac{\text{TrA thickness at rest}}{\text{TrA thickness at rest}}
\]

If the ratio was a 2, that indicated the TrA thickness doubled during the contraction portion of the ADIM.\textsuperscript{12} The ratio was used to standardized activation across all participants. Two participants were excluded from data analysis, as they represented outliers in the data.

**TrA Timing**
The recording was analyzed using slow motion ultrasound in order to observe when the TrA began to contract. This was indicated by when the most medial portion of the TrA started to retract laterally. Since image depth alters the transducer MHz used, the frames captured per second varied, with the average being around 20 frames per seconds. Frames could be advanced one at a time to find the frame where the contraction began. The timing of the frame was converted to seconds using the ultrasound software. One subject was excluded from data analysis due to video data not being captured.

**Data Analysis**
Two 2x2x2 ANOVAs were used to determine the effect of group (exercise and control) and condition (LBP and healthy) on TrA activation and TrA timing following a four-week rehabilitation protocol (baseline and four-weeks). Alpha was set \(\alpha = .05\). Cohen’s d effect sizes were calculated to interpret clinical meaningfulness.

**RESULTS**
All descriptive data for subjects and outcomes are presented in Tables 1 and 2. There were no significant group by condition interactions for TrA activation (\(p = .424\)) or timing (\(p = .609\)). However, there were significant group interactions for TrA activation (\(p = .049\)) and timing (\(p = .008\)), indicating those in the exercise group increased TrA activation and improved timing compared to the control group. Strong effect sizes for TrA activation (0.71 (0.06-1.35)) and TrA timing (-1.88 (-2.63 - -1.11)) were found further indicating the results show clinical differences beyond measurement variability. Means and standard deviations are presented in Table 2.

**DISCUSSION**
According to the results of the study, people are able to increase the activation and decrease timing of the TrA, regardless of having LBP or not. With effect sizes being strong, it is further indicated that TrA muscle function improved in those that participated in the exercise program. It appears that four-weeks is long enough to see changes, however this length of time may be too short to see maximum effectiveness. With the initiation of muscular training programs, neural changes present at about 4-6 weeks and strength gains are not seen until 6-8 weeks.\textsuperscript{30} It is likely the positive findings at four weeks improved neural function of the TrA, however, the effects on LBP were not assessed.

The exercises chosen have been previously identified to activate the TrA.\textsuperscript{12,27,31-33} The side-bridge

### Table 2. Transversus Abdominis Activation and Timing Following a Four-Week Core Stability Program

<table>
<thead>
<tr>
<th></th>
<th>TrA Activation* Baseline</th>
<th>TrA Activation 4-Weeks</th>
<th>TrA Timing† Baseline</th>
<th>TrA Timing 4-Weeks</th>
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<tbody>
<tr>
<td>Exercise (n=19)</td>
<td>1.58 ± 0.07</td>
<td>1.85 ± 0.09‡</td>
<td>2.34 ± 0.07 sec</td>
<td>2.07 ± 0.08 sec‡</td>
</tr>
<tr>
<td>Control (n=20)</td>
<td>1.74 ± 0.08</td>
<td>1.79 ± 0.08</td>
<td>2.22 ± 0.08 sec</td>
<td>2.23 ± 0.09 sec</td>
</tr>
</tbody>
</table>

TrA= Transversus Abdominis

*Activation (expressed as mean ± SD) is the ratio of TrA thickness change from a resting to contracted position during the abdominal drawing-in maneuver calculated as contracted state/resting state.

†Timing was determined as the point when the TrA began contracting when the arm was brought overhead after a three-second wait period.

‡ Significant difference between the control group (\(p\leq .05\))
exercise was reported to be the most challenging, especially in subjects that had previous shoulder injuries. Exercises were not progressed if the subject reported pain or could not perform the exercise correctly. While there are a variety of exercise prescriptions for core stability, this progression was chosen to focus on exercises where limb movements could be added. In addition, these exercises were chosen to decrease loads placed on the lumbar spine, allow arm movement without increased muscle activation of the lateral abdominal muscles, and target muscle activation of the TrA. By progressing the exercises over a four-week time period, the subjects were able to focus on contracting the TrA prior to limb movement utilizing more functional movement patterns. Since arm movement was the activity during post-testing, subjects were accustomed to contracting the TrA prior to movement from the exercise protocol, resulting in improved activation and initial onset of contraction.

Previous authors have indicated that people with LBP have a delay in activation of the TrA, contributing to spinal instability, as measured via EMG. The results of this study do not support the delay observed in people with LBP, but this may be due to the younger age of the participants and/or pain was not severe enough to seek medical advice. ODI scores on average were 13% (range 4-28%) which falls in the minimal disability category where people are coping with everyday activities of daily living, and where treatment is generally not needed. In the future, ODI scores should fall in the 20-40% range where conservative treatment is suggested. This may result in greater differences between groups at baseline. There are conflicting reports regarding TrA activation being lower in people with LBP. Studies that enrolled a young, active population have not shown these differences. Thus, the population chosen and level of disability should be considered in future research.

There has been considerable use of USI to measure TrA muscle activation. Measurement error is minimal compared to other methods, such as EMG, as crosstalk from surrounding musculature does not exist. However, there has been limited use of USI to determine muscle contraction timing. Fine wire EMG has the ability to assess muscular timing, but it is invasive and can be challenging to determine if the wire is in the correct muscle. USI provides a non-invasive way to observe muscle contraction in real time. While it may not be the most accurate method to measure timing, this technology is clinically relevant and could be used by clinicians to assess the progress of their patients. The hook-laying position that the USI was captured in could also be changed in the future to accommodate for and assess the TrA during more dynamic movement. A study by Mangum et al. indicated acceptable to excellent reliability in seated, standing, and walking positions during USI of the TrA (ICC$_{3,k}$ = 0.553-0.737), however, the hook-laying position showed superior reliability (ICC$_{3,k}$ = 0.903). That was why this position was chosen for this study.

**Limitations**

Several limitations need to be reported for this study. First, the population consisted of collegiate-aged people that were not classified as disabled by their LBP. The ODI may not be the best instrument for a physically active population experiencing LBP to quantify disability. Second, the measurement of initial onset of TrA contraction was subjective to the investigator analyzing the frames of the movie. Movement by the subject and movement of the probe can indicate false readings of contraction. Third, two researchers led the exercise sessions. While the same researcher followed the same patient through the exercises, inconsistencies in instructions and verbal cueing across subjects may have occurred.

**CONCLUSION**

In both healthy and LBP participants that completed the four-week rehabilitation protocol, increases in TrA activation and improvement in TrA timing were found. In this study, a change of almost two tenths of a second may be the difference needed to stabilize the spine before extremity movement, at least in an anticipated task. The participants were able to activate the TrA almost one second prior to limb movement. However, it is unknown how these participants would respond to an unanticipated task and how quickly the TrA would contract. The participants were able to prepare the spine for overhead movement, even though they were not given instruction to do so. Core stability is necessary for
any type of movement and should be incorporated during rehabilitation of any injury.

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ABSTRACT

Background: An alternative physical examination procedure for evaluating the integrity of the anterior cruciate ligament (ACL) has been proposed in the literature but has not been validated in a broad population of patients with a symptomatic complaint of knee pain for its diagnostic value.

Purpose: To investigate the diagnostic accuracy of the Lever Sign to detect ACL tears and compare the results to Lachman testing in both supine and prone positions.

Study design: Prospective, blinded, diagnostic accuracy study.

Methods: Sixty-two consecutive patients with a complaint of knee pain were independently evaluated for the status of the ACLs integrity with the Lever Sign and the Lachman test in a prone and supine by a blinded examiner before any other diagnostic assessments were completed.

Results: Twenty-four of the 60 patients included in the analysis had a torn ACL resulting in a prevalence of 40%. The sensitivity of the Lever Sign, prone, and supine Lachman tests were 38, 83, and 67% respectively and the specificity was 72, 89, and 97% resulting in positive likelihood ratios of 1.4, 7.5, and 24 and negative likelihood ratios of 0.86, 0.19, and 0.34 respectively. The positive predictive values were 47, 83, and 94% and the negative predictive values were 63, 89, and 81% respectively. The diagnostic odds ratios were 1.6, 40, and 70 with a number needed to diagnose of 10.3, 1.4, and 1.6 respectively.

Conclusions: The results of this study suggest that Lever Sign, in isolation, does not accurately detect the status of the ACL. During the clinical examination, the Lever Sign should be used as an adjunct to the gold standard assessment technique of anterior tibial translation assessment as employed in the Lachman tests in either prone or supine position.

Level of Evidence: 2

Key Terms: Anterior cruciate ligament, diagnosis, knee, Lachman test, Lever Sign, sensitivity, specificity
INTRODUCTION

Physical examination of patients with knee injuries frequently involves assessment of ligamentous stability. One of the most common ligamentous injuries of the knee is to the anterior cruciate ligament (ACL). Early recognition is crucial in dictating the course of care to optimize outcomes. A variety of examination techniques have been proposed to detect this injury including the Lachman, Anterior Drawer, and Pivot Shift tests. Of these tests, the Lachman test is considered the clinical gold standard for diagnosing this injury because of its well-established sensitivity, specificity, likelihood ratios, and ease of application for patients of any size.1-5 The accuracy of this test is enhanced with an appreciation for the anterior tibial translation endpoint quality in addition to the interpreting the magnitude of the translational asymmetry between limbs.5

Recently, a new test has been proposed that is equally easy to perform and may be a more convenient assessment for the patient when trying to identify both partial and full tears of the ACL.6 The Lever Sign is a manual examination technique in which a posteriorly directed force is applied to the femur with a fulcrum placed under the posterior tibia to assess whether or not this force causes the distal end of the lever (heel) to rise from the support surface. A negative test occurs when an intact ACL allows the examiner’s fist to serve as the fulcrum for a downward levering force on the distal femur. This force should easily overcome the force of gravity and allow the knee to rotate and heel to elevate from the support surface. A positive test is present when the downward force does not cause the heel to rise from the support surface. Lelli A et al retrospectively performed the Lever Sign on both limbs of 400 subjects with unilateral, acute or chronic, and complete or partial tears of the ACL after confirmation based on magnetic resonance imaging (MRI). For the 400 involved subjects, they found perfect sensitivity and specificity using the asymptomatic knee as a true negative control.6 In contrast to the findings based on the Lever Sign results, only the subgroup of subject with chronic, complete tears had similar diagnostic accuracy as interpreted by the Lachman, Anterior Drawer, and Pivot Shift tests.6

Recently investigators evaluated the arthroscopic and radiologic correlation of the Lever Sign findings to detect ACL injury when the subject was pre-anesthesia and under anesthesia.7 These investigators found nearly perfect sensitivity (94, 98%) in pre-anesthesia and under-anesthesia conditions, respectively. The Lachman, Pivot Shift and Anterior Drawer tests demonstrated slightly less sensitivity under anesthesia (all at 88%) with much lower sensitivity during the pre-anesthesia assessment at 80, 62, and 60% respectively. These authors did not reflect on the Lever Sign’s specificity as all subjects had confirmed tears of the ACL and the evaluations were performed at the time of surgery.

Previous findings from these studies may have been prone to selection bias as the index test was applied to subjects with a known ACL tear. The current study aims to report the diagnostic accuracy of this examination technique in a more general population of patients presenting for evaluation of a complaint of knee pain. The purpose of this study was to evaluate the diagnostic accuracy of the Lever Sign to detect ACL tears and compare the results to Lachman testing in both supine and prone positions.

METHODS

The accuracy of the Lever Sign was assessed on consecutive subjects referred from the emergency department of a county teaching hospital to an orthopedic surgery specialty service for definitive evaluation of a painful knee. The subjects were between the ages of 18 and 65 with a complaint of knee pain rated as less than 7/10 on a verbal numerical rating scale. Subjects possessing at least 20-120° range of motion were eligible for inclusion. The study was approved by the institutional review boards at the University of Texas Southwestern Medical Center and Parkland Health and Hospital System in Dallas, TX. All subjects agreed via informed consent to participate in the investigation. Study exclusion criteria included: the suspicion of fracture based on the Ottawa knee rules,8 previous knee joint arthroplasty, suspicion of posterior cruciate ligament (PCL) involvement, knee surgery in the previous six months, or the presence of serious underlying non-mechanical pathology or systemic illness.

The examination was conducted by a licensed physical therapist with 36 years of sports physical therapy experience. This examination was performed before
any other diagnostic evaluation was conducted, including injury history interview or review of previously conducted radiographic or magnetic resonance (MR) images. Therefore, the examiner had minimal knowledge regarding the subject's current condition and complaint.

After enrollment, each subject independently ambulated to the examination room without an assistive device to satisfy one of the items included in the Ottawa knee fracture rules. Active knee flexion to at least 90° and palpation for reproduction of pain complaint was conducted at the patella and fibular head to complete the Ottawa knee rule algorithm. If there were no adverse responses according to the knee rule, the examiners proceeded to screening for PCL injury. PCL injury evaluation was conducted via visual and palpatory assessment of a tibial sag sign with knee flexed at 90°. If the tibial plateau did not appear to be at least 1 cm anterior to the femoral condyle, a quadriceps active drawer test was applied to rule in posterior cruciate ligament (PCL) injury. The palpatory loss of the tibia-femur step-off relationship has been shown to be a sensitive (0.90) and specific (0.99) means by which to detect the presence of a PCL injury.9 The quadriceps active drawer test is performed by the subject gently contracting the quadriceps with the knee flexed at 90° and foot stabilized on the treatment plinth. The posterior displacement of the tibia will be reduced with this isometric contraction in the presence of a PCL tear. The specificity of this maneuver has been reported to be 96% and the sensitivity 53%.9-10 All preliminary exclusion tests were performed by the same examiner who conducted the ACL stability assessment tests.

Following screening to rule on PCL involvement, the examiner assessed the subject for their ACL status by performing the Lever Sign and Lachman tests in the supine position followed by repeating the Lachman test in a prone position. The order in which these tests were conducted was randomized and the results of one examination technique were not allowed to alter the previously recorded results of another assessment maneuver. At the conclusion of the manual examinations, each subject was evaluated with the KT-1000™ arthrometer to record the millimeters of anterior translation at 15, 20, and 30 pounds (6.8, 9.1, and 13.6 kg) of force by a single examiner (EPM). The KT-1000™ is a mechanical joint arthrometer that allows for stabilization of the femur with concurrent instrumented assessment of the amount tibial translation when an anterior displacement force is applied to the proximal end of the lower leg and provides an objective, numerical result. This device has been shown to be an accurate and appropriate gauge of sagittal plane tibial displacement in a research setting.11 Previous studies have shown that the examiner involved in the current study has demonstrated good reliability in performing the KT-1000™ examination with an intraclass correlation coefficient (3,1) of .90, .82, .88, and .78 at 15 pounds (6.8 kg), 20 pounds (9.1 kg), 30 pounds (13.6 kg), and at a manually applied maximal force.3-5 This intratester reliability data is consistent with values reported in other studies.12-13

**Ligamentous Testing Description**

For all subjects, the uninvolved knee was evaluated first to establish a baseline by which the contralateral knee could be judged. The Lachman tests were performed with the subject lying supine and prone on a firm examination table and the knee flexed to 20-30°. Care was taken to ensure that both knees were in the same degree of flexion during the physical examination procedures. For the supine examination, the examiner's upper hand stabilized the unsupported distal thigh, while the lower hand, with the thumb on the anterior joint line, and the fingers feeling to ensure that the hamstrings were relaxed, pulled the tibia forward with approximately 30 pounds of force (Figure 1). For the prone
assessment, the examiner placed the hand closest to the foot (distal hand) on the anterior proximal tibia, with the index and longer finger positioned on each side of the patellar tendon, resting on the anterior joint line. The examiner’s thigh was placed under the subject's shin to support the subject in 20-30° of knee flexion. The heel of the examiner's other hand (proximal hand) was placed over the postero-central aspect of the proximal tibia, with the fingers lightly resting on the proximal gastrocnemius muscle belly. The heel of the proximal hand was used to direct an anterior force on the posterior tibia, while the fingers of the distal hand applied slight pressure directed posteriorly and simultaneously palpated the amount of anterior tibial translation relative to the femur (Figure 2).

The examiner judged both Lachman tests as positive or negative based primarily on the presence or absence of a firm end feel. A positive test in either position was based on the absence of a firm end feel with a perception of greater than 3mm more anterior translation on the injured side as compared to the uninjured side.

The Lever Sign was conducted with the subject supine on an examination table with a rigid transfer board placed underneath the involved extremity during testing. With the examiner positioned alongside the subject, the examiner’s distal hand formed a closed fist and was positioned under the proximal third of the tibia. This caused the knee to flex to approximately the same amount of flexion as a traditional Lachman test (20-30°). The proximal hand of the examiner was then free to apply a moderate (30 pounds) downward force to the distal third of the femur. A positive test was present when the posterior force on the thigh did not result in the elevation of the heel from the support surface. Conversely, a negative test was present when the knee extended and the heel rose from the table (Figure 3).

For 19 subjects the gold standard for diagnostic accuracy was direct arthroscopic visualization of the ACL at the time of surgery. Following the assessment of the 41 subjects for whom direct visual evidence through the arthroscope was not available, each subject’s ACL status (reference standard) was categorized as intact or torn based on a cluster of clinical findings. To be classified as having a torn ACL, the
subject had to have at least two of the three following findings: 1) a positive MRI; 2) excessive laxity on KT-1000™ examination which was defined as more than 3 mm greater translation on the involved side during the instrumented assessment with the 30 lbs (13.6 kg) and/or manual maximum test as compared to the uninvolved side; and 3) a positive finding on a subsequent independent and comprehensive knee ligamentous evaluation conducted by a physician who was blinded to the original examiner’s findings. If less than two of these findings were positive the subject’s ACL status was classified as intact.

Fellowship trained sports medicine physicians, orthopedic surgeons, and musculoskeletal radiology investigators not involved in conducting the ACL tests interpreted the MR images and/or evaluated the ACL under arthroscopic visualization. No adverse events were reported for any of the subjects during the index testing or evaluation of the reference standards.

Statistical Analysis
To determine the necessary sample size the authors assumed a minimal sensitivity and specificity of at least 0.95 and a 95% confidence interval with a desired precision width of ±0.10 resulting in the need to enroll a minimum of 48 subjects. A 2x2 contingency table protocol was used to evaluate the sensitivity, specificity, positive and negative predictive values, and likelihood ratios for all special tests. Sensitivity represents the percentage of true positives in all subjects with the reference injury and specificity represents the percentage of true negatives. Consequently, index tests with high sensitivity are thought to be effective at ruling out the presence of the injury while tests with high specificity are effective at ruling in the injury. Positive and negative predictive values reflect the percentage of time that a positive or negative test (respectively) accurately captures the diagnosis. Exact binomial confidence intervals for the positive and negative predictive values were determined by the Clopper-Pearson method through an on-line calculator at http://statpages.org/ctab2x2.html. Positive and negative likelihood ratios reflect changes in the post-test probability when the index test is positive or negative respectively. The confidence intervals for the sensitivity, specificity, and likelihood ratios were computed via an on-line calculator at http://www.pedro.org.au/english/downloads/confidence-interval-calculator/ using the Wilson score method. The number needed to diagnose was derived from the formula 1/[sensitivity – (1/specificity)] and represents the number of tests that need to be performed to gain a positive response for the presence of the injury.

RESULTS
Figure 4 summarizes the flow of the subjects through the study. Twenty-four of the 60 subjects in this study

Figure 4. Flow chart of eligible subjects.
had a torn ACL resulting in a prevalence of 40%. The examinations were prospectively conducted on 62 consecutive subjects between September of 2016 and March of 2017; however, only 60 of them were included in the study. One subject was excluded due to a suspected posterior cruciate ligament injury during screening and the other because their pain level and muscular guarding prevented tibial or femoral translation assessment. Demographic information about the subjects is presented in Table 1.

In the gold standard of assessment, group 15 individuals had a torn ACL and four had an intact ACL. For the remaining 41 subjects classified by the reference consensus there were nine individuals with a torn ACL and 32 with an intact ACL.

According to the gold standard index, the sensitivity of the Lever Sign was 0.33 (95% CI 0.23 – 0.44) with a specificity of 0.50 (95% CI (0.10 -0.90). For those subjects where the status of the ACL was determined by reference standard, the sensitivity was 0.44 (95% CI 0.17 0- 0.74) and the specificity was 0.75 (95% CI 0.67 – 0.83). For all subjects combined, the sensitivity was 0.38 (95% CI 0.22 – 0.53) and a specificity of 0.72 (95% CI (0.62 – 0.83) with a positive predictive value of 0.47 (95% CI 0.28 – 0.67) and a negative predictive value of 0.63 (95% CI 0.54 – 0.73) (Table 2).

According to the gold standard index, the sensitivity of the Prone Lachman test was 0.81 (95% CI 0.71 – 0.87) with a specificity of 0.67 (95% CI (0.13 – 0.98). For those subjects where the status of the ACL was determined by reference standard, the sensitivity was 0.88 (95% CI 0.53 – 0.99) and the specificity was 0.94 (95% CI 0.86 – 0.97). For all subjects combined, the sensitivity was 0.83 (95% CI 0.68 – 0.93) and a specificity of 0.89 (95% CI (0.78 – 0.95) with a positive predictive value of 0.83 (95% CI 0.68 – 0.93) and a negative predictive value of 0.89 (95% CI 0.78 – 0.95). The overall accuracy was of the Prone Lachman test was 87% for all subjects (Table 3).

According to the gold standard index, the sensitivity of the Supine Lachman test was 0.65 (95% CI 0.55 – 0.65) with a specificity of 1.0 (95% CI (0.21 - ¥). For those subjects where the status of the ACL was determined by reference standard, the sensitivity was 0.71 (95% CI 0.35 – 0.85) and the specificity was 0.97 (95% CI 0.90 – 1.0). For all subjects combined, the sensitivity was 0.94 (95% CI 0.73– 1.0) and a specificity of 0.81 (95% CI (0.73 – 0.84) with a positive predictive value of 0.94 (95% CI 0.73 – 0.99) and a negative predictive value of 0.81 (95% CI 0.73 – 0.84). The overall accuracy of the Supine Lachman test was 85% for all subjects (Table 4).

Likelihood ratios for all subjects were computed based on the sensitivity and specificity of each examination technique, yielding a positive likelihood ratio of 1.35 (95% CI 0.57 – 3.07) and a negative likelihood ratio of 0.87 (95% CI 0.57 – 1.27) for the Lever Sign, a positive likelihood ratio of 7.50 (95% CI 3.19 – 19.29) and a negative likelihood ratio of 0.19 (95% CI 0.57 – 1.27) for the Prone Lachman test, and a positive likelihood ratio of 24.0 (95% CI 4.14 – 482.3) and a negative likelihood ratio of 0.34 (95% CI 0.29 – 0.55) for the Supine Lachman test. The

<table>
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<th>Characteristic</th>
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<td>Age [mean years ± SD (range)]</td>
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<tr>
<td>Sex (frequency)</td>
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<tr>
<td>Mean Days since Injury [mean days ± SD (range)]</td>
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<tr>
<td>Thigh circumference [(mean cm ± SD (range)]</td>
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<tr>
<td>Calf circumference [(mean cm ± SD (range)]</td>
<td>36.8 ± 3.8 (28.5 – 37.1)</td>
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</table>
diagnostic odds ratio for all subjects was 1.6 (95% CI: 0.45 – 5.40), 40 (95% CI: 7.5 – 254), 70 (95% CI: 7.5 - 1639) for the Lever Sign, Prone, and Supine Lachman tests respectfully.

For all subjects, based on the pretesting prevalence of 40%, the posttest probability from a positive test with the Lever Sign, Prone Lachman, and Supine Lachman tests increased to 48, 84, and 94% and the posttest probability from a negative test reduced the likelihood of an ACL injury to 36, 11, and 18% respectively. The overall accuracy of the examination techniques for the Lever Sign, Prone Lachman, and Supine Lachman test was 58, 87, and 85%, and the number needed to diagnose (NND) was 10.3, 1.4 and 1.6 respectively (Table 5).

**DISCUSSION**

In a patient presenting with a possible ACL injury, it is important to know the accuracy of the tests used to confirm or refute a diagnosis. Previous studies have established the Lachman and Pivot shift tests to have outstanding specificity but only moderate sensitivity.1,3-7 One of the compelling qualities regarding the Lever Sign from previous published studies was the improved sensitivity that approached 100% for this examination technique.6-7 The findings of the

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**Table 2.** Lever Sign Classification: 2 x 2 contingency table based on gold standard.

<table>
<thead>
<tr>
<th>Condition according to Gold Standard</th>
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<tr>
<td>Totals</td>
<td>9</td>
<td>32</td>
<td>41</td>
</tr>
</tbody>
</table>

* To be classified as a torn ACL, the subject had to have at least 2 of the 3 following findings: 1) a positive MRI; 2) excessive laxity (> 3mm on KT-1000TM examination; and 3) a positive finding on subsequent independent and comprehensive knee ligamentous evaluation conducted by a physician.

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<table>
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<th>Condition according to Reference or Gold Standard</th>
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<th>Negative</th>
<th>Totals</th>
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<tr>
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</tr>
<tr>
<td>Totals</td>
<td>24</td>
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</table>
current study could not replicate this high sensitivity. In fact, the number of false negatives was greater than true positives resulting in an inadequate level of screening for the injury regardless if the index test was compared to a gold or reference standard. Additionally, the specificity was slightly lower with the Lever Sign than the more traditional Lachman examination performed in either the supine or prone positions.

The NND value provides another statistical perspective on the accuracy of the index test. For the Lever Sign test an NND of 10.3 suggests that this test, in isolation, would rarely be adequate to establish the status of the ACL. Conversely, the NNDs of 1.4-1.6 for the Lachman tests suggest that these tests would be accurate for five of every seven to eight subjects on whom the tests would be performed.

The results from this study for Lachman testing were similar to previous investigations in regards to the test’s sensitivity and specificity. For the Lachman test performed in supine, pooled data from meta-analyses by Benjaminse et al,1 Jackson et al,14

<table>
<thead>
<tr>
<th>Table 3. Prone Lachman Test Classification: 2 x 2 contingency table based on gold standard.</th>
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*To be classified as a torn ACL, the subject had to have at least 2 of the 3 following findings: 1) a positive MRI; 2) excessive laxity (> 3mm on KT-1000™ examination; and 3) a positive finding on subsequent independent and comprehensive knee ligamentous evaluation conducted by a physician.
In contrast, this study could not replicate the diagnostic accuracy found in other investigations for the Lever Sign.6-7 One of the attractive features of the Lever Sign is the simplicity of its interpretation. There should be little debate regarding the rise of the heel. It is possible that the degree of elevation or the force required to impart the lever effect is variable between subjects. Great care was taken to be consistent with the force delivered to minimize this potential confounding variable and properly engage the lever action. It was common to feel an increased posterior translation and/or a soft end feel to this translation during the examination but this not used to classify the result as positive or negative as it was not

and Scholten et al4 indicate a sensitivity ranging from 0.85 to 0.87 and a specificity ranging from 0.91 to 0.94. In the present study, results for the supine Lachman test showed a similar degree of accuracy with a specificity of 0.97 and a sensitivity of 0.89. The current results were also similar to a previous study of the Lachman test performed in a prone position with almost identical overall accuracy.5 In the previous study the specificity was slightly better (0.97 vs. 0.89) with a slightly lower sensitivity (0.70 vs. 0.83). The similar results are likely attributable to the same examiner in each study but are similar to other meta-analyses of the accuracy of the Lachman test.

Table 4. Supine Lachman Test Classification: 2 x 2 contingency table based on gold standard.

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<tr>
<td>Totals</td>
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</table>

* To be classified as a torn ACL, the subject had to have at least 2 of the 3 following findings: 1) a positive MRI; 2) excessive laxity (> 3mm on KT-1000™ examination; and 3) a positive finding on subsequent independent and comprehensive knee ligamentous evaluation conducted by a physician.

Supine Lachman Test Classification: 2 x 2 contingency table for all subjects

<table>
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<td>Totals</td>
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part of the operational definition used in the founding investigations. Many previous studies have demonstrated the importance of considering the “endpoint” in establishing the integrity of the ACL. Inclusion of this criterion in future studies may help improve the accuracy of this diagnostic test.

In the four cases in which all three examination procedures resulted in a false negative for a torn ACL there were no consistent demographic or concurrent injuries to explain the error. In two cases the subjects were older (50 and 53 years of age) than the mean study population, one had arthrofibrotic changes following an ACL reconstruction that mandated a manipulation under anaesthesia eight years previously, and the remaining subject had suffered an ACL graft re-tear approximately nine months previous to the examination. The examiner differed in his interpretation of the Lachman test in prone and supine positions in six cases. In five of these six cases, the prone examination correctly detected the ACL. Conversely, in one instance, the examiner incorrectly categorized the subject as an ACL tear based on the prone examination while the supine examination was correctly interpreted as negative for a torn ACL. There were no consistent demographic or concurrent injuries to explain these phenomena.

The pivot shift test was intentionally not included in this study due to its known lack of sensitivity and the fact that all current evaluation techniques (Lachman and Anterior Drawer tests) have displayed a similar high level of specificity. Additionally, the pivot shift test is an assessment of rotational stability while the Lachman, Anterior Drawer, and Lever Sign are all assessments of translational stability. As with previous investigations this investigation did not evaluate the reliability of the Lever Sign. It was assumed the ease of test interpretation would minimize the need for examiner expertise to categorize the test finding. In retrospect, reliability should be evaluated between examiners to ensure that consistent force levels are applied and if there could be agreement, beyond chance, regarding the endpoint of the posterior femoral translation.

The rationale for the current study sample size was powered by previous research that indicated a high degree of accuracy. Retrospectively, the relatively wide diagnostic accuracy confidence intervals that were reported may have suggested that an even larger sample size to improve the measurement precision of point estimates regarding the diagnostic truthfulness for the Lever Sign. Another acknowledged shortcoming of this study is that 41 of the 60 patients were classified without the benefit of direct, intraoperative visual assessment of the status of the ACL and had to be assigned to a category based on a cluster of clinical impressions and signs. While this

<table>
<thead>
<tr>
<th>Diagnostic Parameters</th>
<th>Lever Test</th>
<th>Prone Lachman Test</th>
<th>Supine Lachman Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity (95% CI)</td>
<td>0.38 (0.22 - 0.53)</td>
<td>0.83 (0.68 - 0.93)</td>
<td>0.67 (0.52 - 0.71)</td>
</tr>
<tr>
<td>Specificity (95% CI)</td>
<td>0.72 (0.62 - 0.83)</td>
<td>0.89 (0.78 - 0.95)</td>
<td>0.97 (0.87 - 0.99)</td>
</tr>
<tr>
<td>Positive Predictive Value (95% CI)</td>
<td>0.47 (0.28 - 0.67)</td>
<td>0.83 (0.68 - 0.93)</td>
<td>0.94 (0.73 - 0.99)</td>
</tr>
<tr>
<td>Negative Predictive Value (95% CI)</td>
<td>0.63 (0.54 - 0.73)</td>
<td>0.89 (0.78 - 0.95)</td>
<td>0.81 (0.73 - 0.84)</td>
</tr>
<tr>
<td>Positive Likelihood Ratio (95% CI)</td>
<td>1.4 (0.57 - 3.07)</td>
<td>7.5 (3.8 - 17.3)</td>
<td>24.0 (4.1 - 482)</td>
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<tr>
<td>Negative Likelihood Ratio (95% CI)</td>
<td>0.86 (0.57 - 1.27)</td>
<td>0.19 (0.08 - 0.42)</td>
<td>0.34 (0.29 - 0.55)</td>
</tr>
<tr>
<td>Diagnostic Odds Ratio (95% CI)</td>
<td>1.6 (0.45 - 5.4)</td>
<td>40 (7.5 - 254.4)</td>
<td>70 (7.5 - 1639)</td>
</tr>
<tr>
<td>Number Needed to Diagnose</td>
<td>10.3 (2.79 - (-)6.1)</td>
<td>1.4 (1.1 - 2.2)</td>
<td>1.6 (1.4 - 2.5)</td>
</tr>
</tbody>
</table>
classification is less than optimal, the authors are confident that the clinical consensus formula based on the subsequent results of MRI findings, orthopaedic surgeon evaluation, and joint arthrometry dichotomized each patient into the category that truly represented the status of the ACL. Of the 19 patients in whom there was direct visual evidence of the ACL through arthroscopy, the clinical cluster accurately identified those patients who had an ACL tear \((n = 15)\) and those who did not \((n = 4)\).

The strength of this study design is that it reduces both selection and verification bias as there was an intentional inclusion of a wide range of musculoskeletal knee disorders. The authors are confident that the study cohort represents a wide, age-appropriate spectrum of patients with both acute and chronic knee pathology severity.

**CONCLUSION**

The results of this study indicate that Lever Sign, in isolation, does not accurately detect the status of the ACL. During the clinical examination, the Lever Sign should be used as an adjunct to the gold standard assessment technique of a Lachman test in either prone or supine positions. Further study of the Lever Sign in a larger patient population of patients with knee pain complaints is recommended with additional consideration for how, or if the endpoint assessment to posterior femoral translation adds value to the diagnostic decision.

**REFERENCES**


ABSTRACT

Background: Stretching of the deep rotators of the hip is commonly employed in patients with lumbosacral, sacroiliac, posterior hip, and buttock pain. There is limited research demonstrating the effectiveness of common stretching techniques on the short external rotators of the hip.

Purpose: The objective of this study was to evaluate length change during stretching of the superior and inferior fibers of the piriformis, superior gemellus, obturator internus, and inferior gemellus.

Study Design: Repeated-measures laboratory controlled cadaveric study.

Methods: Seventeen hip joints from nine embalmed cadavers (5 male; 4 female) with an age between 49-96 years were skeletonized. Polypropylene strings were attached from the origin to insertion sites of the short external rotators. The change of length (mm) noted by excursion of the strings was used as a proxy for change in muscle length, when the hip was moved from the anatomical position to four specific stretch positions: 1) 45° internal rotation from hip neutral flexion/extension, 2) 45° external rotation from 90° hip and knee flexion, 3) 30° adduction from 90° of hip and knee flexion, and 4) 30° of adduction with the hip and knee flexed so the lateral malleolus contacted the lateral femoral epicondyle of the contralateral limb, were recorded.

Results: There was a significant effect on string displacement by stretch position, F (15,166) = 14.67, p < .0005; Wilk’s Λ = .097, partial n² = .540. The greatest displacement of the strings corresponding to the superior piriformis, inferior piriformis, and the superior gemellus occurred in 30° adduction from 90° of hip and knee flexion. The obturator internus and inferior gemellus had the largest string displacement with 45° internal rotation from neutral flexion/extension.

Conclusions: While all stretch positions caused a significant string displacement indicating length changes of the deep rotators of the hip, the three stretch positions that caused the greatest change were: 1) 30° adduction from 90° of hip and knee flexion, 2) 45° internal rotation from neutral flexion/extension, and 3) 45° external rotation with 90° hip and knee flexion.

Clinical Relevance: This study has clinical implications for the effectiveness of specific stretching techniques on the short external rotators of the hip with the potential to improve the validity of stretching protocols for patients with posterior hip or buttock pain. The piriformis and superior gemellus had a larger change in length when adducting the hip from 90° degrees of hip and knee flexion. The obturator internus and inferior gemellus had a greater length change when internally rotating the hip from neutral flexion/extension.

Level of Evidence: 3

Key words: anatomical modeling, posterior hip, reliability, stretching positions

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INTRODUCTION
Posterior hip pain is a common complaint of patients seeking treatment in an orthopedic clinical setting.1 The source of posterior hip symptoms is commonly referred from extra-articular structures including the lumbosacral spine, sacroiliac joint, and hip extensor and rotator muscles.3,4 Pain localized in the buttck (gluteal) region has been associated with shortening of the short hip external rotators.5,6 There are five muscles found in the deep gluteal region known as the short external rotators of the hip joint. They include the piriformis, superior and inferior gemelli, obturator internus, and quadratus femoris. There is limited research demonstrating the effect of common stretching techniques on lengthening of the short hip external rotators.7

The close fascial connection of the short external rotators plays an important role in the transmission of force and movement control from the torso to the lower extremities. Injury to the fascia and/or musculotendinous fibers can cause deficits in flexibility and range of motion.8,9 These limitations are frequently addressed through static stretching in order to overcome passive resistance and increase active range of motion.10 Static stretching has been shown to increase range of motion of the hamstring muscles in comparison to dynamic stretching when performed once a day for six weeks.11,12 Stretching programs have been shown to decrease symptoms relating to posterior hip and buttock pain.5,6 Commonly identified as “piriformis stretching,” these techniques seek to emphasize hip and knee flexion with adduction and external rotation of the hip and have been shown effective in lengthening of the piriformis muscle.5,13,14 Several studies have shown that the gemelli-obturator internus complex can cause significant posterior hip and buttock pain, but specific stretching techniques have not been validated for effectiveness on change of muscle length, to the knowledge of the authors. As a result of the close anatomical association of these five muscles, stretching is generally performed to lengthen all structures uniformly rather than in isolation. Four commonly performed stretches are shown in Figure 1. Although these techniques are frequently utilized in the clinical setting, there is limited research demonstrating the effectiveness of each stretch on change in length of the short external rotators of the hip.

The purpose of this study was to evaluate length change of the piriformis, superior gemellus, obturator internus, and inferior gemellus during four commonly performed stretching positions. Human cadaver specimens were examined to describe changes in the muscle length of the short external rotators in four supine positions: 1) 45° of internal rotation from a neutral anatomical position (45IR0), 2) 45° of external rotation from 90° hip and knee flexion (45ER90), 3) 30° of adduction from 90° of hip and knee flexion (30ADD90), and 4) 30° of adduction with the hip and knee flexed (PIRIFORM) so the lateral malleolus contacted the lateral femoral epicondyle of the contralateral limb. The results of this study could help clinicians select stretching positions that could be incorporated into treatment for patients with posterior hip or buttock pain.

METHODS
Design
Seventeen hip joints from nine formalin-embalmed cadavers (5 male; 4 female) with a lifespan between 49-96 years were included in this study. One hip joint was excluded due to a previous total hip arthroplasty. The lower extremities of the cadavers were skeletonized from the pelvis distally leaving only the short external rotators and capsuloligamentous structures intact. The origin and insertions of the superior (SP) and inferior fibers (IP) of the piriformis, superior gemellus (SG), obturator internus (OI), and inferior gemellus (IG) were identified by the primary investigator and secondary investigator to ensure proper location.18 The primary investigator had one year of dissection experience and the secondary investigator had nine years’ experience at the time this study was performed. Polypropylene strings were attached from the insertion to origin sites of each muscle to represent the musculotendinous fibers of the short external rotators. The strings were secured at the insertion sites on the greater trochanter with a 1/8” screw. Each polypropylene string was then guided from the insertion through an eyelet screw located at each origin (Figure 2). After proper identification and pinning of the origin and insertion sites the muscles were excised. Each pelvis was then secured to a wood platform by two 12” screws, bilaterally placed through the anterior aspect of the ilium. Neutral positioning of the pelvis...
on the board was ensured by a bubble level (Empire® Magnetic Tool Box Level, Mukwonago, WI) sited on the anterior superior iliac spines of each cadaver (Figure 3). The strings were then run through eyelet screws positioned at the edge of the wood platform (Figure 4). Each string was anchored off the table to ensure equal distribution of tension.

A third investigator positioned each cadaver into a neutral anatomical position (0° flexion/extension and 0° abduction/adduction). This positioning was confirmed through use of a standard 12-inch goniometer (Baseline® 12- inch Goniometer, White Plains, NY) for each cadaver. The primary investigator then marked the starting position of each
string by placing a black mark where the string and eyelet screw met at the end of the board. The cadavers were then moved into the four specific stretch positions: 1) 45IR0, 2) 45ER90, 3) 30ADD90, and 4) PIRIFORM (Figure 5). The primary investigator confirmed proper positioning by use of a bubble inclinometer (Baseline® Bubble Goniometer, Irvington, NY) for stretch position 1 and a standard 12-inch goniometer for the remaining three stretch positions (2-4). With each position maintained the primary investigator measured the change in length (mm) by excursion of the strings with a digital caliper (General® Digital Caliper, Secaucus, NJ) (Figure 6). Each stretch position was performed three times and separate measurements were taken from the established neutral position to ensure intrarater reliability. This study was approved by the ethics committee for anatomical studies of Duquesne University.

**Statistical Analysis**

Descriptive data are presented as mean length change ± standard deviation. Standard error of measurement (SEM) values were calculated to ensure test-retest reliability for each stretch position with 95% confidence intervals. SEM values are expressed in actual units of measurement (mm) to summarize the variation in length change during the three trials of each stretch position.19 A multivariate analysis of variance (MANOVA) was performed with post-hoc testing to determine the effect of the four stretching techniques on the length change of each muscle. Wilk’s Λ was utilized to show the relation of error variance in comparison to total variance of the

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*Figure 2. Polypropylene string placement from insertion to origin of the short external rotators. 1) superior piriformis; 2) inferior piriformis; 3) superior gemellus; 4) obturator internus; 5) inferior gemellus.*

*Figure 3. Neutral positioning of the pelvis on wood platform with level placement bilaterally on the anterior superior iliac spines.*
stretching positions. All data was analyzed using a common statistical software program (IBM SPSS Statistics, Version 23, Armonk, NY).

RESULTS

SEM values for intra-rater reliability are presented in Table 1. The SEM values of 1.05mm (45ER90), 1.00mm (30ADD90), 0.63mm (PIRIFORM), 0.62mm (45IR0) demonstrated strong consistency of measurement for the three trials of each stretch position. There was a significant effect on string displacement corresponding to stretch position, F (15,166) = 14.67, p < .0005; Wilk's Λ = .097, partial η² = .540. The average length changes for each stretch position are presented in Table 2. The three stretch positions that caused the greatest string displacement of the corresponding short external rotators were: 1) 30ADD90, 2) 45IR0, and 3) 45ER90. PIRIFORM caused the least amount of length change for any of the muscles (p < 0.05).

DISCUSSION

This study was designed to assess the effect of four stretching positions on change in length of the short hip external rotators. While all stretch positions resulted in length change to the short external rotators, the greatest length changes for the SP, IP, and the SG occurred in 30° adduction from 90° of hip and knee flexion. The OI and IG had the greatest length change with 45° internal rotation from neutral flexion/extension. When selecting stretching as an intervention to lengthen the short hip external rotators, the three stretch positions that caused the greatest length change were: 1) 30° adduction from 90° of hip and knee flexion, 2) 45° internal rotation from neutral flexion/extension, and 3) 45° external rotation with 90° hip and knee flexion. This is the first study that assessed the effects of four commonly performed stretching techniques on length changes of the short hip external rotators.

The results of this study found the three most proximal muscles fiber models (SP, IP, and SG) had the greatest change in length when positioned in 30ADD90 (SP: 30.7mm, SD 10.2mm; IP: 23.7mm, SD 7.8mm; SG: 20.8mm, SD 5.4mm) followed by 45IR0 (SP: 22.2mm, SD 5.9mm; IP: 20.6mm, SD 5.3mm; SG: 17.4mm, SD 3.0mm) and 45ER90 (SP: 19.4mm, SD 10.2mm; IP: 10.4mm, SD 7.8mm; SG: 9.4mm, SD 7.0mm). The two distal muscles (OI and IG) had the greatest length change in 45IR0 (OI: 18.2mm, SD 7.7mm; IG:15.5mm, SD 3.3mm) followed closely by 30ADD90 (OI: 17.1mm, SD 6.0mm; IG: 14.7mm, SD 7.2mm). The PIRIFORM stretch caused minimal lengthening of the short external rotators, specifically in the piriformis (SP: 7.7mm, SD 5.7mm; IP: 2.5mm, SD 3.7mm).

The short external rotators are ideally aligned to compress the articular surfaces of the hip joint.7 These postural muscles stabilize the hip in a manner similar to the rotator cuff at the glenohumeral joint. During cutting and propulsion type movements the short external rotators are regularly contracted for dynamic stability of the hip.7 Due to the strain transmitted during rotational activities, stretching of these muscles is commonly employed in athletes with chronic posterior hip and buttock pain.4-6 Previous cadaveric studies have shown that up to 120° of hip flexion increased the excursion of the short hip.
The greatest increase in lengthening of the piriformis and gemelli-obturator internus complex was observed when the limb was positioned in adduction between 60° and 105° of hip flexion. Similarly, the results of the present study demonstrated the greatest length change of the piriformis and SG when the hip was flexed to 90° with 30° of hip adduction (30ADD90). External rotation with 105° of hip flexion has been

Figure 5. Stretching positions for change of length measurements of the short external rotators. 1) 45° internal rotation from a neutral position (with bubble inclinometer); 2) 45° external rotation from 90° hip and knee flexion; 3) 30° adduction from 90° of hip and knee flexion; 4) 30° of adduction with the hip and knee flexed so the lateral malleolus contacted the lateral femoral epicondyle of the contralateral limb.
The results corresponded to the results previously described with 45° of internal rotation from anatomical neutral (45IR0) causing the largest observed length change of the OI and IG. While previous authors reported length change for several movements of the hip they did not assess ranges of motion specifically associated with the four stretching techniques evaluated in this study. The results of this study offer evidence to validate the inclusion of the 30ADD90, 45IR0, and 45ER90 in protocols designed for stretching of the piriformis, SG, OI, and IG.

There are limitations to this study that need to be considered when interpreting the results. First, this study utilized formalin-embalmed cadavers for data collection. The use of embalmed cadavers in anatomical research has been shown to cause increased soft tissue stiffness and decreased joint flexibility in comparison to fresh-frozen cadavers. While all specimens in this study were successfully positioned for each measurement, the surrounding musculature had to be removed for proper string placement. This study does not account for individual limitations in range of motion that could be present due to the surrounding musculature. The capsuloligamentous structures were kept intact to maintain normal femoral head motion in the acetabulum during each stretch position. Joint stiffness related to preserving these structures could have caused a limitation in the measured movement of the short external rotators. Stretching techniques performed in the clinical setting may vary depending on the flexibility, range of motion, and anatomical limitations of an individual.

An additional limitation to this study was the use of a goniometer for determination of hip range of motion during the evaluated stretching techniques. Previous studies have validated the use of

| Table 1. Standardized error of measurement values for intra-rater reliability. |
|---|---|---|
| Stretch Position | SEM Values (mm) | 95% Confidence Intervals |
| 30ADD90 | 1.00 | 19.42 – 23.40 |
| 45IR0 | 0.62 | 17.56 – 20.03 |
| 45ER90 | 1.05 | 7.35 – 11.51 |
| PIRIFORM | 0.63 | (-0.22) – 2.48 |

30ADD90 = 30° adduction from 90° of hip and knee flexion, 45IR0 = 45° internal rotation from a neutral anatomical position, 45ER0 = 45° external rotation from 90° hip and knee flexion, PIRIFORM = supine piriformis test, SEM = standardized error of measurement.
a goniometer for measurements of hip flexion and external rotation, but no evidence has been presented for evaluation of hip adduction. This study attempted to account for this limitation by stabilizing each cadaver to limit pelvic rotation and tilt as well as the initial neutral positioning of each hip. Slight differences in measured adduction could have caused an increase or decrease in the measurement of length change for the short external rotators. Clinicians commonly use more than 30° of hip adduction during the PIRIFORM stretching technique, however, the cadaver specimens were unable to consistently be moved beyond this range of motion. Therefore, 30° of adduction was utilized as the standard range of motion for this study. Additionally, the PIRIFORM is performed in the clinical setting with the patient in a prone position. In the current study, this stretching technique was performed with the cadaver positioned supine. While this positioning was found to be most effective for administration in this study, it could have caused a limitation in the measured movement of the short external rotators when compared to the technique performed from a prone position. Absolute reliability was evaluated through the calculation of SEM for each stretch position to ensure consistency of measurement. This statistic evaluated the reliability in actual units of measurement (mm) to show the variation in length change during the three trials of each stretch position. The SEM showed a low value range of 1.05mm to 0.62mm which established effective test-retest reliability for all four positions.

Several cadaveric studies have been performed to assess length change in order to evaluate movement of the muscles in relation to the posterior approach for total hip arthroplasty, as well as peak strength and stretch as it relates to normal, gait-related movements. These studies utilized string modeling for representation of musculature, in order to assess the excursion or lengthening of the short external rotators, respectively. The use of string models has previously been validated and demonstrated the effectiveness of dividing muscles into different sections in order to accurately show movement. The present study utilized this technique with only the piriformis being divided into a superior and inferior section based on the origin location of the anterior surface of the sacrum and greater sciatic notch.

**CONCLUSION**

While all stretch positions caused a length change for the deep rotators of the hip, the three stretch

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**Table 2. Mean and standard deviation for the changes in length from the anatomical position to four stretch positions.**

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Stretch Position</th>
<th>Mean Change in Length (mm)</th>
<th>Standard Deviation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior piriform</td>
<td>30ADD90</td>
<td>30.7</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>45IR0</td>
<td>22.2</td>
<td>5.9</td>
</tr>
<tr>
<td></td>
<td>45ER90</td>
<td>19.4</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>PIRIFORM</td>
<td>7.7</td>
<td>5.7</td>
</tr>
<tr>
<td>Inferior piriform</td>
<td>30ADD90</td>
<td>23.7</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>45IR0</td>
<td>20.6</td>
<td>5.3</td>
</tr>
<tr>
<td></td>
<td>45ER90</td>
<td>10.4</td>
<td>7.7</td>
</tr>
<tr>
<td></td>
<td>PIRIFORM</td>
<td>2.5</td>
<td>3.7</td>
</tr>
<tr>
<td>Superior gemellus</td>
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<td>20.8</td>
<td>5.4</td>
</tr>
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<td></td>
<td>45IR0</td>
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<tr>
<td>Obturator internus</td>
<td>30ADD90</td>
<td>17.1</td>
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<tr>
<td></td>
<td>45IR0</td>
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<td></td>
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<tr>
<td>Inferior gemellus</td>
<td>30ADD90</td>
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</tr>
<tr>
<td></td>
<td>45IR0</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>PIRIFORM</td>
<td>-4.3</td>
<td>4.6</td>
</tr>
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</table>

30ADD90 = 30° adduction from 90° of hip and knee flexion, 45IR0 = 45° internal rotation from a neutral anatomical position, 45ER90 = 45° external rotation from 90° hip and knee flexion, PIRIFORM = supine piriformis test.
positions that caused the greatest change in the short external rotators were 30° adduction from 90° of hip and knee flexion, 45° internal rotation from a neutral anatomical position, and 45° external rotation from 90° hip and knee flexion. The piriformis and SG had the greatest length change when adducting the hip 30° from 90° degrees of hip and knee flexion. The OI and IG had the greatest length change when internally rotating the hip 45° from neutral flexion/extension. These results have clinical implications for choices of the proposed stretches to effectively elongate the short external rotators of the hip in the clinical setting. Further studies are needed to validate the use of these stretches in patients who present with posterior hip and/or buttock pain.

REFERENCES


ABSTRACT

Background: Clinical testing to determine the presence of a cam morphology is becoming more common however the correlation between hip range of motion and the degree of cam morphology remains controversial in the literature. The prevalence of a cam morphology in athletes has been reported as higher than in the general population but the prevalence of cam morphology has not been reported in Australian Football (AF).

Purpose: The purpose of this study was to determine the correlation between hip range of motion and hip alpha angle and report the proportion of players with a cam morphology in a sample of AF players.

Design: Cross-sectional Study.

Methods: Twenty-one semi-elite AF players (42 hips) from the Peel Thunder Football Club were included in this study. A hip Flexion Internal Rotation (IR) test and a modified maximal squat test using the difference in depth of squat in hip internal and external rotation were used. These measures were then compared to alpha angles on 90 degree Dunn view x-rays.

Results: Four of the 42 hips (9.5%) had a cam morphology (alpha angle >60 degrees). There was no significant correlation between alpha angle and ROM in a Flexion IR test or the difference in modified maximal squat test depth within this sample of players.

Conclusions: The proportion of cam morphology seems to be lower in this sample than the previously reported prevalence in other sports. The lack of correlations between hip range and hip alpha angle in players means that screening hips using clinical measures to detect cam morphology associated with poor hip range of motion may be inaccurate.

Level of Evidence: Level 3a

Key Words: Femoroacetabular impingement syndrome, groin pain, range of motion, screening tests
INTRODUCTION

Anterior hip and groin pain is highly prevalent within some sporting populations. The hip joint is a possible source of symptoms for athletes who complain of anterior hip and groin pain. Hip related groin pain in young athletes is often attributed to Femoroacetabular Impingement Syndrome (FAIS). Cam morphology is the most common type of FAIS. Cam morphology likely develops during adolescence when the proximal femoral growth plate is open and there is some evidence to suggest this is correlated with training load(s) during this period. The implications of these morphologies are still not thoroughly understood, and cam morphology has been proposed as a risk factor of hip osteoarthritis.

In the 2013 Australian Football (AF) League season, 1.1 new injuries and 4.6 missed games per club were attributed to hip pathology. These figures decreased in 2014 to 0.3 new injuries and 0.8 missed games per club, and it is suspected that in part this drop is due to better detection and injury prevention programs.

Radiological findings of cam morphology have been reported previously as highly prevalent, with a recent systematic review reporting a prevalence of 5-75% across a variety of clinical populations. The prevalence appears to be specifically high in athletic groups, with cam morphologies evident in 72% of collegiate football players, 68% of elite soccer players and 75% of youth ice hockey players, however to date no studies have explored the prevalence of these radiological findings within an AF population. It has also been shown within semi-professional soccer players that the presence of cam morphology differs between the kicking and non-kicking legs however this has yet to be investigated in AF. Finally the prevalence of cam morphology also appears to be significantly related to ethnic backgrounds with white soccer players having a higher proportion of large cam morphology compared to their black counterparts.

Radiological examination is currently used to detect these morphologies, however screening to detect cam morphologies with clinical examination is becoming more common. Cam type morphology has been associated with decreased internal rotation (IR) of the hip and correlations between clinical testing of hip IR and the degree of cam morphology as measured by the alpha angle on x-ray have been reported as ranging from -0.35 to -0.59. However, a recent systematic review did not support differences in IR range between people with symptomatic FAIS and asymptomatic controls making uncertain the validity of clinical screening for these morphologies.

A plethora of clinical tests for FAIS were identified in a systematic review by Reiman et al. (2015). The Flexion Adduction Internal Rotation test (FADDIR) was the most commonly studied clinical test with a pooled sensitivity and specificity of 0.94-0.99 and 0.05-0.09 respectively, however the FADDIR is a test of pain provocation and does not provide a measure of hip range of motion. The second most commonly studied clinical test was the Flexion IR test with a pooled sensitivity and specificity of 0.96 and 0.25 respectively which is not only a test for pain provocation but also provides an objective measurement of hip IR. The only functional test identified was a maximal depth bilateral lower extremity squat which was reported by Ayeni et al. (2014) with a sensitivity and specificity of 0.75 and 0.41 respectively. The advantage of the Flexion IR test and the maximal squat test are that they both provide objective measures of range of motion which is important in screening procedures.

The lack of functional tests for FAIS has been previously reported in the literature with a maximal squat test being identified as the only functional test that has demonstrated evidence for use in screening for FAIS. Functional tests play an important role in the assessment of FAIS as FAIS has been shown to alter biomechanics during normal functional tasks such as walking and deep squatting when compared to controls. Functional tests help identify these impairments and hence enable clinicians to address them and return the normal function seen in controls.

If a correlation exists between decreased hip ROM and cam morphology, it would be expected that clinical examination of hip range of motion would be correlated with the degree of cam morphology on X-ray. Specifically increases in the alpha angle of the hip joint, which demonstrates the degree of...
bony cam morphology, should be correlated with a decrease in the hip joint ROM. The purpose of this study was to determine the correlation between hip range of motion and hip alpha angle and report the proportion of players with a cam morphology in a sample of AF players.

METHODS

Study Design
The study was a retrospective cross-sectional design as data collection was planned after both the index and reference tests had been performed.

Data Collection
All data were collected between November 2014 and February 2016 during two consecutive AF club seasons.

Participants
Participants were men competing in the semi-elite level West Australian Football League training three times per week and playing once per week. The sample included athletes with and without anterior hip and groin pain and all athletes who attended pre-season screening were included in the study (Figure 1).

Outcome Measures
Radiological testing (reference test) and physical testing (index tests) were completed as a part of routine club screening. Index tests were performed first, with the reference test being performed within the two weeks of the index tests. Radiological investigations occurred in a variety of radiological imaging centres by qualified radiographers and all imaging was performed with a standard protocol. Physical examination occurred at the football club in Mandurah by the club’s head physiotherapist (MM) who has postgraduate qualifications in sports physiotherapy and four years of experience. The 90 degree Dunn view radiograph was the reference test, with the index tests being the Flexion IR test and modified maximal squat test.

90 Degree Dunn View Radiograph
The reference test was a 90 degree Dunn view radiograph of both hip joints and was chosen due to being a recommended measure of detecting cam morphology.18 This view has a sensitivity of 91% and specificity of 88% for diagnosing cam morphology and was superior to other radiographs for detecting cam morphology.17 The 90 degree Dunn view also showed a Pearson’s correlation coefficient of 0.702 when compared to MRI in detecting cam morphology, which was superior to an anterior-posterior (AP) pelvis or cross table lateral radiograph.17 The 90 degree Dunn view x-rays of the hips were taken with the player supine on the table with the hip and knee flexed to 90 degrees and the hip abducted to 20 degrees.17,18 The cross hairs of the x-ray were directed mid-way between the anterior
superior iliac spine and pubic symphysis with the x-ray tube to film distance approximately 102cm in a line directed perpendicular to the table.\textsuperscript{17,18} The alpha angle was determined manually by measuring the angle between two lines as described by Barton et al.\textsuperscript{2011} (Figure 2).\textsuperscript{17} The first line was from the centre of the femoral head to the point on the anterolateral aspect of the head neck junction, where the radius of the femoral head first becomes greater than the radius found in the acetabulum.\textsuperscript{17} The second line is drawn through the centre of the femoral neck connecting to the centre of the femoral head. The alpha angle was determined manually by measuring the angle between the two lines.

Players were diagnosed with a Cam morphology if they had an alpha angle of greater than 60 degrees\textsuperscript{29} on the 90 degree Dunn view radiograph and the proportion with corresponding 95% confidence interval was determined from the sample.

\textbf{Flexion and Internal Rotation Test}

The Flexion IR test has been previously used to assess the degree of hip internal range of motion in FAIS.\textsuperscript{19}

\textbf{Modified Maximal Squat Test}

The modified maximal squat test is a test which involves a functional movement (squatting) in both a position of provocation and ease for participants with FAIS. Given hip flexion and IR is aggravating a squat in more IR was theorized to be more provocative and limiting for participants with FAIS. The test was performed in standing with players directed to stand with the medial aspect of heels 45cm apart adjacent to a fixed line and the posterior heel aligned on another fixed line. The medial aspect of the player’s 1st MTP joint was then aligned with a line either 20 degrees internally or externally rotated from the line the medial aspect of the heel was adjacent to. In the positions of 20 degrees internal and external rotation the players were asked to squat as deeply as possible (Figure 4) and a line was measured (cm) between the inferior aspect of the posterior superior iliac spine and the floor on both sides and then repeated three times. The mean squat depth in IR was then subtracted from the mean squat depth in external rotation to get the difference in squat depth. Intra-rater reliability was evaluated by repeat measure of 20 players three days following with an absolute ICC of 0.88 (95% CI: 0.73-0.95), SEM of 3.3cm and MDC of 9.1cm (Appendix A).

\textbf{Ethics Statement}

This study was approved by the Human Research Ethics Committee at Curtin University in Western Australia, Australia with the following approval number:
RDHS-205-15 and the subjects gave informed consent to the work. The declaration of Helsinki was followed and the rights of the players were protected.

**Power Calculation**

Power calculations for Pearson's and Spearman's correlations were performed with power set at 0.8 and significance set at 0.05. It was determined that to detect a correlation of 0.44, which has previously been demonstrated as the correlation between the hip alpha angle and a flexion IR test by Kapron et al. 2012 in collegiate football, that a sample of 38 hips were required.

**Statistical Analysis**

The mean of the left and right alpha angles, the mean of the left and right Flexion IR tests and the mean of the left and right maximal squat depth difference...
were determined. Statistical significance between sides of all participants and between asymptomatic and symptomatic sides of participants with symptoms were determined using unpaired t-tests. The correlation between the left and right alpha angles, the correlation between the left and right Flexion IR tests and the correlation between the left and right maximal squat depth difference were determined using Pearson’s correlation coefficients and corresponding 95% confidence interval. Finally, the correlation of the index tests and the reference tests was determined using Spearman’s correlation co-efficient, corresponding 95% confidence interval and statistical significance was determined. Statistical significance was set at 0.05. Data were analysed using IBM SPSS Statistics 22.0 (Chicago, USA).

RESULTS

Demographics
Participants were a mean of 21.1 (+/- 2.5) years old; 184 (+/- 7.4) cm tall; 78.1 (+/- 5.1) kg in weight, and had a mean BMI of 23.1 (+/- 1.2) kg/m².

Proportion of Players with Cam Morphology
Four of the 42 hips had a cam morphology with two players having bilateral cam morphology and no players having a unilateral cam morphology. Hence the proportion of hips in this sample with cam morphology was 9.5% (95% CI 3.8 to 22.1).

Differences between Index and Reference Tests between sides
The mean measurements for the alpha angle, flexion IR test ROM, and difference in modified maximal squat test depth of the entire sample are presented in Table 1. No significant differences were detected between sides.

The symptomatic players mean data for the alpha angle, flexion IR test ROM, difference in modified maximal squat test depth are presented in Table 2. No significant differences were detected between sides.

Correlation between Index and Reference Tests
Pearson’s r (95% CI) correlations between left and right hip measurements were $r = 0.81$ (0.59 to 0.92) for Flexion IR; $r = 1.00$ (0.99 to 1.00) for maximal squat difference; and $r = 0.98$, (0.94 to 0.99) for alpha angles. The Spearman’s rho (95% CI, p) between the Flexion IR and alpha angles (n=42) was 0.15 (-0.16 to 0.43, p=0.36) and is shown in Figure 5. After the removal of the players with cam morphology (n=38) the adjusted Spearman’s correlation co-efficient was 0.48 (0.19 to 0.69, p=0.002). The Spearman’s rho (95% CI, p) between the modified maximal squat test depth difference and alpha angles (n=42) was -0.25 (-0.51 to 0.06, p=0.11) and is shown in Figure 6. After the removal of the players

### Table 1. Index and Reference Tests.

<table>
<thead>
<tr>
<th>Number of players</th>
<th>Alpha Angle (degrees)</th>
<th>21</th>
<th>48.4 (11.6)</th>
<th>49.4 (10.3)</th>
<th>0.77</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion IR Test (degrees)</td>
<td>21</td>
<td>23.1 (11.3)</td>
<td>24.6 (11.1)</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td>Modified Maximal Squat Depth (cm)</td>
<td>21</td>
<td>27.3 (14.1)</td>
<td>27.4 (14.1)</td>
<td>0.97</td>
<td></td>
</tr>
</tbody>
</table>

IR= internal rotation

<table>
<thead>
<tr>
<th>Number of players</th>
<th>Symptomatic mean(SD)</th>
<th>Asymptomatic mean(SD)</th>
<th>Unpaired t-test (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha Angle (degrees)</td>
<td>4</td>
<td>50.0 (14.2)</td>
<td>48.8 (15.4)</td>
</tr>
<tr>
<td>Flexion IR Test (degrees)</td>
<td>4</td>
<td>14.2 (9.3)</td>
<td>25.2 (11.4)</td>
</tr>
<tr>
<td>Modified Maximal Squat Depth (cm)</td>
<td>4</td>
<td>22.2 (5.3)</td>
<td>23.2 (5.6)</td>
</tr>
</tbody>
</table>

Table 2. Symptomatic Players Index and Reference Tests.
with cam morphology (n=38) the adjusted Spearman's correlation co-efficient was -0.30 (-0.56 to 0.02, p=0.07).

**DISCUSSION**

This study aimed to examine the relationship between cam morphology and clinical tests as well as to determine the proportion of AF players with cam morphology. The prevalence of cam morphology was 9.5%, with no significant correlation between the size of cam morphology and performance on clinical tests.

Strong correlations were found when comparing the results of index and reference tests against themselves from left to right with no statistically significant differences between sides. The findings in the study differ with those reported previously in semi-professional soccer players, where some players had unilateral cam morphology. This suggests that within AF players, differences between cam morphology on the kicking and non-kicking leg are less common. These differences may be due to the variations in training load with differences in the proportion of kicking on the dominant and non-dominant legs during adolescence.

When comparing the symptomatic and asymptomatic sides there was no significant difference between groups which supports the results presented in the systematic review by Freke et al. 2016. However, there was a non-significant trend towards decreased hip IR on the symptomatic side, independent of the alpha angle, which has been reported previously by Tak et al. 2016 in professional soccer players. While not statistically significant having a mean difference of 11 degrees between symptomatic and non-symptomatic sides may be considered clinically significant. This difference may have become more apparent and been considered statistically significant if the sample had a higher proportion of athletes with anterior hip and groin pain and this is a limitation of the current study.

The results of this study failed to show a significant correlation between the alpha angle on radiographs and the degree of hip rotation in a Flexion IR test or mean difference in squat depth. Positive correlations existed between hip IR during a flexion IR test when compared to the alpha angle, but only after the removal of hips with cam morphology. These findings suggest that in players without cam morphology greater hip IR correlated to higher alpha angles. There was no correlation between the maximal squat test difference when compared to the alpha angle, even after the removal of hips with cam morphology. This lack of correlation further supports that cam morphology is not associated with a reduction in hip joint range of motion. It may also be possible that a non-linear relationship exists between clinical measures of hip range of motion and cam morphology, as cam morphology has been shown to have a binomial distribution. However, as only four hips had a cam morphology in this study, it was not possible to evaluate this supposition, and larger cohort studies are needed to investigate this further.
This study reported the proportion of hips with cam morphology within a sample of semi-elite AF players as 9.5% which sits inside the range reported in the systematic review by Dickenson et al. 2016.11 Interestingly however, the proportion of hips with cam type morphology observed using radiographs was substantially lower within this sample of AF players than what has previously been reported in other athletic populations such as collegiate football,12 soccer13 and ice hockey.14 These differences may, in part, be explained by a different alpha angle considered diagnostic of cam morphology as this study used an alpha angle of 60 degrees which is higher than other studies which have used alpha angles of 50-55 degrees.12-14 The justification for the use of an alpha angle of 60 degrees is Agricola et al. (2014) found a definite binomial distribution of the alpha angle, within two cohorts (n = 1002 and n = 1003 respectively), with a normal distribution up to 60 degrees indicating a clear distinction between normal and abnormal alpha angles.29 Large reductions in the prevalence can be observed with one study showing a reduction in the prevalence of cam deformity from 92% to 46% by changing the alpha angle cut off from 50 to 60 degrees.32 It has been shown that even by increasing the alpha angle cut-off from just 55 to 60 degrees a marked reduction in the prevalence of cam morphology from 30-61% to 17-47% is seen.31 A further reason for a smaller proportion of cam morphology in this sample may relate to only performing a single view radiograph, and including an AP radiograph may capture cam morphology in more participants.21 The smaller proportion of players with cam morphology within this sample may also relate to players having a lower frequency of training due to the current practices of Australian Football if a relationship between training and the development of cam morphology truly exists.5 6 Based on current training practices the players in this sample likely trained less than equal to three sessions per week before 12 years of age which may decrease the likelihood of developing a cam morphology.6

Finally, the small proportion of players with cam morphology may relate to small sample size and larger, prospective studies including more clubs are needed in this area to more realistically measure the prevalence of cam morphology within AF players. Larger, prospective studies are also needed to investigate the relationship between range of motion and structure to help inform clinicians on the validity of clinical assessment to the degree of cam deformity.

**CONCLUSION**

Hip IR range of motion and differences in squat depth performance tests did not correlate to the degree of cam deformity in AF players however further research is needed in a sample with a larger prevalence of cam morphologies to determine the role of functional testing in the diagnosis and management of athletes with FAIS. The proportion of cam morphology in this sample of semi-elite AF players was significantly lower than other sports.

**REFERENCES**

ABSTRACT

Background: Functional and structural asymmetries attributed to limb dominance are equivocal in soccer players. Previous authors hypothesize the existence of between-limb asymmetry secondary to the repetitive unilateral nature of kicking. However, symmetry is often present, particularly in measures of muscle strength.

Purpose: The purpose of the present study was to determine if lateral dominance is accompanied by corresponding between-limb asymmetries in a comprehensive assessment of body composition, muscle strength, and range of motion in healthy soccer players.

Study Design: Cross-sectional, observational.

Methods: 17 healthy male NCAA Division One collegiate soccer players participated (age 19.6±1.5 years; BMI 23.9±1.4 kg/m2). Footedness was attained via participant self-report. Lower limb muscle strength (hand held dynamometry), range of motion (goniometry), and body composition (dual energy x-ray absorptiometry scan) were measured. Lower-leg symmetry was analyzed comparing the dominant versus non-dominant limb using paired t-tests.

Results: Comparisons revealed no statistically different differences in outcomes, indicating remarkable symmetry in all measures of body composition, muscle strength, and range of motion (p>0.05) between the dominant and non-dominant lower limbs.

Conclusions: The authors speculate the prevalence of running versus kicking, the longitudinal effects of playing careers, and/or functional compensation attenuates the expected asymmetries in healthy male collegiate soccer players.

Level of Evidence: 2b

Key words: Bone density, footedness, lateral dominance, muscle strength, range of motion

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INTRODUCTION

Lateral dominance is the natural tendency for an individual to use one side of the body to complete tasks. In soccer, lateral dominance can be defined as footedness: the preferred foot for kicking the ball, and the limb that mobilizes through an open kinetic chain. A number of researchers have assumed between-limb asymmetry in soccer players as a product of unilateral kicking and greater repetition with the dominant limb. These previous hypotheses of expected asymmetry are logical: as an asymmetrical skill with unipedal posture, the dominant limb in soccer kicking displays greater ball velocity values and greater forces produced throughout the motion: pelvic rotation increases with faster kicks, suggesting the dominant limb experiences greater torque around the pelvis. Coupled with the different internal demands of the dominant mobilizing versus the non-dominant stabilizing limbs, a force production disparity between limbs likely exists. These potential asymmetries have been further linked to increased lower extremity injury risk.

In cohorts of professional soccer players, Daneshjoo et al. reported hip flexibility disparities between limbs while Oliveira et al. reported no differences in between-limb goniometric measures of hip flexion. Between-limb comparisons are most commonly measured by assessing muscle strength and torque. Idoate et al. reported non-dominant side hypertrophy of the rectus abdominis in professional players, which they speculate was stronger to provide for the stabilizing demands of the non-kicking limb. In elite soccer players, Aginsky and Neophytu reported greater hamstring strength and endurance in the dominant limb, agreeing with Blache and Monteil who concluded that greater dominant limb knee flexor and extensor strength existed at 40% and 60% maximal load in a sample of recreational players. On the contrary, Rahnama et al. found soccer players' dominant limb knee flexors to be weaker than the non-dominant limb. Despite discrepancies in which limb exhibits greater muscle strength, the existence of between-limb differences seems logical: the action of soccer kicking produces different force production between limbs as the dominant limb mobilizes and the non-dominant limb stabilizes. The non-dominant, stabilizing limb provides the foundation for the kicking motion, demanding actions of the postural musculature to enable the dominant, mobilizing limb to move forcefully to impact the ball. In addition to differing functions between the dominant and non-dominant limbs, the dominant limb is utilized more frequently and with improved coordination and intersegmental patterning for kicking tasks.

However, despite reasonable inferences to suggest that between-limb asymmetry exists, other authors describe symmetry with regards to muscle strength between the dominant and non-dominant limbs. Despite the inherent force production differences between limbs and greater repetition of kicking with the dominant limb, perhaps underlying mechanisms exist that can explain between-limb symmetry in soccer players as previously reported. For example, the utility of running in soccer may overshadow the unilateral repetition of kicking. Fousekis et al. suggests between-limb asymmetry diminishes later in a player's career, attributed to the athlete adopting a more balanced use of the lower extremities to attain high-level play. Perhaps, other factors in the kinetic chain have not yet been assessed and lower limb symmetry measures do not capture the full scope of the function of soccer players. The present study examines collegiate soccer players in an effort to assess individuals between youth and professional soccer and further examine the effect of soccer on between-limb symmetry.

The purpose of the present study was to determine if lateral dominance is accompanied by corresponding between-limb asymmetries in a comprehensive assessment of body composition, muscle strength, and range of motion in healthy soccer players. Classifying a cohort of healthy soccer players as symmetrical or asymmetrical can assist in describing appropriate baselines for health professionals to attain in rehabilitation; if between-limb asymmetry is common, then achieving rehabilitation to match the contralateral limb is an insufficient measure of return-to-play criteria. The authors hypothesized that the asymmetrical nature of kicking would elicit between-limb asymmetry in the present sample. The authors wished to clarify the conflicting reports of symmetry versus asymmetry in soccer players by examining collegiate players via comprehensive testing of body composition, muscle strength, and range of motion.
MATERIALS AND METHODS
Seventeen healthy male collegiate soccer players (height = 1.82 ± 0.07 m; mass = 79.0 ± 6.1 kg) volunteered to participate from a NCAA Division One program. The athletes self-identified as single-sport athletes in college with primary positions yielding four defenders, five midfielders, five forwards, and three goalkeepers. The participants were chosen by convenience sampling from the team’s pool of 29 players during preseason of the 2014 fall campaign and were all healthy by standard of availability for full participation in training. The Oakland University Institutional Review Board approved all methods and procedures and participants signed written informed consent before inclusion. All participants were tested for all measures in a single day in the university health building.

Footedness
The researchers explained to the athlete that footedness is the preferred limb to kick the ball during game play. Each participant verbally reported his dominant foot via personal preference to the researchers, herein referred to as self-reported footedness. Testers were blinded to participant footedness during data collection.

Symmetry measurements included body composition, muscle strength, and range of motion.

Body Composition
Body composition was measured via dual-energy X-ray absorptiometry (DXA; Hologic Discovery A, Boston, MA). All whole-body DXA scans were performed by a single technician following a standardized protocol procedure for a whole body scan. Both total body and regional analyses were calculated by the DXA scanner, as per the default settings inherent to this device.

Muscle Strength
Lower limb isometric muscle torque to serve as an indirect measure of strength was assessed using a handheld dynamometer (Lafayette Instrument Company, Model 01163 Lafayette, IN). Two research assistants performed muscle strength assessments using dynamometer placements as described by Bohannon. Ease of use with minimal training provides practicality for handheld dynamometry, with good intra-rater (ICC = 0.77 to 0.97) reported. One tester measured muscle strength at the hip (flexion/extension, adduction/abduction, internal/external rotation), while a second tester measured the knee (flexion/extension) and ankle (plantarflexion/dorsiflexion, pronation/supination). Three measurements were obtained, with the recorded value being the highest value of the three measurement attempts. All muscle strength values were recorded in kilograms.

Range of Motion
One research assistant performed testing using a manual goniometer and standard positions as recommended by Norkin and White. The investigators were trained and supervised by a licensed physical therapist who ensured that there were no substitutions on standard positions or measurements. Three measurements were obtained, with the recorded value being the highest value of the three measurement attempts. Areas of focus included joint mobility at the hip (flexion/extension, adduction/abduction, internal/external rotation), knee (flexion/extension), and ankle (plantarflexion/dorsiflexion, inversion/eversion).

Paired t-tests were utilized to assess differences in laterality when all participants were categorized into dominant side versus non-dominant limb. All participants remained eligible throughout, and there is no missing data to report. Statistical significance was set at \( p < 0.05 \). All analyses performed using STATISTICA version 12 software (StatSoft Inc., Tulsa, OK, USA).

RESULTS
Table 1 presents demographic data organized by right- and left-footedness and exemplifies the total participant pool demographic information.

The limited number of left-footed participants (n = 2) prevented adequate analyses of right-versus left-footed between-limb differences. Post-hoc analyses
of dominant versus non-dominant limb were considered. There were no significant differences in body composition as measured via bone mineral content (BMC), lean mass, or fat mass when considering the dominant and non-dominant limb (Table 2). Muscle strength trended toward the dominant limb having marginally greater values, except for hip external rotation (dominant = 42.3 ± 8.1 kg; non-dominant = 43.7 ± 8.5 kg) and foot supination (dominant = 31.6 ± 8.7 kg; non-dominant = 36.2 ± 10.1 kg); however, none of the differences were statistically significant (Table 2). Range of motion scores across all participants in all measured movements were not statistically significantly different (Table 2).

**DISCUSSION**

Despite expected asymmetries, the results of the present study instead demonstrate symmetry between limbs across all measures of body composition, muscle strength, and range of motion. Due to the symmetry found between limbs despite lower limb lateral dominance and the asymmetrical nature of soccer kicking, understanding why such symmetry may persist would be valuable to soccer research.

The present cohort is comparable to other studies on soccer players. Percent body fat reported for soccer players in prior research is consistent with 10.4 ± 2.8% from the present study: 10.5 ± 4.3%27 and 13.9 ± 5.8%.27 A study of NCAA Division One soccer players demonstrated similar height, weight, and body composition as the present study (presented as Silvestre et al.28; present data): height (1.78 ± 0.06 m; 1.82 ± 0.07 m), body mass (77.5 ± 9.2 kg; 79.0 ± 6.1 kg), total lean body mass (63.2 ± 4.9 kg; 66.9 ± 4.7 kg), and total fat mass (10.6 ± 5.8 kg; 8.2 ± 2.5 kg). The 15 right-footed and two left-footed subjects in the current study are similar to previous studies in the ratio of right: left dominance: 11:1,29 6:1,16 16:2 in youth players and 14:3 in professionals,6 and 13:2.13 Thus, the disproportionate participant pool of foot dominance in the current study is similar to most samples of soccer players, and is not a reason for the symmetry demonstrated. Further investigation into proposed theories as to why lower extremity symmetry exists in soccer players may be advantageous for organizing exercise protocols, injury rehabilitation, and performance enhancement.

**Symmetry Theory #1) Running > Kicking**

While high force production occurs during soccer kicking, it is not necessarily the primary movement throughout the course of a game or training session. Rampinini et al.30 reported ball involvements per 90 minutes as ranging from 34.5-44.7 involvements depending on team success. This is remarkably low when compared to the high incidence of running in soccer, where total distances per field player range 10-12 km per match.30 In a study of elite European professional teams, “high-intensity running” and “very high-intensity running” accounted for 2.7 ± 0.7 km and 1.0 ± 0.3 km of total distance covered.32 Prevalent high-intensity running, a crucial element for performance, may effectively outweigh the repetitive unilateral motion created by kicking. If the bilateral running movement facilitates the foundation of

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### Table 2. Dominant versus non-dominant limb results for body composition, muscle strength, and range of motion.

<table>
<thead>
<tr>
<th>Body Composition</th>
<th>Dominant (n=17)</th>
<th>Non-Dominant (n=17)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMC - Arm (g)</td>
<td>228.5±18.4</td>
<td>220±0.237</td>
<td>0.25</td>
</tr>
<tr>
<td>BMC - Ribs (g)</td>
<td>92.9±23.2</td>
<td>98.8±24.8</td>
<td>0.48</td>
</tr>
<tr>
<td>BMC - Leg (g)</td>
<td>638.4±54.8</td>
<td>648.7±60.1</td>
<td>0.61</td>
</tr>
<tr>
<td>Lean - Arm (g)</td>
<td>4471.9±371.7</td>
<td>4301.7±491.3</td>
<td>0.26</td>
</tr>
<tr>
<td>Lean - Leg (g)</td>
<td>11727.5±1008.1</td>
<td>11605.2±896.0</td>
<td>0.71</td>
</tr>
<tr>
<td>Fat - Arm (g)</td>
<td>525.3±162.2</td>
<td>510.9±159.0</td>
<td>0.80</td>
</tr>
<tr>
<td>Fat - Leg (g)</td>
<td>1750.3±705.9</td>
<td>1709.5±699.6</td>
<td>0.87</td>
</tr>
<tr>
<td>Muscle Strength</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip Extension (kg)</td>
<td>66.6±14.4</td>
<td>63.8±11.7</td>
<td>0.55</td>
</tr>
<tr>
<td>Hip Abduction (kg)</td>
<td>71.9±20.5</td>
<td>67.0±13.5</td>
<td>0.43</td>
</tr>
<tr>
<td>Hip Adduction (kg)</td>
<td>53.0±11.7</td>
<td>48.8±9.3</td>
<td>0.26</td>
</tr>
<tr>
<td>Hip Int. Rotation (kg)</td>
<td>35.3±9.3</td>
<td>35.2±8.8</td>
<td>0.98</td>
</tr>
<tr>
<td>Hip Ext. Rotation (kg)</td>
<td>42.3±8.1</td>
<td>43.7±8.5</td>
<td>0.64</td>
</tr>
<tr>
<td>Hip Flexion (kg)</td>
<td>66.0±14.0</td>
<td>62.1±9.7</td>
<td>0.27</td>
</tr>
<tr>
<td>Knee Flexion (kg)</td>
<td>65.0±8.6</td>
<td>61.3±6.3</td>
<td>0.18</td>
</tr>
<tr>
<td>Knee Extension (kg)</td>
<td>61.0±11.5</td>
<td>57.4±11.2</td>
<td>0.37</td>
</tr>
<tr>
<td>Ankle Dorsiflexion (kg)</td>
<td>48.5±5.0</td>
<td>47.6±5.2</td>
<td>0.63</td>
</tr>
<tr>
<td>Ankle Plantarflexion (kg)</td>
<td>49.7±9.6</td>
<td>46.4±8.5</td>
<td>0.32</td>
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<tr>
<td>Foot Pronation (kg)</td>
<td>28.0±7.4</td>
<td>27.3±7.5</td>
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<tr>
<td>Foot Supination (kg)</td>
<td>31.6±8.7</td>
<td>36.2±10.1</td>
<td>0.18</td>
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<tr>
<td>Range of Motion</td>
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<td></td>
</tr>
<tr>
<td>Hip Abduction (°)</td>
<td>31.9±9.7</td>
<td>34.7±8.6</td>
<td>0.38</td>
</tr>
<tr>
<td>Hip Adduction (°)</td>
<td>19.1±4.9</td>
<td>17.6±4.3</td>
<td>0.38</td>
</tr>
<tr>
<td>Hip Int. Rotation (°)</td>
<td>33.2±10.8</td>
<td>30.2±10.4</td>
<td>0.41</td>
</tr>
<tr>
<td>Hip Ext. Rotation (°)</td>
<td>37.9±10.1</td>
<td>39.1±10.4</td>
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</tr>
<tr>
<td>Hip Flexion (°)</td>
<td>96.3±6.2</td>
<td>99.4±6.9</td>
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</tr>
<tr>
<td>Knee Flexion (°)</td>
<td>132.6±7.3</td>
<td>133.7±7.2</td>
<td>0.67</td>
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<tr>
<td>Knee Extension (°)</td>
<td>179.2±16.6</td>
<td>180.1±2.4</td>
<td>0.22</td>
</tr>
<tr>
<td>Ankle Dorsiflexion (°)</td>
<td>7.4±5.8</td>
<td>7.0±5.1</td>
<td>0.86</td>
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<tr>
<td>Ankle Plantarflexion (°)</td>
<td>47.0±8.1</td>
<td>48.2±5.2</td>
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<tr>
<td>Foot Inversion (°)</td>
<td>34.5±9.8</td>
<td>31.9±9.4</td>
<td>0.44</td>
</tr>
<tr>
<td>Foot Eversion (°)</td>
<td>12.2±4.6</td>
<td>13.6±5.9</td>
<td>0.44</td>
</tr>
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</table>

BMC = bone mineral content
the sport, possible asymmetries created by kicking may be dominated and negated by running.

Asymmetries attributable to lateral dominance are apparent in athletes of other sports, but there have not been between-limb lower extremity studies outside of soccer. The authors citing asymmetries have primarily studied athletes in upper limb sports that do not contend with weight-bearing functions of standing and running. Volleyball players have reported with marked muscle and postural asymmetries, while tennis players have demonstrated skeletal asymmetry due to repetition of high intensity dominant limb motion. Without the responsibility of weight bearing, perhaps the upper limb is more susceptible to unilateral tissue adaptation. In soccer, running applies constant bilateral forces that may essentially negate lower limb asymmetry.

Symmetry Theory #2) Longitudinal Effect of Playing Time

Although expecting a longer playing career to result in the summation of asymmetrical kicking forces and subsequently greater lower limb asymmetries as proposed by Gur et al., other researchers suggest soccer players with longer professional careers presented with lesser lateral imbalances. This chronicity-dependent process is more sensible when considering the nature of high-level soccer: competence with the non-dominant limb is often necessary for success. If professional soccer facilitates bilateralism, as most players become serviceable with the non-dominant limb to perform at the highest levels, then subsequent between-limb symmetry is sensible. As players’ careers lengthen and the level of play heightens, the development of the non-dominant limb becomes more important. Furthermore, more qualified players display greater movement coordination and improved muscular activity differentiation in a sport that requires maximum efficiency of motor action. Despite inherent dominance to one side, perhaps elite soccer players demonstrate symmetry.

The present cohort, however, is not comprised of professional players, however, these were amateurs playing at the highest level of university soccer in the United States. Fousekis et al. reported an absence of asymmetry in players whose professional careers had continued for more than 11 years, however the present participants have not played professionally. Longitudinal information about length of playing careers was not obtained, but may have been useful; perhaps the youth careers of these players were in high-level environments, and the players developed non-dominant foot competence from an early age. Sport-specific development even from a young age can result in adaptations, greater psoas major cross-sectional area is displayed in early adolescent soccer players, while tennis players can develop structural asymmetries from a young age. Thus, the overall symmetry displayed by the present participants could coincide with the longitudinal effects of high level soccer extrapolated to the collegiate level. A longitudinal study of soccer athletes highlighting training logs and bilateral competence could help illuminate this theory of a chronicity-dependent soccer career working towards lower limb symmetry.

Symmetry Theory #3) Compensation for Dominant Limb Proficiency/Coordination

Functional compensation for lower limb differences in force production and function may allow symmetry to present itself despite underlying factors. While most literature on soccer kicking focuses on the lower limb, even noting hip flexion as the initiating motion, the entire kinetic chain is involved, including the spine and pelvis before moving the distal lower limb. The backswing phase requires lumbar spine rotation and extension to facilitate trunk rotation to the kicking leg; furthermore, the spine’s functional mechanism both stabilizes and balances the body during upright activity while also transmitting forces to the pelvis and then throughout the lower extremities. The spine, ever active in the weight-bearing lower limb, has even been acknowledged in a recent pilot study with kicking performance in soccer, demonstrating lumbar spine and sacroiliac joint manipulation provided short-term benefit for increased kicking speed. The asymmetric force distribution created by soccer kicking may not be directly visible within the lower limb; rather, may be referred proximally up the kinetic chain, with the spine receiving the majority of the stress and strain. Functional spinal compensation for unilateral force production during soccer kicking may be a possible explanation for lower limb symmetry in soccer players.
Limitations and Future Research

The limited sample size and lack of longitudinal player injury data impact the generalizability of the current study; however, further research should expand on these concepts. Longitudinal information about length of playing careers or playing levels was not obtained, but may be useful for expanding on Theory #2. Addressing only lower limb adaptations may be insufficient in viewing soccer players; perhaps, additional research considering the trunk and spine could illuminate factors further up the kinetic chain that impact symmetry or asymmetry. Future research should explore why symmetry may be present in soccer players despite inherent lateral dominance and varying between-limb force disparities from the kicking motion.

Previous authors have proposed that asymmetries are a characteristic adaptation in experienced soccer players despite growing evidence supporting between-limb symmetry in healthy players. In some cases, asymmetries in soccer players have been linked to increased injury risk. The growing evidence in favor of symmetry would solidify clinical advice that lower leg asymmetries are likely representative of a pathomechanical adaptation. Thus, sports medicine professionals should strive to preserve or achieve lower limb symmetry in range of motion, muscle strength, and body composition in male soccer players as a potential strategy to reduce or prevent injuries. The authors further propose that the identification of asymmetries by researchers and health professionals should be addressed in injury prevention and exercise prescription. Rather than assuming the presence of lower limb asymmetry in soccer players, future research should seek to understand why symmetry exists by addressing the proposed theories above.

CONCLUSION

No asymmetries existed in any of the measures tested in a cohort of Division I male soccer players including body composition, muscle strength, or range of motion. Thus, contrary to the authors’ hypothesis and in agreement with much of the literature, healthy male collegiate soccer players demonstrate remarkable lower limb symmetry. This symmetry prompted three speculative theories on how lateral dominance may be attenuated by other factors within playing soccer that warrant further investigation.

REFERENCES


ABSTRACT

Background: It is well known that eccentric and concentric exercise produce varied amounts of stress on the connective tissues. Diagnostic ultrasound has been used to measure these structural changes by observing fascicle length, angle, and thickness; however, there is a lack of evidence comparing the structural changes as it relates to eccentric, concentric, and stretching protocols.

Purpose: The purpose of this study was to compare the acute effects of static stretching, eccentric, concentric, and a combination of eccentric/concentric exercises on structural changes of the muscle tendon unit at the inferior patellar pole utilizing the diagnostic ultrasound.

Study Design: A repeated measures 2 x 4 within factorial study design with repeated measures on both factors was used to determine the differences in patellar tendon thickness within and between groups.

Methods: Forty-seven healthy subjects were screened for any lower extremity deficits or orthopaedic pathology. Forty-four (N=44) subjects completed all four protocols; the attrition was due to injuries to the lower extremity, occurring unrelated to the study. A baseline measurement of the anterior inferior patellar tendon was performed with the diagnostic ultrasound prior to each participant completing one of the four interventions per week over a four-week period. Interventions completed by each participant included static stretching, concentric, eccentric, and combined concentric and eccentric exercises. Immediately following each intervention, a post-intervention inferior patellar tendon measurement was recorded using the diagnostic ultrasound.

Results: Significant differences in anterior to posterior tendon thickness of the inferior patellar tendon were observed between pre (4.983 ± 0.041mm) and post (5.198 ± 0.055mm) measurements (p<0.0005) for the main effect of time. However, no differences in tendon thickness were noted comparing each intervention to one another (p=0.351).

Conclusion: Differences in tendon thickness were noted acutely for pre- to post measurements across all interventions. Further research is needed to determine if differences in tendon thickness exist with a longer duration of exercise over time and with different types of intervention.

Keywords: Diagnostic ultrasound, inferior patellar pole, jumping, patellar tendon

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INTRODUCTION
As healthcare professionals, it is essential to understand how various forms of exercise impact the structure of contractile tissues that are involved in the performance of a specific movement. More specifically, investigating the impact of various exercises on the structure of the patellar tendon will help clinicians select an effective intervention in treating pathologies of the knee such as patellar tendinopathy or jumper's knee. Tendinopathies are commonly seen in sports medicine settings with more than 30% of upper and lower extremity sports related injuries being associated with this pathology. Previous research has revealed that patellar tendinopathy creates activity-related anterior knee pain and jumping athletes can be at the greatest risk with repetitive loading to the knee. Patellar tendinopathy may continue to cause problems for years if proper treatment or therapy is not conducted.

Exercise-induced stress placed on connective tissue structures has been the topic of considerable research. It is well known that eccentric and concentric exercise produce altered amounts of stress on the connective tissues. As such, structural changes within the tendon have been shown to occur after exercise, especially after lengthy periods of time. Other authors have revealed that significant changes in tendon structure do not occur during the treatment period. These results, in addition to other research showing no correspondence to improvements in pain or function suggest that mechanism(s) other than structural adaptation may be responsible for clinical improvement during rehabilitation, although a discussion of these mechanisms is beyond the scope of this paper.

Successful results have been shown using eccentric exercise as treatment for chronic patellar tendon injuries with different protocols showing positive effects short-term and some long-term. However, a systematic review by Malliaras et al suggested performance of eccentric-concentric loading in conjunction with or instead of eccentric loading for Achilles and patellar tendinopathies.

Other research has investigated functional and symptomatic changes to connective tissues as a result of different modes of strengthening and stretching exercises. Diagnostic ultrasound has been used to measure these structural changes by observing fascicle length, angle, and thickness and allows for an immediate method to observe the effect of the intervention on the inferior pole of the patella. Duclay et al concluded that tendinous structures and muscular architecture were affected by a seven-week eccentric training exercise program. After training, the fascicle angle and thickness increased during rest and type of contraction, whereas the fascicle length increased only during rest and not with contraction. Visnes et al examined characteristics of jumper's knee and the inferior patellar pole in young athletes and found no difference in tendon thickness in athletes examined weekly following a 10 month training program. In other studies looking at risk factors and treatment for jumper's knee, the researchers concluded that eccentric contraction exercises are a viable option for treating this pathology. Biernat et al used ultrasonography to examine the structural changes of the patellar tendon during a rehabilitation protocol that consisted of eccentric exercise in competitive volleyball players and found that eccentric exercise can be effective when combined with functional exercises in treating patellar tendinopathy. Although studies have been conducted using diagnostic ultrasound to evaluate structural changes in various tendons and muscle-tendon units (MTUs), these studies have not compared different types of exercise and/or stretching. An increase in knowledge of structural changes is needed to aid healthcare professionals in rehabilitation of patients.

Though the effects of various types of exercise on connective tissue have been investigated, the effects of exercise comparing stretching as well as concentric and eccentric activities on the inferior patellar pole have yet to be clearly defined. The purpose of this study was to compare the acute effects of static stretching, eccentric, concentric, and a combination of eccentric/concentric exercises on structural changes of the MTU at the inferior patellar pole utilizing diagnostic ultrasound. The purpose of this study was to compare the acute effects of static stretching, eccentric, concentric, and a combination of eccentric/concentric
exercises on structural changes of the muscle tendon unit at the inferior patellar pole utilizing the diagnostic ultrasound.

METHODS

Research Design
A quasi-experimental study with a 2 x 4 within factorial design with repeated measures on both factors was used to determine the differences of patellar tendon thickness within groups. The study received approval by Western Kentucky University’s Institutional Review Board.

Subjects
A convenience sample of 47 healthy, generally active adults between the ages of 18 and 40 (21 males and 26 females) were recruited from Western Kentucky University’s Doctor of Physical Therapy Program. Out of the 47 healthy subjects that began participation in the study, 44 completed all four interventions (N=44) with a mean age of 25 and standard deviation of 3.4. The attrition was due to injuries to the lower extremity that occurred unrelated to the study.

Inclusion criteria included the ability to perform the required exercises, no musculoskeletal injuries, and the ability to speak English. Exclusion criteria included any previous lower extremity deficit or pathology. Pathologies included, but were not limited to, chronic tendinopathy, sprains or strains requiring orthopedic surgery, or any underlying chronic musculoskeletal impairment such as medically diagnosed osteoarthritis or active and tenderness to palpation Osgood Schlatter tibial tuberosities. All subjects were provided with an informed consent prior to participation in the study. The subjects were assigned de-identified case numbers and all documents were kept confidential.

During the study, participants were requested to avoid physical exercise including running, jumping, and lower extremity weight lifting for a period of 24 hours prior to the testing window, as well as during the testing procedure. Participants were also asked to avoid taking any nonsteroidal anti-inflammatory medication 48 hours before the testing period. Pre-measurements were taken before the intervention to focus on the effects of the intervention only, instead of possible external factors.

Instrumentation
Ultrasonographic images (UI) were captured using the MyLab25 Gold (Esaote, Indianapolis, IN). An inter-rater reliability value of 96.4% has been found when measuring the tendons attachment site at the bone. A single operator received a one-on-one course training from a certified operator from Easote using a linear array transducer functioning at a frequency of 10 MHz. An intra-rater reliability study was performed for the single operator resulting in an intraclass coefficient single of 0.725, which is representative of good reliability. Images were recorded under specific case numbers to blind the evaluator to the participant's images. The ultrasound operator evaluated images with software-based measurements from the MyLab25 Gold system for musculoskeletal images. The inferior patellar pole was used as a standard reference point for all images (approximately center of image, 2 cm of structure on each side) as this is a common site for repetitive micro-trauma to occur at the patellar tendon during activities that involve prolonged running or repetitive jumping.

Procedure
Testing was conducted in the University Medical Center Health Complex exercise lab with each participant having a 10-minute testing window. Each participant was asked to return each week at approximately the same time on the same day of the week as their initial session. Prior to beginning testing and interventions, each participant was screened for inclusion/exclusion criteria and demographic information (gender, height, weight, BMI) was obtained, along with informed consent. Baseline testing consisted of three measurements of the infrapatellar tendon using diagnostic ultrasound to produce UI. The baseline UI was taken with the participant in a supine position and the knee flexed to approximately 30 degrees. Images were taken of the tendon insertion point of the inferior patellar pole approximately 4 cm in length (2 cm of inferior patella, 2 cm of patellar tendon). The average of the three images was used as the baseline measurement for each participant.
After baseline UI measurements were conducted, the participant performed the randomized exercise intervention (stretching, concentric, eccentric, combination concentric/eccentric) depending on the phase of the study. Each researcher was assigned a specific role that was maintained throughout the study: intervention specialist, ultrasound operator, and recorder. The ultrasound operator was blinded to the assignment of interventions each participant performed.

**Exercise Protocol**

The exercise protocol consisted of one intervention per week targeting the right patellar tendon for a total of four weeks. Each week the participants randomly selected an intervention from the pool of unrepeated interventions until all had been completed. The interventions were listed on different pieces of paper and turned face down for participants to draw from. After an intervention was drawn it was eliminated from the choices during the next selection. The stretching intervention (Protocol A) consisted of three static stretches: standing quadriceps stretch, reclining quadriceps stretch, and kneeling quadriceps stretch (Figure 1). Each stretch was held for 30 seconds for three repetitions. The second intervention was a concentric exercise intervention (Protocol B): the participant was asked to jump to a maximum height off the right leg and land on the left leg. The participant was instructed to jump at maximal exertion for one minute. The third intervention was an eccentric intervention (Protocol C): the participant was instructed to jump to a maximum height off the left leg and land on the right leg at maximal exertion for one minute. The fourth and final intervention was a combination concentric/eccentric intervention (Protocol D): the participant was asked to jump to a maximum height off both legs and to land on both legs at maximal exertion for one minute. See Figure 2 for the flight phase of Protocols B-D.

Immediately following each exercise intervention, UI of the same tendon was performed as previously described for the baseline UI. Exercise protocol and UI were performed in the same location to ensure no delay in imaging for extraneous control. Baseline and post-exercise images were then evaluated for any structural changes that may have been produced by the exercise protocol (see Figures 3 and 4). A total of six images (three baseline, three post-intervention) were captured for each intervention to ensure accurate readings of the structural changes.

**Figure 1.** Protocol A. Image 1 - kneeling quad stretch, image 2 - reclining quad stretch, image 3 - standing quad stretch.
Averages were then taken from each of the three sets of images and used for the results.

**STATISTICAL ANALYSIS**

A 2 x 4 repeated measures ANOVA within factorial study design with repeated measures on both factors was used to determine the differences of the infrapatellar MTU thickness within and between groups utilizing the IBM SPSS version 22.0 (SPSS, Inc., Chicago, IL). Tendon thickness measurements were classified as ratio data. Mean demographic characteristics such as age, height, weight, and BMI were documented and summarized. All images recorded from the ultrasound machine were saved.
and stored onto a flash drive with each individual case file. Any missing data/images excluded the participant from the study.

RESULTS

Significant differences in anterior to posterior tendon thickness of the inferior patellar tendon between pre and post measurements $F(1,43)=34.435$, $p<0.0005$ were found for the main effect of time. The tendon thickness was greater at post measurements (mean = $5.19 \pm 0.055$mm) than at pre-measurements (mean = $4.983 \pm 0.041$mm) with an effect size of 0.895, as displayed in Table 1. However, no significant differences in tendon thickness were noted when comparing each intervention ($p=0.351$). Table 2 compares the results of pre- and post-measurements of stretching, concentric/eccentric, concentric, and eccentric exercise protocols. Protocol A (stretching) had a pre-measurement average of $5.02 \pm 1.047$mm and a post measurement average of $5.106 \pm 0.968$mm. Protocol B (concentric exercise) resulted in a pre-measurement average of $5.01 \pm 0.999$mm and post measurement average of $5.27 \pm 0.955$mm. Protocol C (eccentric exercise) produced a pre-measurement average of $4.97 \pm 0.928$mm and post measurement average of $5.15 \pm 1.096$mm. Protocol D (combination of concentric and eccentric exercise) resulted in a pre-measurement average of $4.93 \pm 0.903$mm and post measurement average of $5.21 \pm 1.007$mm.

DISCUSSION

The purpose of this study was to compare the effects of static stretching, eccentric, concentric, and a combination of eccentric/concentric exercises on acute structural changes of the muscle tendon unit (MTU) at the inferior patellar pole utilizing diagnostic ultrasound. The results suggest that there were no significant differences in tendon thickness when comparing each intervention. The findings agree with Kubo et al when comparing dynamic versus static training who found no differences obtained when observing the cross sectional area of the patellar tendon after dynamic and static training utilizing MRI. A study completed by Malliaras et al had similar results with change in patellar tendon stiffness and modulus being significantly greater when comparing all exercise groups to the control. However, no significant changes were found comparing eccentric training and concentric training.

Previous research has been performed using diagnostic ultrasound to compare structural changes in tendons. Utilizing diagnostic ultrasound, Visnes et al discovered that there was an increase in tendon thickness of the quadriceps and patella tendons of male athletes that went on to develop jumper’s knee.

Although previous studies looked at the differences of structural changes between stretching or a specific exercise protocol, there are no studies that have compared eccentric, concentric, and stretching. Samukawa et al showed no structural changes in tissues while investigating the effects of dynamic stretching on the muscle-tendon properties of the plantar flexors after stretching. Frizziero et al looked at the role of eccentric exercise as a treatment option to common sports injuries in the Achilles tendon. They found that, although there was no change to the thickness of the tendon, possible remodeling was taking place resulting in tendon healing. This conclusion was reached based on the premise that the use of eccentric contractions to treat the impairment and the length of time between interventions and tendon measures was sufficient to overcome the acute phase of tendon enlargement. McCreesh examined the vascular changes associated with an eccentric exercise program in a case report and determined that a reduction of vascularization and

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**Table 1.** Significant outcome measures via 2x4 repeated measures ANOVA for the main effect of time.

<table>
<thead>
<tr>
<th>Measures</th>
<th>Pre Mean</th>
<th>Post Mean</th>
<th>Effect Size</th>
<th>p value</th>
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<tr>
<td>Tendon Thickness (mm)</td>
<td>4.983</td>
<td>5.19</td>
<td>0.895</td>
<td>&lt;0.0005</td>
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</table>

**Table 2.** Pre and post measurements of tendon thickness for each intervention.

<table>
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</thead>
<tbody>
<tr>
<td>Mean (mm)</td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
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<tr>
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<td>5.015909</td>
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<td>5.268182</td>
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<tr>
<td>Standard Deviation (mm)</td>
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<td>0.999627</td>
<td>0.955224</td>
</tr>
</tbody>
</table>
accompanying nerve fibers actually improved the patient’s function.26

In an orthopedic physical therapy setting, the impact of concentric and eccentric exercise on tendon physiology can guide therapy choices for patient populations such as muscle strengthening using concentric exercises or treating tendonitis using high force eccentric exercises. In a sports or training setting it is also important to understand tendon response as it relates to muscle performance and exercise to determine appropriate protocol. Understanding the physiological effects of the connective tissues can provide a basis for conservative treatment that would benefit the individual the most. These physiological changes were addressed in the study conducted by Yin et al when looking at the microcirculation of the patellar tendon following eccentric exercise and how that circulation impacted tendon stiffness. They concluded that, following four rounds of eccentric exercise, microcirculation improved resulting in increased tendon flexibility.27

There are several limitations to the present study, one being the small sample size (N = 44). Further study would need to be completed with a larger and more diverse sample size to generalize the results to a larger population. Another limitation that may have involved tendon properties may be that the sample size was too homogenous. This could have resulted in a potential ceiling effect, since only normal subjects were observed in the study. The ultrasound operator may have had measurement errors as well. Another limitation may involve the procedure itself. Several factors are important when determining successful performance. For example, it was expected that subjects gave a maximal effort for each jump. Participants with previous training may be more experienced at the activities and perform at an optimal level compared to an individual with no athletic training or experience. It is likely that the subjects may not have felt prepared or skilled enough in the exercise to give a maximal effort or that there were individual differences in motivation levels and perspective to obtain maximal effort. This limitation is magnified by looking at the study conducted by Earp et al due to the change in tendon structure. Researchers examined the force conducting properties of tendons during different phases of the stretch shortening cycle (SCC) and how the tendon changed with varying loads. They concluded that with larger amplitude forces the tendons changed from a power amplifier at light loads to a rigid force transducer at higher loads.26 Also when dealing with participants’ maximum effort, it is important to understand the buffering principle of the patellar tendon in relation to the eccentric control of the quadriceps. Hicks et al concluded that during a low-intensity jump the muscular fascicles undergo greater lengthening than during a maximal jump in which the fascicles and tendons become stiffer.28 This change in tendon performance could possibly impact tendon structural integrity and should be investigated further.

Contrary to previous research involving numerous forms of concentric, eccentric, and stretching interventions in isolation, the current study compared various forms of exercise as they relate to an increase in tendon thickness. Although no significance differences were determined between the different interventions, this study provides a baseline for future research to further investigate the structural effects on tendon from stretching, concentric, eccentric, and a combination of concentric and eccentric exercises with chronic exercise over time and with different types of intervention. This is only a comparative study of four different interventions. The authors speculate that, since the duration of the study was only four weeks, there may be a potential increase in collagen overlay during this time, resulting in an increase thickness size of the MTU.

CONCLUSION

This study compared the effects of static stretching, eccentric, concentric, and a combination of eccentric/concentric exercises on structural changes at the MTU of the inferior patellar pole utilizing diagnostic ultrasound. Although there were no differences noted between exercise types, findings revealed acute, statistically significant changes in the thickness of the inferior patellar pole pre-to post exercise. This finding is clinically important for those individuals who engage in impact activities and for clinicians treating adverse conditions related to overuse. Further research is needed to determine the duration of acute effects of the various contractions and the chronic effects of structural changes of the inferior patellar pole.
REFERENCES


ABSTRACT

Background: Anterior cruciate ligament injury is higher in soccer athletes as compared to athletes of other sports. Risk factors for anterior cruciate ligament injury include low knee hamstring/quadriceps strength ratio and bilateral strength deficits.

Purpose: To investigate isokinetic thigh muscles strength, hamstring/quadriceps strength ratio, and bilateral strength comparisons in athletes who participate in professional soccer, futsal, and beach soccer.

Study Design: Cross-sectional study.

Methods: Brazilian professional soccer (n=70), futsal (n=30), and beach soccer (n=12) players were isokinetically assessed to examine strength of knee extensors and flexors at 60 degrees/second in concentric mode, to measure peak torque of dominant and non-dominant limbs.

Results: In the dominant limb, for extensors muscles, futsal players presented significantly lower peak torque values (223.9±33.4 Nm) than soccer (250.9±43.0 Nm; p=0.02) and beach soccer players (253.1±32.4 Nm; p=0.03). Peak torque for extensor muscles in the non-dominant limb was significantly lower in futsal (224.0±35.8 Nm) than in beach soccer players (256.8±39.8 Nm; p=0.03). Hamstring/quadriceps strength ratio for dominant limbs for futsal (57.6±10.1%), soccer (53.5±8.8%), and beach soccer (56.3±8.4%) players presented no significant differences between groups; however, the mean values were lower than recommended values found in the literature. There were no strength deficits for any of the evaluated groups when compared bilaterally.

Conclusions: Futsal athletes presented lower values for quadriceps strength than soccer and beach soccer athletes. Futsal, soccer, and beach soccer players presented no strength asymmetries, but they presented with strength imbalance in hamstring/quadriceps strength ratio.

Level of Evidence: 3

Key words: injury; isokinetic; muscle strength; performance; soccer
INTRODUCTION
Soccer is the most popular sport in the world, with an estimated 265 million active players. Performance depends upon a myriad of factors including technical, biomechanical, tactical, physiological, and musculoskeletal health. Furthermore, a low incidence of injuries is highly desirable in order to improve the team success.

Considering traditional soccer (hereafter referred to simply as soccer), beach soccer and futsal, the technical and skills principles used in all of the variations of the game remain the same as soccer. However, there are some differences between them, including: (a) futsal and beach soccer involve fewer players (four field players and a goalkeeper) and allow an unlimited number of substitutions, while soccer involves eleven players (ten field players and a goalkeeper) and a limited number of substitutions, giving futsal and beach soccer a more dynamic characteristic (players need to run more and faster); (b) futsal and beach soccer are played in a confined space within boards; in addition, each time the ball goes off to the side of the enclosure, a fault is marked, or a goal is scored, the timer is stopped. Together these characteristics make futsal and beach soccer a multiple-sprint sport (more high-intensity phases) that differs from soccer; (c) ball direction changes are faster in futsal and beach than soccer, which could impact knee joint demands; (d) match length differs between futsal (two periods of 20 minutes separated by a 10-min rest interval), beach (three periods of 12 minutes separated by 3-min rest intervals), and soccer (two periods of 45 minutes separated by a 15-min rest interval) and (e) there are differences in ball dimensions (~420g to beach and field soccer, and ~250g to futsal). In addition, there are major differences between beach soccer and futsal in terms of playing surface (unstable versus rigid), techniques (beach soccer requires more acrobatic actions), running speed (beach soccer players are unable to run at high speed) and jump height (lower maximum force and take-off velocity in beach soccer because of compliance and surface instability). Altogether, these differences can generate different physiological adaptations in athletes, especially in musculoskeletal system. Despite these different adaptations, the most frequent injuries in the three sports are those that affect the knees, ankles, and thighs. However, there are particularities in injury incidence associated with the three variations of the sport.

The incidence of knee injuries in soccer (18.8%) and in futsal (15.8%) is higher than in beach soccer (6.3%). On the other hand, thigh injury incidence in soccer (19.9%), futsal (13.9%), and beach soccer (24.3%) are similar. Risk factors, commonly perceived to be predictive of injury for knee or thigh injuries include: a decreased hamstring to quadriceps (H/Q) strength ratio, bilateral strength deficit, and muscular weakness, although most authors agree that single variables were inconsistently identified as associated factors.

H/Q strength ratio plays an important role in knee joint stability and it has been extensively used to examine functional ability, knee joint stability, and muscular balance between thigh muscles. Additionally, it has been shown that an imbalance in H/Q peak torque strength balance ratio correlates with a greater incidence of lower extremity injury, including anterior cruciate ligament (ACL) injuries. In addition, it has been suggested that muscular weakness and bilateral lower limb muscular strength deficits affect posture, sports performance, and increases hamstring strain rate. Thereby, in order to screen H/Q strength ratio and bilateral symmetry, it is common to assess athletes in the beginning of the season.

Given the different physical requirements, incidence of lower limb injuries and muscle strength demands in lower limbs, the above cited risk factors for knee or thigh injuries (strength balance and bilateral symmetry) may differ somewhat among the soccer variations (futsal, soccer, and beach soccer). To assess muscular strength profile, isokinetic testing has been used by clinicians and physical therapists. Several studies have been carried out to establish strength profiles in soccer players. However, only one study has investigated isokinetic strength in futsal players while none have been conducted in beach soccer players.

Thus, the main objective of this study was to investigate isokinetic knee muscle strength, H/Q strength ratio, and bilateral strength comparisons in professional athletes who participate in soccer, futsal, and...
beach soccer. It was hypothesized that athletes of different soccer variations would have a different isokinetic profile due to physiological, playing surface, biomechanical demands, and specificities.

METHODS

Participants

This study included 112 professional athletes who had been playing for at least five years, training regularly for five sessions per week and had no history of major lower limb injury or chronic disease. The sample of volunteers comprised soccer players (n = 70), futsal players (n = 30), and beach soccer players (n = 12). Anthropometric characteristics (age, height, and body mass) of the groups are presented in Table 1.

The soccer players were selected from professional teams in the city of São Paulo (Brazil), during the 2012 competitive season. All players participated in respective Brazilian official league championships (First Division). Participants were informed of the potential risks and benefits of the study and signed an informed consent form to take part in this study. All experimental procedures were approved by the University Human Research Ethics Committee (Federal University of São Paulo, Brazil) and conformed to the principles outlined in the Declaration of Helsinki.

Procedure: Isokinetic test

Before isokinetic testing, the participants performed a five-minute warm-up on a cycle ergometer (Cybex Inc., Ronkonkoma, NY, USA) at a resistance of 25 Watts, followed by low-intensity dynamic stretching exercises for the hamstring and quadriceps. After this period, concentric isokinetic torque (strength) of both knees was assessed.

Knee dominance was determined by asking the participants which limb they preferred to use when kicking a ball. The participants assumed a seated position on the isokinetic dynamometer (Biodex Medical Systems Inc., Shirley, NY, USA) with their hips flexed at approximately 85 degrees, and standard stabilization strapping was placed around the trunk, waist, and the distal femur of the limb being tested in order to minimize additional movement and ensure the same conditions for all participants. The axis of the dynamometer was visually aligned with the lateral femoral condyle while the knees were flexed at 90 degrees.

The length of the lever arm was set individually based on the length of the participant’s lower legs, and the resistance pad was placed proximal to the medial malleolus. Following direct measurement of the mass of the lower limb lever system at 30 degrees of knee extension, gravity correction procedures were applied according to the manufacturer’s specifications to reduce the risk of inaccurate data. The knee was tested from 5 to 95 degrees of knee flexion, with full knee extension considered 0 degrees, as previously described.

This range of motion was chosen to prevent injury, although maximal torque output is not altered by variations in the range of motion during isokinetic activity testing. For familiarization, the participants were given standard verbal instructions regarding the procedures and allowed several submaximal practice attempts. The participants then performed a maximum of five repetitions at an angular speed of 60 degrees/second and the results were stored for analysis. This angular speed was chosen as the lowest speed in order to avoid high joint pressure while producing the highest torque values, since there is an inverse relationship between isokinetic angular speed and load range.

Consistent verbal commands (e.g.: “As hard as possible” or “as hard and fast as possible”) were given by the examiner before each test to ensure maximal

Table 1. Characteristics of subjects.

<table>
<thead>
<tr>
<th>Soccer variation</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Body mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Futsal (n=30)</td>
<td>21.3±6.1</td>
<td>175.8±5.3</td>
<td>72.3±8.8</td>
</tr>
<tr>
<td>Soccer (n=70)</td>
<td>19.3±4.8</td>
<td>177.8±7.3</td>
<td>73.9±8.2</td>
</tr>
<tr>
<td>Beach soccer (n=12)</td>
<td>29.7±4.4</td>
<td>177.1±6.1</td>
<td>74.7±6.5</td>
</tr>
<tr>
<td>p-Value</td>
<td>&lt;0.0001</td>
<td>0.38</td>
<td>0.58</td>
</tr>
</tbody>
</table>

Data are expressed as mean±SD. Significant difference versus soccer and futsal soccer players.
was collected for the quadriceps and hamstring muscles of both lower limbs. Based on concentric hamstring and quadriceps peak torque values, H/Q peak torque ratios were calculated for each participant. To evaluate the influence of soccer modality and side on isokinetic variables, a 2x3 design side (D versus ND) and sport (soccer versus futsal versus beach soccer) ANOVA was used. Newman-Keuls post-hoc procedures were used to identify specific differences when significant interactions were present on the ANOVA test. In the absence of interactions, only main effects were analyzed. Statistical significance was set at an alpha of 0.05 for all statistical procedures. All statistical analyses were performed using the Statistica (version 7.0, Statsoft Inc., Tulsa, OK, USA) software package.

**RESULTS**

Table 2 shows the isokinetic muscular strength characteristics for the dominant (D) and non-dominant (ND) limbs with the mean values obtained for soccer, futsal, and beach soccer players. Regarding the D limb, absolute quadriceps concentric muscle peak torque values of futsal players were lower than those of soccer (p=0.02) and beach soccer (p=0.03) players, while there were no significant group differences in flexor muscle performance. Considering the peak torque values relative to body mass, the same differences can be seen. Futsal players values were lower than those of soccer (p=0.01) and beach soccer (p=0.04) players, while there were no significant group differences in flexor muscle strength.

<table>
<thead>
<tr>
<th>Soccer variation</th>
<th>Futsal (n=30)</th>
<th></th>
<th>Soccer (n=70)</th>
<th></th>
<th>Beach soccer (n=12)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dominant</td>
<td>Non-dominant</td>
<td>Dominant</td>
<td>Non-dominant</td>
<td>Dominant</td>
<td>Non-dominant</td>
</tr>
<tr>
<td><strong>Extensor muscles</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Peak torque (Nm)</td>
<td>223.9±33.4*† (169.2-284.7)</td>
<td>224.0±35.8† (157.4-299.7)</td>
<td>250.9±43.0 (152.0-364.7)</td>
<td>241.9±47.1 (148.5-384.7)</td>
<td>253.1±32.4 (207.2-299.2)</td>
<td>256.8±39.8 (169.8-316.6)</td>
</tr>
<tr>
<td>Peak torque/BM (Nm/kg)</td>
<td>3.1±0.3*† (2.2-4.0)</td>
<td>3.1±0.3† (2.4-3.9)</td>
<td>3.4±0.4 (2.5-4.4)</td>
<td>3.3±0.5 (2.1-4.7)</td>
<td>3.4±0.4 (2.9-3.9)</td>
<td>3.4±0.4 (2.5-4.3)</td>
</tr>
<tr>
<td><strong>Flexor muscles</strong></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak torque (Nm)</td>
<td>128.6±27.6 (79.4–191.0)</td>
<td>124.1±20.1 (88.7–161.4)</td>
<td>133.1±25.7 (59.6–187.7)</td>
<td>127.6±25.0 (77.4–184.4)</td>
<td>140.5±11.2 (117.8–156.6)</td>
<td>136.2±11.4 (116.8–153.1)</td>
</tr>
<tr>
<td>Peak torque/BM (Nm/kg)</td>
<td>1.8±0.3 (1.1–2.4)</td>
<td>1.7±0.2 (1.3–2.0)</td>
<td>1.8±0.3 (0.75–2.4)</td>
<td>1.7±0.3 (1.2–2.4)</td>
<td>1.9±0.2 (1.5–2.2)</td>
<td>1.8±0.1 (1.5–2.0)</td>
</tr>
<tr>
<td>H/Q ratio (%)</td>
<td>57.6±10.1 (37.9–90.4)</td>
<td>55.7±6.8 (46.9–77.9)</td>
<td>53.5±8.8 (27.4–76.5)</td>
<td>53.2±7.2 (36.8–71.2)</td>
<td>56.3±8.4 (42.3–67.7)</td>
<td>53.9±7.1 (46.1–68.9)</td>
</tr>
</tbody>
</table>

Data are expressed as mean±SD (min - max). BM= body mass; H/Q ratio= knee hamstring/quadriceps strength ratio
*Significant difference relative to soccer (p<0.05). †Significant difference relative to beach soccer (p<0.05).
Regarding ND limbs, absolute and relative quadriceps concentric peak torque values were significantly lower in futsal than in beach soccer (p = 0.03 and p = 0.04, respectively) players. In ND knee, there were also no significant intergroup differences in flexor muscle performance.

Table 2 also shows H/Q strength ratios for D and ND knees. There were no significant differences between groups for this measure. The percentage of athletes who presented knee imbalance, characterized by lower values than 60%, is presented in Table 3.

Regarding bilateral strength comparisions, no group presented significant difference, neither for extensor nor for flexors muscles. Futsal players had deficits of -0.32 ± 9.6% and 1.7 ± 14.5% for extensors and flexors muscles, respectively. Soccer players had bilateral strength deficits of 3.3 ± 11.2% and 4.2 ± 11.5% for extensor and flexor muscles, respectively. Beach soccer players had strength asymmetry of -1.7 ± 12.3% and 2.4 ± 11.4% for extensor and flexor muscles, respectively. Despite means values being lower than 15%, some athletes presented higher bilateral strength deficits. The percentage of athletes who presented bilateral strength deficit higher than 15% was presented in Table 4.

**DISCUSSION**

The main purpose of the present study was to compare isokinetic muscular strength parameters in competitive soccer, futsal, and beach soccer players. Concentric extensors peak torque was found to be higher in soccer and beach athletes compared to futsal players while there were no significant differences between groups for peak torque of knee flexor muscles or for H/Q ratio. Moreover, the three groups presented with symmetrical strength between dominant and non-dominant knee flexors and extensors muscles.

Lower concentric strength values for quadriceps muscles in futsal players could be expected because the match is played in a restricted space in which the kicks and passes are performed over shorter distances than in soccer. In the same way, Cheung et al. compared maximal isokinetic knee concentric flexion and concentric extension at 60 degrees/second and 300 degrees/second of field (soccer) and court sports players (basketball and volleyball) and found higher strength values for soccer players at both angular speeds. Comparing the current results with those of Cheung et al. higher peak torque relative to body mass values were found for the extensor muscles in soccer (present study: 3.4 ± 0.4 Nm/kg versus Cheung et al.: 1.89 ± 0.25 Nm/kg) and court soccer players (present study: 3.1 ± 0.3 Nm/kg versus Cheung et al.: 1.68 ± 0.24 Nm/kg). These results are expected since the soccer volunteers in the present study were professionals while those studied by Cheung et al. were drawn from college teams. On the other hand, the present results were similar to those reported in the study by Eniseler et al. in Turkish elite soccer players, Ardern et al. in Australian elite soccer players, and Ruas et al. in Brazilian south state soccer players comparing the peak torque of extensors and the flexors muscles.

In the present study, despite the lower quadriceps muscles peak torque observed in futsal versus soccer and beach soccer players and the absence of differences between flexor muscle strength for both limbs, there were no significant differences in H/Q ratio among the three groups studied. However, mean

<p>| Table 3. Number of athletes (percentage) who presented H/Q ratio lower than 0.6. |
|---------------------------------------------|------------------|------------------|------------------|</p>
<table>
<thead>
<tr>
<th>Soccer variation</th>
<th>Futsal (n=30)</th>
<th>Soccer (n=70)</th>
<th>Beach (n=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H/Q ratio ≤ 0.60 D</td>
<td>20 (67%)</td>
<td>56 (80%)</td>
<td>8 (67%)</td>
</tr>
<tr>
<td>H/Q ratio ≤ 0.60 ND</td>
<td>23 (77%)</td>
<td>58 (83%)</td>
<td>10 (83%)</td>
</tr>
<tr>
<td>H/Q ratio= knee hamstring/quadriceps strength ratio; D= dominant; ND= non dominant</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

<p>| Table 4. Number of athletes (percentage) who presented bilateral strength deficit higher than 15%. |
|-----------------------------|------------------|------------------|------------------|</p>
<table>
<thead>
<tr>
<th>Soccer variation</th>
<th>Futsal (n=30)</th>
<th>Soccer (n=70)</th>
<th>Beach (n=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bilateral deficit for extensor muscles</td>
<td>2 (6%)</td>
<td>10 (14%)</td>
<td>3 (25%)</td>
</tr>
<tr>
<td>Bilateral deficit for flexor muscles</td>
<td>9 (30%)</td>
<td>13 (18%)</td>
<td>3 (25%)</td>
</tr>
</tbody>
</table>
H/Q ratios values for D and ND limbs in futsal, soccer, and beach players were lower than 0.6, which has been traditionally associated with a higher incidence of knee injuries.\(^{38-43}\) Croisier et al\(^{26}\) showed that preseason thigh muscle strength imbalances put an athlete (football player) at 4.6 times increased risk of hamstring strain.

In this scenario, individual data analysis revealed lower values (≤60%) for D limbs in 80% of soccer, 67% of futsal, and 67% of beach soccer players, which indicates muscle strength imbalance and a possible predisposing factor for injury.\(^{26,39,44}\) In this study, H/Q ratios present a large variation between the athletes; in soccer players ranging from 27.4 to 76.5%, futsal players from 37.9 to 90.5%, and beach soccer players from 42.3 to 67.7%. Eniseler et al,\(^{38}\) Fousekis et al,\(^{31}\) Greco et al,\(^{45}\) and Ruas et al\(^{39}\) found higher H/Q ratio mean values for professional soccer players (range: 55 to 68%) than the values presented in the present study, however individual values were not reported. Previous authors have shown that introducing a specific hamstring strengthening program during soccer training is able to reduce the incidence of hamstring injuries.\(^{46, 47}\) Therefore, as the present study presented lower H/Q ratios for each of the three groups, the results highlight the need for hamstrings strength training programs for all the groups studied. Moreover, an individual evaluation should be conducted, before the injury risk reduction program is suggested because the H/Q ratios differed widely between the athletes in the same variation of soccer (e.g. the standard deviation was large).

On the other hand, it is important to note that the association between H/Q strength imbalance and hamstrings injury is not universally agreed upon in the literature. Dyk et al\(^{21}\) demonstrated only a small associations between lower hamstring eccentric strength and lower quadriceps concentric strength with hamstrings injury. However, lower limb muscle strength demands are sport-specific, which may indicate that H/Q ratio may differ somewhat between athletes from different sports modalities and competitive levels.\(^{40}\) In a previous study, a significant H/Q ratio difference has been demonstrated between judokas, handball players, and soccer players.\(^{23}\) In the study, male soccer players presented a mean H/Q ratio of 66%. However, the volunteers involved were not professional athletes. Those results suggested that younger athletes, or those not competing at elite levels, do not present with stronger quadriceps relative to the hamstring muscles, which is observed in elite athletes. Therefore H/Q ratio may be not only sport-specific, but also to each competitive level within that sport.

In addition to H/Q ratio, muscular bilateral asymmetry also has been considered a risk factors for lower limb injuries,\(^{26,39}\) and it also may affect sport performance.\(^{25}\) Specific motor demands of sports and training methods are a possible cause of muscular asymmetries and most soccer athletes had a preference for use of one lower limb over the other. Therefore, an analysis of bilateral strength asymmetry has been considered important to control and reduce injury risk.\(^{26}\) However, in the present study, athletes had no lower limb asymmetry, since bilateral strength deficit was lower than 10%. In a study of elite professional soccer players, Menzel et al\(^{15}\) also found low mean values for bilateral peak torque deficit (9.14±8.65%). Despite the low mean values of bilateral strength deficit found in volunteers of the present study (<10%), individual values ranged from -37% to 34%. Therefore, the fact that elite soccer, futsal, and beach soccer players presented symmetrical strength for the lower limbs does not preclude the need to conduct individual evaluations to identify this potential injury risk factor.

One potential limitation of this study was the age of the athletes. Beach soccer players were older than the other athletes. Nevertheless, this difference in age is expected since, generally, beach soccer teams are made up of former athletes from futsal and soccer and by players that have not turned professional in futsal or soccer. Another limitation of the study, is the lack of eccentric strength evaluation. Although H/Q concentric strength ratio measures may give an indication of muscle function and knee stability, they do not include the eccentric contractions involved in the kicking action, and so do not fully reflect muscle function during activity. During soccer actions, the agonist (quadriceps) muscles produce concentric movement to accelerate the limb forward, whereas the antagonist muscles (hamstrings) generate eccentric work to control (decelerate) this concentric movement, maintaining the joint dynamic stability. Finally, beach soccer (n = 12) and futsal (n = 30)
groups presented lower sample sizes than the soccer player group (n=70), which can be considered a potential weakness of the study. Therefore, the authors suggest that future studies, conducted with bigger sample sizes, could investigate the eccentric strength measure of hamstrings muscles and the functional strength ratio assessed by eccentric action of hamstrings and concentric action of quadriceps.

CONCLUSIONS
H/Q ratio did not differ significantly among soccer, futsal, and beach soccer players, while extensors muscles were stronger in soccer and beach soccer players than in futsal players. In the three soccer variations, mean values for H/Q ratio were lower than the recommended literature values. Injury risk reduction programs that utilize strength training for hamstring muscles can be useful to improve H/Q ratio. An individual strength evaluation to identify bilateral strength deficits or deficits in the H/Q ratio in the different soccer variations could help identify injury risk factors and establish injury risk reduction programs, resulting in less interruption of soccer training and competition. In addition, beach soccer is a relatively new sport for which no national professional leagues exist in many countries. Thus, future studies investigating other characteristics of beach soccer players are warranted.

REFERENCES


ABSTRACT

Background: An aberrant upper body posture has been proposed as one of the etiological factors contributing to the development of subacromial impingement syndrome (SAIS). Clinicians have translated this supposition into assessment and rehabilitation programs despite insufficient and conflicting evidence to support this approach.

Purpose: The purpose of this study was to compare several postural variables between the SAIS patients and asymptomatic healthy controls.

Study Design: Case-Control Study

Methods: A total of 75 participants including 39 patients (20 females; 19 males) and 36 healthy controls (15 females; 21 males) participated in the study. Study evaluated several postural variables including forward head posture (FHP), forward shoulder posture (FSP), thoracic kyphosis index (TKI), scapular index (SI), normalized scapular protraction (NSP), and the lateral scapular slide test (LSST). The variables were compared between patient and control groups according to sex.

Results: Significant differences were observed in the female patients compared to asymptomatic controls for the FHP (49.3° ± 9.6° vs 55.5° ± 8.3°, p = 0.03), FSP (45.5° ± 10.1° vs 53.6° ± 7.0°, p = 0.02), and LSST in third position (10.2 ± 2.1 cm vs 11.5 ± 0.7 cm, p = 0.01). Male patients showed a significant difference only in the FSP compared to controls (61.9° ± 9.4° vs 49.7° ± 9.2°, p < 0.001).

Conclusions: While inadequate data on the relationship between dysfunctional posture and SAIS has led to broad variations in current rehabilitation strategies, the results of the present study revealed different patterns of postural aberrations in female and male patients with SAIS. This clarifies the need to develop individualized or sex-specific approaches for assessing posture in men and women with SAIS and rehabilitation programs based on the assessment results.

Level of Evidence: 3b

Key words: Forward head posture, forward shoulder posture, movement system, postural assessment, scapular positioning, shoulder impingement, thoracic kyphosis
Subacromial Impingement Syndrome (SAIS) is one of the most common causes of shoulder pain affecting manual and sedentary workers as well as athletes.\(^1,2\) Individuals with SAIS present with insidious pain during overhead movements and arm elevation within the painful arc (70°-120° of abduction), leading to considerable functional incapacity. The underlying etiology of SAIS is multifactorial with symptoms triggered by both extrinsic and intrinsic factors including inflammation of the subacromial bursa, rotator cuff tendon degeneration, weak or dysfunctional rotator cuff and scapular musculature (muscle imbalances), aberrant activation patterns of shoulder girdle muscles, and postural dysfunction of the spinal column and scapula.\(^1,3\) The condition is more common in athletes where altered activation patterns, scapular dyskinesis, and muscle imbalances involving key postural muscles (upper, middle, lower trapezius and serratus anterior) are frequently observed.\(^4,5\)

Upper body postural dysfunction (i.e. alteration in the alignment of the head, neck, shoulders and thoracic spine) has been suggested as one of the key underlying factors in association with the SAIS. Previous authors have suggested that aberrant upper body posture (i.e. increased thoracic kyphosis together with a forward shoulder posture) results in the narrowing of subacromial space and prompts tendon inflammation/tendon degeneration and upper limb movement dysfunction due to mechanical compression.\(^6-11\) Hence, assessment of upper body posture has received considerable attention in order to facilitate developing enhanced management strategies for the SAIS.\(^7,12,13\) While postural alterations can occur independently within thoracic and cervical spine, shoulder, and scapula, they are typically linked together leading to aberrant and dysfunctional upper body alignments. Common postural alterations within the sagittal plane include increased forward head posture (FHP), forward shoulder posture (FSP), and thoracic spine kyphosis. Figure 1 provides a schematic presentation of potential pathways through which an aberrant posture may progressively contribute to the development of SAIS. These aberrant alignments are suggested to particularly influence scapular kinematics and produce dysfunctional postural adjustments with detrimental effect on the pressure and dimensions of the subacromial space.\(^11,14-16\)

The majority of researchers have used common methods, accessible in clinical practice, for fast yet reliable quantitative assessment of static upper body posture in SAIS patients. The results have however been conflicting. Using bony landmarks as reliable markers and taking into account the physical appearance of the head, neck and shoulders as principal characteristic of human posture, several researchers have identified postural differences between patients with asymptomatic and symptomatic shoulders.\(^9,17,18\) Despite these reports of differences in upper body posture between asymptomatic and symptomatic subjects, it is not possible to determine whether these altered postures have an etiological relationship with the SAIS or occur as consequences of underlying pathology. Lewis et al, evaluated postural variables including FHP, FSP and...
scapular protraction in 60 asymptomatic subjects and 60 subjects with SAIS and highlighted limited role of these factors in the clinical decision-making process.\textsuperscript{7,8} Ratcliffe et al, conducted a systematic review and reported insufficient evidence to support the role of aberrant posture in the pathogenesis of SAIS potentially due to the complex and multifactorial nature of SAIS and lack of consistency between study methodologies.\textsuperscript{10}

Considering contradictory reports, more research is needed for the identification of aberrant postural adaptations in SAIS patients in order to facilitate the implementation of assessment-driven targeted interventions. Hence, the purpose of this study was to compare several postural variables between the SAIS patients and asymptomatic healthy controls.

**METHODS**

**Participants**

The study received ethical approval from a local research ethics committee and all participants gave their written consent prior to participation. A total of 75 controls and patients with SAIS participated in the study: 1) the control Group included 36 healthy volunteers (15 female, 21 males); with normal upper limb clinical assessment and no history of upper extremity painful conditions or surgery; 2) the patient group was comprised of 39 participants (20 females, 19 males) who were diagnosed and recruited through a specialized Upper Limb Orthopaedic Unit overseen by a leading orthopaedic surgeon. Participant demographics are summarized in Table 1. All patients presented with persistent shoulder pain for at least 12 weeks (average pain duration: 15 months, range 7 – 30 months) and a range of positive clinical tests.\textsuperscript{19} Patients with at least three positive tests (3/5) were included in the SAIS groups.\textsuperscript{20} The patient exclusion criteria included receiving treatment other than pain relief medication during the last three months, positive imaging (rotator cuff tear, instability, and osteoarthritis), hypermobility syndrome, and systemic diseases affecting the function of neck, back, or upper extremity. The same experienced clinician (senior orthopaedic surgeon/PhD fellow) located the specific bony landmarks during postural measures, and performed all assessments in order to enhance the measurement accuracy.\textsuperscript{21}

**POSTURAL MEASUREMENTS**

**Measurement Protocol**

Subjects stood 30cm in front of a plumb line hanging from the ceiling and 20cm away from a wall on their side while assuming their normal posture. Non-allergenic adhesive markers were placed on following bony prominences (Figure 2): 1) posterolateral angle of the acromion (A); 2) root of the spine of the scapula (B); 3) inferior angle of the scapula (C); 4) thoracic spinous process levelled with acromion's posterior-lateral angle (D); 5) thoracic spinous process corresponding to the root of scapula spine (E); 6) thoracic spinous process corresponding to the scapula's inferior angle (F); 7) ear tragus (G); 8) C7 spinous process (H); 9) mid-point of the humeral head half-way between the acromion process and posterior acromial angle and 4 cm downward on the lateral aspect of the shoulder (I); 10) mid-point of the sternal notch (J); and 11) tip of the coracoid process (K). Five postural variables were measured for each participant: 1) forward head posture (FHP); 2) forward shoulder posture (FSP); 3) normalized scapular protraction (NSP); 4) thoracic spinous process levelled with acromion's posterior-lateral angle (D); 5) thoracic spinous process corresponding to the root of scapula spine (E); 6) thoracic spinous process corresponding to the scapula's inferior angle (F); 7) ear tragus (G); 8) C7 spinous process (H); 9) mid-point of the humeral head half-way between the acromion process and posterior acromial angle and 4 cm downward on the lateral aspect of the shoulder (I); 10) mid-point of the sternal notch (J); and 11) tip of the coracoid process (K). Five postural variables were measured for each participant: 1) forward head posture (FHP); 2) forward shoulder posture (FSP); 3) normalized scapular protraction (NSP); 4) thoracic spinous process levelled with acromion's posterior-lateral angle (D); 5) thoracic spinous process corresponding to the root of scapula spine (E); 6) thoracic spinous process corresponding to the scapula's inferior angle (F); 7) ear tragus (G); 8) C7 spinous process (H); 9) mid-point of the humeral head half-way between the acromion process and posterior acromial angle and 4 cm downward on the lateral aspect of the shoulder (I); 10) mid-point of the sternal notch (J); and 11) tip of the coracoid process (K). All measurements were repeated three times and average calculated and used during analysis.

| Table 1. Participant demographics presented as Mean (SD) for Control and Patient Groups |
|-----------------------------------------------|-----------------------------------------------|
| Control Group | Patient Group |
| Male N=21 | Female N=15 | All N=36 | Male N=19 | Female N=20 | All N=39 |
| Age | 47.6 (10.3) | 42.9 (9.3) | 45.8 (10) | 54.2 (8.1) | 55.5 (5.3) | 54.9 (6.7) |
| Height | 172.4 (10) | 168.4 (7) | 170.9 (9) | 173.8 (9.7) | 161.3 (7.1) | 167.4 (10.5) |
| Weight | 76.8 (12.6) | 69.1 (8.6) | 73.9 (11.7) | 83.6 (11.7) | 78.0 (15.6) | 80.7 (13.9) |
FHP and FSP
A lateral photograph was taken from the cervicothoracic region using a digital Sony Camera with a 28- to 50-mm adjustable lens and set at 100 ASA mounted on a levelled tripod placed two meters from the participant. The C7 marker was placed approximately in the centre of the lens to eliminate lens error. The base and front of the camera were parallel to the ground and the facing wall, respectively to minimise parallax error. FHP and FSP angles were determined as the angle between the ear tragus and the midpoint of the shoulder with the C7 spinous process (α and β, respectively) (Figure 2-middle). A high intratester reliability has been reported for this measurement method.

Thoracic Kyphosis Index (TKI)
Thoracic spine curvature was measured in standing position by placing the flexible ruler between C7 and T12 aligned to the curve of the spine. The ruler was then marked at C7 and T12 and placed flat on paper: a straight line was drawn from the ruler position of C7 to T12 to determine the length of thoracic kyphosis and a perpendicular line from the highest point in the thoracic curve to the point at which it intersected the straight line drawn from C7 to T12 to determine the height of thoracic kyphosis. The depth of the curve was divided by the height of the curve to determine the TKI (%) (Figure 3). Both high intrarater and interrater reliability have been reported in association with the TKI.

Normalized Scapular Protraction (NSP) and Scapular Index (SI)
Using a measuring tape, the distances AE and A’E then AB and A’B’ were measured and the NSP at each side was calculated as AE/AB and A’E/A’B’ (Figure 2). This normalization process reduced the impact of individual body size on results. A larger NSP value indicates a more protracted scapula. The SI or also referred to as pectoralis minor index (PMI) was measured as the distance from the mid-point of the sternal notch (J) to the medial aspect of the coracoid process on each side (K, K’) and the horizontal...
distance from the posterolateral angle of the acromion on each side (A, A') to the thoracic spine (D) were measured (Figure 2). The SI was calculated as a potential clinical indicator of pectoralis minor influence on scapular position, using the equation:

\[
\frac{[J \text{ to } (K)]}{(A \text{ to } (D))} \times 100
\]

and

\[
\frac{[J \text{ to } (K')]}{(A' \text{ to } (D))} \times 100
\]
on the right and left sides, respectively. Both tests have been associated with sufficient reliability in human cadavers, but their in-vivo reliability has not yet been addressed.

The Lateral Scapular Slide Test (LSST)

LSST is a reliable objective measure of scapular position determined as the distance between the inferior angle of each scapula (points C, C') and the nearest thoracic spinous process (point F) (Figure 2). Measures were taken in three different positions: 1) LSST1: arms placed at sides in resting anatomical position (Figure 4A); 2) LSST2: hands resting on hips with the fingers pointing anterior and the thumbs pointing posterior (Figure 4B); and 3) LSST3: arms abducted 90° with full shoulder internal rotation (thumb to floor) (Figure 4C).

Data Analysis and Statistics

Descriptive statistics for six postural variables (FHP, FSP, TKI, NSP, SI, LSST) are reported separately for female and male groups of patient and controls as mean ± standard deviation (SD). The Shapiro–Wilk's test was applied to determine normal distribution assumption of the quantitative variables. To determine differences between patient and healthy groups, variables with a normal distribution were analyzed with parametric independent sample t-test, whereas data without a normal distribution were analyzed with the nonparametric Mann-Whitney U test. The level of significance was set at p<0.05. The SPSS statistical package (Version 20.0; IBM, Armonk, NY, USA) was used for analysis and modeling of the data.

RESULTS

Postural variables were measured in 36 healthy volunteers and 39 SAIS patients during this study. There was no difference in the demographics between controls and patients for either gender. All patients had at least three positive tests: Painful arc, Neer's, Hawkins, Empty Can, and Full Can tests were positive in 95%, 86%, 81%, 71%, and 52% of female patients; and 88%, 81%, 81%, 73%, and 46% of male patients, respectively. Table 2 presents and compares the values of all of the postural measurements in the female and male patients and controls. In females, significant differences (p<0.05) were detected between SAIS patients and controls for FHP, FSP, and LSST3. Regarding males, a significant difference was observed only for the FSP (p<0.05). The differences in the majority of postural

Figure 4. Measurements of Lateral Scapular Sliding Test. A) Arm at the side standing in dependent position; (B) Arm abducted with hand resting at hip with thumbs posterior; (C) Arm abducted 90° with full shoulder internal rotation. “Used with permission of The International Journal of Sports Physical Therapy, formerly known as The North American Journal of Sports Physical Therapy.”

The International Journal of Sports Physical Therapy | Volume 12, Number 7 | December 2017 | Page 1115
measurements between the compared male groups were generally small and not significant.

**DISCUSSION**

Despite over 90% of SAIS patients being managed conservatively, the broad variation in the existing therapeutic strategies indicates a need for more individualized and tailored approaches. Clinicians commonly believe that aberrant upper body posture potentially leads to the impingement of supraspinatus tendon against the anterior portion of the acromion process. This has been widely translated into clinical practices to inform patients of the role of poor posture in the development of SAIS, to underpin postural assessments, and to rationalize rehabilitation strategies. Unfortunately, research studies investigating postural alterations in SAIS have reported conflicting findings.

The results of the present study identified multiple postural alterations in female patients with SAIS, including greater FHP, FSP, and LSST (LSST3) compared to only greater FSP in male patients. Increased FHP and FSP are considered potential clinical indicators of faulty posture due to altered scapular positioning. The scapula provides a stable base for efficient function of the rotator cuff and other muscles crossing the glenohumeral joint in individuals with good upper body posture. Furthermore, altered scapular kinematics and muscle activation patterns reported by motion analysis and EMG studies in asymptomatic individuals with increased FHP and FSP have suggested a subsequent mechanical impact on subacromial space. Persistent FHP leads to shortening of the posterior neck extensors, tightening of the anterior neck and shoulder muscles with subsequent impact on normal scapular position and kinematics. Abnormal scapular orientations can then alter the activation of the stabilizing muscles such as levator scapulae and upper trapezius muscles as well as the mobilizing muscles such as pectoralis minor. Continuous FSP causes adaptive shortening and tightness of the anterior musculature such as the pectoralis minor resulting in increased scapular anterior tilt, internal rotation, and downward rotation. These scapular patterns associated with FSP would depress the acromion, restrict clearance of subacromial space, and increase the pressure on subacromial soft tissues leading to painful shoulder elevation, restricted motion, weakness, and functional disability.

<table>
<thead>
<tr>
<th>Postural Measurement</th>
<th>SAIS Patients</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td><strong>Females</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FHP (°)</td>
<td>49.3</td>
<td>9.6</td>
</tr>
<tr>
<td>FSP (°)</td>
<td>45.5</td>
<td>10.1</td>
</tr>
<tr>
<td>NSP (%)</td>
<td>161.0</td>
<td>8.7</td>
</tr>
<tr>
<td>SI (%)</td>
<td>70.5</td>
<td>6.7</td>
</tr>
<tr>
<td>TKI (%)</td>
<td>10.4</td>
<td>2.9</td>
</tr>
<tr>
<td>LSST (cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- LSST1 (Position 1)</td>
<td>8.8</td>
<td>2.0</td>
</tr>
<tr>
<td>- LSST2 (Position 2)</td>
<td>9.6</td>
<td>1.9</td>
</tr>
<tr>
<td>- LSST3 (Position 3)</td>
<td>10.2</td>
<td>2.1</td>
</tr>
<tr>
<td><strong>Males</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FHP (°)</td>
<td>52.5</td>
<td>5.9</td>
</tr>
<tr>
<td>FSP (°)</td>
<td>61.9</td>
<td>9.4</td>
</tr>
<tr>
<td>NSP (%)</td>
<td>157.0</td>
<td>9.9</td>
</tr>
<tr>
<td>SI (%)</td>
<td>75.6</td>
<td>8.3</td>
</tr>
<tr>
<td>TKI (%)</td>
<td>11.8</td>
<td>2.1</td>
</tr>
<tr>
<td>LSST (cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- LSST1 (Position 1)</td>
<td>9.7</td>
<td>1.5</td>
</tr>
<tr>
<td>- LSST2 (Position 2)</td>
<td>10.9</td>
<td>2.0</td>
</tr>
<tr>
<td>- LSST3 (Position 3)</td>
<td>11.6</td>
<td>1.2</td>
</tr>
</tbody>
</table>

FHP= Forward Head Posture; FSP= Forward Shoulder Posture; NSP= Normalized Scapular Protraction; SI= Scapular Index; LSST= Lateral Scapular Slide Test; TKI= Thoracic Kyphosis Index.

**Bolded values** indicate statistically significant differences.
Other researchers have reported opposing results. In a study of 60 controls and 60 SAIS patients, Lewis et al.,7 reported no relationships between various postural components including FHP and FSP. They attributed this to large individual variations and challenged the hypothesis that posture and resultant muscle imbalance play an etiologic role in the pathogenesis of SAIS. McClure et al.,40 assessed FSP using goniometrical indicators of scapular posture combined with electromagnetic motion analysis of the shoulder kinematics in 45 patients with SAIS and 45 asymptomatic participants and found no correlation between SAIS and FSP. However, none of above studies, reported gender-specific results.

Despite suggestions from the biomechanical studies that increased thoracic kyphosis may increase compression under the acromion and subacromial tissues due to scapular dyskinesis,41,42 no differences in thoracic spine curvature and TKI were found in the present study between SAIS patients and controls. This is agreement with the results of previous studies which failed to establish a direct etiologic link between increased thoracic kyphosis and development of SAIS even in the presence of altered FHP and FSP. A study of 160 asymptomatic subjects failed to support an association between increased FHP and FSP and increased thoracic curvature.33 The results of an epidemiologic study of 2144 normal participants did not demonstrate a direct association between thoracic curvature and SAIS, and the authors of that study suggested that thoracic kyphosis may only play an indirect role in the development of SAIS by reducing shoulder elevation which would be induced by restriction in thoracic spine extension and scapular dyskinesis.43 A strong correlation reported between thoracic kyphosis and age suggests that kyphosis may have a more prominent role in the development of SAIS in during aging, particularly in females due to their anatomical and physiological disadvantages.44

The present study evaluated scapular positioning in the coronal plane by means of SI, NSP, and LSST. The SI and NSP are related to anterior/posterior tilting of the scapula and provide helpful information regarding scapular protraction and function of surrounding muscles.26 Scapular protraction is indicative of alterations in pectoralis minor length and individuals with a shortened muscle demonstrate scapular kinematics similar to those seen in SAIS patients.16,45,46 It has been theorized that shortening of the pectoralis minor could lead to the narrowing of the subacromial space due to lack of posterior tilting.45 Consistent with previous studies, the current results indicated no difference in the SI and NSP of SAIS patients of either gender.26,32

Current research on LSST has challenged the reliability and specificity of the original technique described by Kibler.5,47 Hence, the present study used a more reliable measure compared to the original technique by means of the distance between inferior angle of the scapula and thoracic spinous process at the same level for comparisons with controls at each position.28,30 The only significant alteration in LSST was observed in female patients when the affected arm was abducted to 90° (LSST3). Among the three LSST positions with graded functional difficulty, only LSST3 provides an active challenge for the muscles involved in stabilizing the scapula.8 EMG studies report a small number of scapular muscles (serratus and lower trapezius) being activated at low levels during the first two positions, but LSST3 is associated with a noticeable activation of the upper and lower trapezius, serratus, and rhomboids.48,49 Thus, the LSST3 utilizes a more functional (although still static) position of the shoulder complex in which a major contribution from the scapular stabilizers is crucial for the stabilizing and accurate positioning of the scapula. Hence, in SAIS patients with underlying scapular dyskinesis it could be expected that scapula positioning would change when going from the first to the third position due to an increasing demand for the contribution of stabilizing muscles in controlling the retraction and upward rotation of the scapula. It is also possible that excessive scapular protraction combined with other postural abnormalities in female patients (i.e. increased FSP and FHP) could restrict scapular upward rotation during shoulder abduction in the range of 60°-90° and reduces subacromial space clearance. Lewis et al6 evaluated the impact of scapular taping in SAIS patients and reported a significant effect on glenohumeral range of motion but not on pain experience. While it has been suggested that maintaining the shoulder position at around 90° would minimize the effect of pain-related muscle inhibition by avoiding the position.
of impingement,\(^5\) it is still likely that LSST3 alterations could be partially the result of pain-avoidance phenomenon as the arm is abducted in an internally rotated position.\(^3\) This finding in female patients again emphasizes the importance of categorizing postural assessments according to the gender. While male patients had a significant increase in the FSP; it may have had less detrimental effects on the LSST3 than in female patients who had both FHP and FSP.

### Methodological Considerations and Study Limitations

The present study compared several postural variables in female and male SAIS patients and healthy controls to identify potential postural abnormalities that may contribute to the development of or coexist with the condition. The postural measures chosen were undertaken using methodologies consistent with previous studies in which the reliability and practicality of the techniques were detailed. Furthermore, upper extremity/shoulder pain is more prevalent in females compared to men (22.8%-30.9% vs 13.3%-21.4%) between the ages of 25–64\(^5\) and a significant association exists between SAIS and female gender.\(^5\) Judging the posture of men and women by the same standards may also affect group comparisons.\(^5\) Hence the authors reported group results separately by sex and some findings of this study may be attributed to this approach.

Finally, while there were no statistically significant differences in the demographics between controls and patients for either sex, the relatively higher age in patient groups (female patients in particular) compared to the healthy participants could have partly attributed to the study findings. There is a growing body of literature suggesting complex structural age-related changes in body posture and physiological curvature of the spine due to reduced efficiency of central and peripheral mediation, gradual decrease in skeletal muscle function and connective tissue elasticity, and regressive changes in ligaments and articular cartilage (reduced flexibility). However, such changes start with a slow progression between the ages of 40–50 years and increase mainly after 60 years of age.\(^3,5\) Large studies have reported marked postural changes occurring in men and women, above 59 and 60 years of age respectively.\(^5,5\)

The selection of patients through a single upper limb unit overseen by an orthopaedic surgeon could have caused selection bias (spectrum bias) depending on the chosen clinical tests as well as accuracy and expertise in performing the tests.\(^6\) The sample size was relatively small mainly due to focusing on separate data reporting for female and male groups of patients and controls. This approach was taken based on the evidence suggesting a significant association between SAIS and female sex\(^3\) and higher prevalence of upper extremity/shoulder pain in females compared to men.\(^1\) While the use of a single assessor to perform all tests could have enhanced the internal validity of study reliability, it may limit the external validity and generalizability of findings particularly when combined with a small sample size. The study examined and compared the outcome measures only in patients with active SAIS symptoms and future studies are needed to evaluate the changes in outcome following common surgical and conservative interventions for SAIS.

### CONCLUSION

Earlier understanding of the crucial elements influencing the relationship between dysfunctional posture and SAIS has not been rigorously examined. While studies of asymptomatic subjects established the likelihood of a connection between SAIS and posture; studies involving SAIS patients have largely failed to clarify this relationship. Female SAIS patients in the current study exhibited abnormal FHP, FSP, and LSST3 as compared to controls, while male patients presented only with an increased FSP. Randomized controlled trials of rehabilitation interventions addressing defined postural alterations, particularly in female patients, are needed to support their integration into prevention and intervention programs. Further research should explore whether a common gender-related pattern in scapular positioning exists in SAIS patients or whether subgroups of patients with common patterns can be identified to facilitate the development of tailored interventions.

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ABSTRACT

**Background:** Shoulder pain affects up to 67% of the population at some point in their lifetime with subacromial pain syndrome (SAPS) representing a common etiology. Despite a plethora of studies there remains conflicting evidence for appropriate management of SAPS.

**Purpose:** To compare outcomes, for individuals diagnosed with SAPS, performing a 6-week protocol of eccentric training of the shoulder external rotators (ETER) compared to a general exercise (GE) protocol.

**Study Design:** Randomized controlled trial

**Methods:** Forty-eight individuals (mean age 46.8 years +/-17.29) with chronic shoulder pain, and a clinical diagnosis of SAPS were randomized into either an experimental group performing ETER or a control group performing a GE program. The intervention lasted for six weeks, and outcomes were measured after three weeks, six weeks, and again at six months post intervention.

**Results:** The primary outcome of function, measured by the Western Ontario Rotator Cuff Index, demonstrated a significant interaction effect derived from a multilevel hierarchical model accounting for repeated measures favoring the experimental group at week 3: 14.65 (p=.003), Week 6: 17.04 (p<.001) and six months: 15.12 (p=.007). After six months, secondary outcome measures were improved for Numeric Pain Rating Scale levels representing pain at worst (p=.006) and pain on average (p=0.02), external rotator (p<.001), internal rotator (p=0.02), and abductor strength (p<.001). There were no statistically significant differences in secondary outcome measures of Global Rating of Change, Active Range of Motion, the Upper Quarter Y Balance Test and strength ratios after six months.

**Conclusion:** An eccentric program targeting the external rotators was superior to a general exercise program for strength, pain, and function after six months. The findings suggest eccentric training may be efficacious to improve self-report function and strength for those with SAPS.

**Level of Evidence:** 2b

**Key Words:** Eccentric Training, shoulder exercise, subacromial pain

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INTRODUCTION
Shoulder pain is prevalent, affecting up to 67% of community dwelling individuals and resulting in a significant loss of function and associated disability. Chronic shoulder pain is also common with 46.7% of cases persisting after one year. Although the etiology of shoulder pain is variable, a body of evidence has implicated subacromial pain syndrome (SAPS) as a primary source. Symptoms arising from the subacromial space are thought to be the most common cause of shoulder pain comprising 44-65% of all reports.

Exercise can be considered the standard of care and an accepted first line intervention for individuals experiencing SAPS. Variations of exercise interventions for SAPS have demonstrated effectiveness including supervised exercise, unsupervised home program exercise, and multi-modal interventions provided by a physical therapist. No significant, long term difference has been demonstrated between these various management approaches, however, efficacy of exercise over placebo treatment or no treatment has been established. Moreover, when comparing exercise versus surgery for SAPS and rotator cuff tendinopathy no significant difference exists for pain and function at both short and long term follow up. While a variety of exercise protocols demonstrating effectiveness exist, a clearly defined best method of resisted exercise has yet to be established. Exercise, as an intervention, has been found to benefit patients with SAPS, however, further study is needed due to the paucity of quality investigations examining specific shoulder resistance training programs.

Eccentric training of shoulder musculature as an intervention for the management of SAPS has been examined in six published clinical trials to date. The authors of these investigations have utilized a variety of training protocols, specific exercises, dosing strategies, experimental and non-experimental methodology. None of these investigations have targeted the external rotators in isolation but rather the shoulder abductors alone or in combination with the external rotators. Exercises targeting shoulder abduction may improperly emphasize an existing abnormal deltoid to rotator cuff muscle imbalance, thereby further accentuating an underlying cause of SAPS. Individuals with SAPS have been identified as having weakness of the shoulder external rotators compared to healthy controls. The effects of eccentric training, of only the shoulder external rotators, in patients experiencing SAPS has not been studied in a randomized controlled trial. Moreover, limitations due to single arm designs, a focus on eccentric loading of the shoulder abductors, or a lack of appropriate load for the provided eccentric exercises warrants further study of eccentric training to the shoulder external rotators.

Prior investigations for eccentric training of the shoulder abductors have primarily utilized a pain provocation model for exercise progression. This method of progressing resistance training load and volume assumes that pain must be increased during the exercise movement for clinical benefit to occur. The contrast to this approach would be a performance based progression as utilized in the Blume et al. study for shoulder eccentric training. This method progresses a patient based on the ability to perform a higher number of repetitions at a given load without increasing symptoms which could be favorable in many clinical settings. Optimal loading management has the potential for improving patient outcomes by strengthening the affected tendon tissue while concurrently creating a hypoalgesic affect.

Further investigation on the role of eccentric training, specifically of the shoulder external rotators, in patients with SAPS is warranted. Thus, the purpose of this investigation was to compare outcomes, for individuals diagnosed with SAPS, performing a six-week protocol of eccentric training of the shoulder external rotators compared to a general exercise protocol.

METHODS
Participants
Forty-eight participants with SAPS (20 women, 28 men, mean 46.8 years (+/- 17.29)), volunteered and qualified for participation in this clinical study. The presence of SAPS was determined by the presence of a positive result for at least three of the following criteria: the Neer impingement test, the Hawkins-Kennedy impingement test, the empty can test, pain with resisted external rotation, palpable tenderness at the insertion of the supraspinatus or infraspinatus,
or painful arc from $60^\circ$ to $120^\circ$ during active abduction.\textsuperscript{24-26} Moreover, the onset of shoulder pain had to be greater than three months so only individuals with non-acute shoulder pain were included. Participants were recruited from the local community with publicly displayed flyers. Exclusion criteria were red flags noted in the patient's medical screening questionnaire, suspected full thickness supraspinatus or infraspinatus tendon tears as identified by a positive drop arm test,\textsuperscript{24} external rotation lag sign\textsuperscript{27} or rent test,\textsuperscript{28} adhesive capsulitis as identified by multiple plane passive motion loss,\textsuperscript{29} or history of shoulder surgery. The primary investigator enrolled all participants and conducted all outcome measure assessments while being blinded to group allocation. All participants signed an informed consent form approved by the institutional review boards from the University of St. Augustine and Nova Southeastern University. This investigation was registered with the United States National Institutes of Health (clinicaltrials.gov identifier: NCT02153827)

**Outcome Measures and Procedures**

Participants completed the primary outcome measure, The Western Ontario Rotator Cuff Index (WORC), as well as the Numeric Pain Rating Scale (NPRS) for worst pain, best pain, and average pain as a secondary measure.\textsuperscript{30} Both the WORC and NPRS have been validated previously and demonstrate good to high reliability for individuals with shoulder pain (ICC's of .89 and .74 respectively).\textsuperscript{31-34} Additional secondary outcome measures were tested in the following order: Isometric strength values, active range of motion (AROM), the upper quarter Y-balance test (UQYBT) and Global Rating of Change (GROC). Isometric strength values were measured using the microFET\textsuperscript{2}© hand held dynamometer (HHD) (Hoggan Health Industries, West Jordan, Utah)\textsuperscript{35} per the protocol described by Kolber et al.\textsuperscript{35} Isometric external rotation, internal rotation and abduction strength were all tested with participants seated and supported by an armless chair. A stabilization belt was applied to the participant's torso to restrict movement during the tests. A stabilization device was used to restrict movement of the HHD during testing. Strength tests were performed in consecutive order for three repetitions, with an isometric hold time of approximately six seconds each. The participant was instructed to provide their best effort for the duration of the six second total time. Peak force for each trial was recorded in kilograms. A 10 second rest between trials occurred and the highest strength value of the three trials, for each position, was recorded. Mean peak strength levels were calculated and adjusted for bodyweight. Strength ratios were then determined by dividing the peak strength value of one measurement by the peak value from another measurement. High reliability of HHD (ICC = .97) has been established when using a stabilization device as described previously.\textsuperscript{35,36}

AROM was tested with a standard 12-inch goniometer utilizing the procedures outlined by Riddle et al.\textsuperscript{37} The motions that were tested include abduction, flexion, extension, external rotation and internal rotation. Participants were verbally and passively guided in the movement to be performed for one repetition prior to testing. Participants were then asked to perform the movement actively until limited AROM or pain was experienced. Good reliability (ICC .76-.91) of goniometry for shoulder AROM has been established in subjects with shoulder pain.\textsuperscript{38}

The UQYBT was used to determine closed chain performance as described by Gorman et al.\textsuperscript{39} with high reliability (ICC .90). The test was performed with the participant in the push-up position. Participants used a single arm to stabilize while the other arm performed a reaching motion in three directions, relative to the participant's free hand. The participant moved the free hand as far as possible in the medial, superolateral and inferolateral directions. For each direction, the length of reach was recorded in centimeters. The participant was allowed three practice trials and then three testing trials were performed to determine the distance sum. Limb length was taken into consideration and normalized by taking the total excursion distance and dividing it by 3 times the limb length.

The GROC\textsuperscript{40} was used to evaluate participant perceived change at week three, week six, and at the six-month follow up. This outcome measure asks the participant to rate their overall perception of improvement. The GROC contains a 15 point scale ranging from -7 “a very great deal worse”, to 0 “about the same”, to +7 “a very great deal better”. A change
of (+3) points on the GROC has been described as the minimal clinical important difference (MCID) and associated with meaningful improvement in a patients perceived quality of life.\(^{40}\)

**Interventions**

The study design is outlined in (Figure 1). All participants were randomized to one of two exercise programs by blindly placing a pen on a table of random numbers\(^{41}\) with odd numbers allocating the control group and even numbers allocating the experimental group. Each participant was seen by a physical therapist for a total of four treatment visits over six weeks. One program consisted of eccentric training to the external rotators (ETER) (Figures 2a and 2b) along with scapular retraction with a resistance band (Figures 3a and 3b) and posterior shoulder stretching exercises (Figure 4). The other program comprised of a general shoulder exercise protocol (GE) of active flexion, abduction, scapular retraction and posterior shoulder stretching exercises all into maximum tolerated range of motion without increasing symptoms. All participants maintained an exercise diary to record adherence to the home program. Both the treatment and control group interventions are shown in (Table 1).

The eccentric exercise used in this study was performed without an associated increase in resting symptoms. The TheraBand™ system of progressive resistance (The Hygienic Corporation, Akron, OH) was used to provide resistance for the eccentric exercises. Load was increased by resistance band thickness (color coded) from Green, Blue, Black, Silver, to Gold. Each participant was given a four-foot length band and instructed to use it for the home program. The starting position was established by the participant standing just far enough away from the anchor point so that no slack remained in the band. If a participant reported an increase in pain from rest...
while performing the exercise a reduced load was prescribed until the pain level was the same or less compared to resting pain levels. To perform each repetition only eccentrically the contralateral arm assisted the exercising arm through the concentric portion to achieve the end range external rotation position. Dosing of the eccentric external rotation exercise consisted of 3 sets of 15 repetitions each performed with the eccentric phase lasting three seconds in duration. Load was prescribed by the appropriate band thickness so that volitional muscle

**Figure 2.** Standing eccentric training of the external rotators exercise, a) start position, b) end position. Resistance band tension is standardized so that the starting position begins with all slack taken out of the band. The contralateral arm assists in the concentric phase to maximum available external rotation. A 2 second isometric contraction is held at end-range before a slow 3 second eccentric return to the starting position.

**Figure 3.** Standing scapular retraction exercise, a) start position with no slack in resistance band, b) end position with maximum scapular adduction.

**Figure 4.** Cross body posterior shoulder stretch consisting of horizontal adduction of the affected shoulder with contralateral arm assistance to hold the sustained stretch.
### Table 1. Treatment and control group interventions

<table>
<thead>
<tr>
<th>Exercise and Intervention Description</th>
<th>Experimental Group Interventions</th>
<th>Control Group Interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eccentric external rotator with 3 second eccentric phase using resistance band</td>
<td>3 sets of 15 repetitions performed once daily</td>
<td>Active range of motion in standing with no resistance for flexion in the sagittal plane and abduction in the coronal plane</td>
</tr>
<tr>
<td>Scapular retraction using resistance band</td>
<td>2 sets of 10 repetitions performed once daily</td>
<td>Scapular retraction using resistance band</td>
</tr>
<tr>
<td>Cross body horizontal adduction stretch in the standing position</td>
<td>3 repetitions, 30-45 seconds each performed once daily</td>
<td>Cross body horizontal adduction stretch in the standing position</td>
</tr>
</tbody>
</table>

### Table 2. Baseline descriptive statistics

<table>
<thead>
<tr>
<th>Descriptive Characteristics</th>
<th>GE Group (N=23)</th>
<th>ETER (N=25)</th>
<th>p value†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>48.35 (16.89)</td>
<td>43.35 (17.88)</td>
<td>.550</td>
</tr>
<tr>
<td>Body mass (kilograms)</td>
<td>81.90 (18.55)</td>
<td>79.87 (15.04)</td>
<td>.677</td>
</tr>
<tr>
<td>Pain onset duration (months)</td>
<td>44.91 (75.51)</td>
<td>53.36 (84.67)</td>
<td>.715</td>
</tr>
<tr>
<td>Best Pain (NPRS)</td>
<td>1.22 (1.28)</td>
<td>1.64 (1.71)</td>
<td>.396</td>
</tr>
<tr>
<td>Average Pain (NPRS)</td>
<td>3.30 (1.61)</td>
<td>3.72 (2.03)</td>
<td>.572</td>
</tr>
<tr>
<td>Worst Pain (NPRS)</td>
<td>7.00 (2.09)</td>
<td>7.00 (1.78)</td>
<td>.673</td>
</tr>
<tr>
<td>WORC</td>
<td>65.40 (14.08)</td>
<td>66.63 (15.95)</td>
<td>.741</td>
</tr>
<tr>
<td>External rotation strength (BWKG)</td>
<td>.130 (.029)</td>
<td>.133 (.024)</td>
<td>.665</td>
</tr>
<tr>
<td>Internal rotation strength (BWKG)</td>
<td>.141 (.036)</td>
<td>.168 (.059)</td>
<td>.062</td>
</tr>
<tr>
<td>Abduction strength (BWKG)</td>
<td>.146 (.064)</td>
<td>.185 (.071)</td>
<td>.052</td>
</tr>
<tr>
<td>IR/ER ratio</td>
<td>1.100 (.237)</td>
<td>1.243 (.295)</td>
<td>.067</td>
</tr>
<tr>
<td>ABD/ER ratio</td>
<td>1.098 (.367)</td>
<td>1.360 (.352)</td>
<td>.015*</td>
</tr>
<tr>
<td>Flexion AROM (degrees)</td>
<td>148 (31)</td>
<td>154 (15)</td>
<td>.395</td>
</tr>
<tr>
<td>Abduction AROM (degrees)</td>
<td>149 (35)</td>
<td>149 (30)</td>
<td>.988</td>
</tr>
<tr>
<td>External rotation AROM (degrees)</td>
<td>79 (17)</td>
<td>82 (13)</td>
<td>.425</td>
</tr>
<tr>
<td>Internal rotation AROM (degrees)</td>
<td>60 (16)</td>
<td>59 (14)</td>
<td>.887</td>
</tr>
<tr>
<td>Medial UQYBT (cm/limb length)</td>
<td>1.052 (.203)</td>
<td>1.120 (.193)</td>
<td>.244</td>
</tr>
<tr>
<td>Superior lateral UQYBT (cm/limb length)</td>
<td>.546 (.177)</td>
<td>.648 (.189)</td>
<td>.060</td>
</tr>
<tr>
<td>Inferior lateral UQYBT (cm/limb length)</td>
<td>.614 (.131)</td>
<td>.712 (.156)</td>
<td>.023*</td>
</tr>
</tbody>
</table>

NOTE. Values are mean (SD). Abbreviations: GE=general exercise; ETER= eccentric training of the external rotators; NPRS= numeric pain rating scale; WORC= Western Ontario rotator cuff index; BWKG= kilograms of force adjusted for bodyweight; IR/ER ratio= ratio of external rotation strength to internal rotation strength; ABD/ER ratio= ratio of external rotation strength to abduction strength; AROM= active range of motion; UQYBT= upper quarter Y-balance test.

*Statistically significant, †P values obtained from Mann Whitney U for NPRS and WORC, Independent samples t test for all others.
Table 3. Mean values for patient-reported function, global change, pain, external rotation strength, internal rotation strength, abduction strength (all strength outcomes adjusted for body-weight), ABD/ER and IR/ER.

<table>
<thead>
<tr>
<th>Outcome measure</th>
<th>GE Group</th>
<th>ETER Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 0 (N=23)</td>
<td>Week 3 (N=21)</td>
</tr>
<tr>
<td>WORC</td>
<td>65.40 (14.08)</td>
<td>64.17 (16.30)</td>
</tr>
<tr>
<td>GROC</td>
<td>NA</td>
<td>+1.17 (2.06)</td>
</tr>
<tr>
<td>Best Pain NPRS</td>
<td>1.22 (1.28)</td>
<td>1.43 (1.44)</td>
</tr>
<tr>
<td>Average Pain NPRS</td>
<td>3.30 (1.61)</td>
<td>3.26 (1.88)</td>
</tr>
<tr>
<td>Worst Pain NPRS</td>
<td>7.00 (2.09)</td>
<td>6.65 (2.20)</td>
</tr>
<tr>
<td>ERS</td>
<td>.130 (.029)</td>
<td>.122 (.031)</td>
</tr>
<tr>
<td>IRS</td>
<td>.141 (.036)</td>
<td>.136 (.037)</td>
</tr>
<tr>
<td>AbdS</td>
<td>.146 (.064)</td>
<td>.139 (.058)</td>
</tr>
<tr>
<td>ABD/ER SR</td>
<td>1.09 (.36)</td>
<td>1.12 (.32)</td>
</tr>
<tr>
<td>IR/ER SR</td>
<td>1.10 (.23)</td>
<td>1.15 (.28)</td>
</tr>
<tr>
<td>Flexion AROM</td>
<td>148 (31)</td>
<td>151 (24)</td>
</tr>
<tr>
<td>Abduction AROM</td>
<td>149 (35)</td>
<td>150 (36)</td>
</tr>
<tr>
<td>ER AROM</td>
<td>79 (17)</td>
<td>77 (16)</td>
</tr>
<tr>
<td>IR AROM</td>
<td>60 (16)</td>
<td>59 (13)</td>
</tr>
<tr>
<td>Medial UQYBT</td>
<td>1.05 (.20)</td>
<td>1.02 (.22)</td>
</tr>
<tr>
<td>Superior/Lateral UQYBT</td>
<td>.54 (.17)</td>
<td>.50 (.14)</td>
</tr>
<tr>
<td>Inferior/Lateral UQYBT</td>
<td>.61 (.13)</td>
<td>.58 (.15)</td>
</tr>
</tbody>
</table>

NOTE. Values are presented as mean (SD). Units of measurement: Strength measured as peak force divided by bodyweight in kilograms, AROM measured in degrees, UQYBT reach distance divided by limb length in cm.

Abbreviations: GE= general exercise; ETER= eccentric training of the external rotators; WORC= Western Ontario rotator cuff index; GROC= global rating of change scale; NPRS= numeric pain rating scale; NA= not applicable; ERS= external rotation strength; IRS= internal rotation strength; AbdS= abduction strength; ABD/ER SR, external rotation abduction strength ratio; IR/ER SR, external rotation internal rotation strength ratio; AROM= active range of motion; ER= external rotation; IR= internal rotation; UQYBT= upper quarter Y-balance test.
failure of the external rotators occurred between 15 and 18 repetitions.

**Data Analysis**

With an effect size of .40 for the primary outcome measure WORC, significance level of $p < .05$, statistical power set at $P = .80$, it was estimated that a total study sample size of 48 participants were needed for this study. Baseline between group differences for all outcome measures and demographics were analyzed using the independent samples $t$-test. The non-parametric Mann-Whitney U test was used to analyze between group differences for all ordinal level data including the NPRS, shoulder strength

### Table 4. Pairwise comparisons of mean differences for each WORC time point.

<table>
<thead>
<tr>
<th>Time point</th>
<th>Mean difference between groups</th>
<th>Standard Error</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 3</td>
<td>14.65</td>
<td>4.18</td>
<td>0.003</td>
</tr>
<tr>
<td>Week 6</td>
<td>17.04</td>
<td>4.18</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>6 Month</td>
<td>15.12</td>
<td>4.69</td>
<td>0.007</td>
</tr>
</tbody>
</table>

Note: Results describe the interaction effect derived from a multilevel hierarchical model accounting for repeated measures. Post hoc testing for pairwise comparisons were performed using Tukey correction.

### Table 5. Interaction effect between experimental and control groups at week 3, week 6 and 6-month time points. Positive values indicate higher scores in the experimental group with negative values indicating higher scores in the experimental group.

<table>
<thead>
<tr>
<th>Outcome measure</th>
<th>3 weeks</th>
<th>p value</th>
<th>6 weeks</th>
<th>p value</th>
<th>6 months</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>GROC</td>
<td>NA</td>
<td>NA</td>
<td>-0.8</td>
<td>0.29</td>
<td>-0.12</td>
<td>0.88</td>
</tr>
<tr>
<td>Best Pain NPRS</td>
<td>1.1</td>
<td>&lt;.001</td>
<td>0.55</td>
<td>0.12</td>
<td>0.91</td>
<td>0.02</td>
</tr>
<tr>
<td>Average Pain NPRS</td>
<td>1.24</td>
<td>0.03</td>
<td>1.71</td>
<td>&lt;.001</td>
<td>1.44</td>
<td>0.02</td>
</tr>
<tr>
<td>Worst Pain NPRS</td>
<td>1.41</td>
<td>0.03</td>
<td>2.51</td>
<td>&lt;.001</td>
<td>2.05</td>
<td>0.006</td>
</tr>
<tr>
<td>ERS</td>
<td>-0.03</td>
<td>&lt;.001</td>
<td>-0.04</td>
<td>&lt;.001</td>
<td>-0.04</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>IRS</td>
<td>-0.02</td>
<td>0.11</td>
<td>-0.02</td>
<td>0.12</td>
<td>-0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>AbdS</td>
<td>-0.01</td>
<td>0.38</td>
<td>0.02</td>
<td>0.12</td>
<td>0.04</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>ABD/ER SR</td>
<td>0.16</td>
<td>0.05</td>
<td>0.19</td>
<td>0.02</td>
<td>0.11</td>
<td>0.22</td>
</tr>
<tr>
<td>IR/ER SR</td>
<td>0.1</td>
<td>0.23</td>
<td>0.17</td>
<td>0.04</td>
<td>0.14</td>
<td>0.13</td>
</tr>
<tr>
<td>Medial UQYBT</td>
<td>-0.07</td>
<td>0.2</td>
<td>-0.09</td>
<td>0.1</td>
<td>-0.07</td>
<td>0.22</td>
</tr>
<tr>
<td>Superior/ Lateral UQYBT</td>
<td>-0.05</td>
<td>0.17</td>
<td>-0.05</td>
<td>0.25</td>
<td>0.01</td>
<td>0.82</td>
</tr>
<tr>
<td>Inferior / Lateral UQYBT</td>
<td>-0.04</td>
<td>0.28</td>
<td>-0.04</td>
<td>0.25</td>
<td>0.02</td>
<td>0.63</td>
</tr>
<tr>
<td>Flexion AROM</td>
<td>-1.18</td>
<td>0.83</td>
<td>0.75</td>
<td>0.89</td>
<td>0.69</td>
<td>0.91</td>
</tr>
<tr>
<td>Abduction AROM</td>
<td>-6.84</td>
<td>0.33</td>
<td>-8.56</td>
<td>0.23</td>
<td>-8.41</td>
<td>0.29</td>
</tr>
<tr>
<td>ER AROM</td>
<td>-1.61</td>
<td>0.64</td>
<td>-4.96</td>
<td>0.15</td>
<td>-4.23</td>
<td>0.27</td>
</tr>
<tr>
<td>IR AROM</td>
<td>-1.31</td>
<td>0.72</td>
<td>-4.58</td>
<td>0.21</td>
<td>-5.05</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Note: Results describe the interaction coefficient derived from a multilevel hierarchical model accounting for repeated measures.

GROC= global rating of change scale; NPRS= numeric pain rating scale; NA= not applicable; ERS= external rotation strength; IRS= internal rotation strength; AbdS= abduction strength; ABD/ER SR= external rotation abduction strength ratio; IR/ER SR= external rotation internal rotation strength ratio; AROM= active range of motion; ER= external rotation; IR= internal rotation; UQYBT= upper quarter Y-balance test.
ratios, and WORC. The interaction coefficient derived from a multilevel hierarchical model accounting for repeated measures was utilized for between and within group measures at all time points (beginning of the study, week 3, week 6, and at 6-month follow up). Post hoc testing for pairwise comparisons were performed using a Tukey correction.

RESULTS
Seventy-one individuals were recruited over 18 months. Seven were ineligible to participate due to medical screening exclusions, confirmed rotator cuff tears, or adhesive capsulitis. Sixteen individuals failed to meet the physical examination inclusion criteria of three positive SAPS tests. After randomization, the ETER group included 25 individuals (10 women and 15 men), while the GE group included 23 individuals (10 women and 13 men) (Figure 2). Descriptive statistics are provided in Table 2. Two participants requested to cease participation before the week three follow-up and 10 did not return phone calls to schedule the 6-month data collection time points, resulting in a total participant retention rate for the 6-month follow up at 75% (9 missing from GE group and 3 from ETER group). Individuals who did not return for the 6-month follow up were contacted two times by telephone to improve retention. Demographic data and week six primary and secondary outcome measure results were compared between the participants who chose to cease participation and those who returned for the 6-month follow up without any significant within group difference identified. Due to the asymmetric attrition between the GE and ETER group intention to treat analysis was not utilized to prevent a potential Type I error. Participants that were retained in the study did not demonstrate a significant difference between groups for home program adherence.

Table 3 provides mean and standard deviation values for all outcome measures at the baseline, 3-week, 6-week, and 6-month follow up time points. Table 4 provides pairwise comparisons of mean differences for the primary outcome WORC scores at week 3, week 6 and 6-month time points. A significant difference (p<0.007) favoring the experimental group was identified across all time points for the primary outcome of self-report function as measured by the WORC. The interaction effect for the secondary outcome measures at all time points is described in Table 5. After three weeks only NRPS (p<0.03) and ERS (p<.001) displayed a statistically significant interaction effect. Upon the conclusion of treatment at week six, a significant interaction for average and worst NPRS values (p<.001), ERS (<.001) and the external rotator to abductor and external rotator to internal rotator strength ratios (p<0.04) were identified. After six months secondary outcome measures were improved for pain on average and pain at worst as measured by the NPRS (p<0.02), external rotator, internal rotator and abductor strength (p<0.02). The secondary outcome measures of GROC, AROM, UQYBT and strength ratios were not statistically significantly different in the multilevel model after six months.

DISCUSSION
The primary objective of this study was to investigate if individuals with SAPS would benefit from a six-week protocol of ETER compared to a group of individuals who performed a GE program. Based on these results, it can be concluded that pain levels, participant reported function, and external rotator strength were significantly improved for individuals with SAPS after six weeks of treatment. Six months after an ETER protocol pain levels, participant reported function, external rotator, abductor, and internal rotator strength measures were significantly improved. The changes experienced by the intervention group were superior to those seen in participants who underwent a GE program (control group).

Significant improvements in the mean body weight adjusted external rotation strength was demonstrated by comparing the baseline value of .133 to three weeks mean measures of .153, six week measures of .156 and six month measures of .171 in the ETER group. Contributing factors to the increase in strength after only three weeks in this study could possibly be attributed to short-term neurological changes (e.g. rate coding and motor unit recruitment). Strength improvements are often correlated with increases in muscle hypertrophy and cross sectional muscle size after long term exposure to training, most commonly occurring after eight weeks.42 Long-term strength changes can also be attributed to improvements in tendon stiffness which has been
documented to occur after 14 weeks of training. Exercise training has a positive effect on motor unit recruitment and could reverse the effects on muscular strength inhibition in the injured population of individuals, in a relatively short period of time. The authors are unable to make a suggestion regarding why the strength improvements were achieved as muscle hypertrophy and neurological mechanisms were not measured.

A comparison of these results to the prior experimental studies examining eccentric training for SAPS reveal similar reductions in pain and improved function. Bernhardsson et al. reported visual analog scale (VAS) improvements from 57 to 29 mm before and after 12 weeks of eccentric shoulder training. The results reported by Bernhardsson et al. are comparable to the results of the current study for average pain improvement after training. However, Bernhardsson et al. recruited individuals with at least one year of chronic shoulder pain and resting VAS scores of at least 30 mm. It appears that Bernhardsson et al. had a sample of individuals with more severe pain levels upon initial examination whereas the sample in this study had mean initial ratings of 3 and final ratings of 0 for average pain.

The WORC was utilized to measure participant reported shoulder function. A significant between group difference was identified (p < .007) from the baseline mean score of 66.63%, week 3 score of 82.10%, week six score of 87.6% and six-month score of 92.72% for the ETER group. The MCID for the WORC has been reported to be 13%. These results identified a 26.09% improvement for the ETER group which exceeded MCID compared to the 11.75% change in the GE group which did not exceed established values for MCID. Prior investigations on shoulder eccentric training utilize a variety of patient report functional measures. This study utilized the WORC because it is a disease specific tool unique to individuals with SAPS and rotator cuff tendinopathy.

Blume et al. did not identify a significant between group difference for pain and function when comparing an eccentric only shoulder protocol to a traditional isotonic program for individuals with SAPS. It should be noted that the Blume et al. study utilized equal levels of resistance for each group. This lack of appropriately prescribed heavy load resistance is contrary to the purpose of eccentric training which should utilize loads that cannot be performed concentrically. The benefit of eccentric training is that the heavier resistance could provide tendon remodeling and hormonal changes that benefit the nervous, endocrine and musculoskeletal systems.

An important feature of this exercise protocol was that pain was not reproduced during the interventions. Participants were asked to conduct exercises without increasing symptoms which is in direct contrast to the prior investigations for shoulder eccentric training. Another difference identified in this study is the use of eccentric training with a maximal load that is progressed based upon the individual’s ability to increase the number of repetitions performed. Utilizing an achieved repetition based progression could have a greater benefit for rotator cuff strength gains compared to a symptom reproducing system of advancement. Finally, the emphasis on training the external rotators in isolation may have a greater biomechanical benefit in restoring function of the shoulder complex as the causative factor of external rotator cuff weakness has been attributed to SAPS.

**Study limitations**

Study limitations include the possibility of including participants without an isolated rotator cuff tendinopathy diagnosis. The inclusion and exclusion criteria in this study were formulated according to those used in prior eccentric rotator cuff studies but without advanced imaging technologies the diagnostic accuracy of these examination criteria may have been a limitation. Moreover, the generic control group interventions may not be generalizable to a typical exercise program utilized by an individual experiencing SAPS. Nevertheless the methodology from this study followed methods utilized in previous trials. Another limitation could be the possibility of a Type II error for between group differences in GROC, strength ratios, the UQYBT, and AROM measurements. This investigation did demonstrate a lack of statistical power for several of these dependent variables and the relatively small sample size is a limitation. This investigation remains unique in that heavy load eccentric training to only the external rotators was utilized providing value for future studies.
Future research
The clinical examination and diagnosis of SAPS is critically important for future research. The variability in clinical presentation for SAPS likely influences outcomes and a classification system for patient subgrouping could be helpful to determine which patient characteristics respond most favorably to ETER. The prescription/dosage of exercise and progression should also be investigated in more detail. The dosing protocol utilized in this investigation of 3 sets of 15 for ETER was utilized in prior shoulder research but its origin could be considered arbitrary and developed from research studies conducted on the Achilles tendon. A progressive protocol with varying dosing strategies based on symptom response and functional status would be more generalizable to clinical practice. Varying the speed, duration, and shoulder positions during ETER in comparison to traditional rotator cuff strengthening exercises should be investigated.

CONCLUSIONS
Shoulder pain, function, and rotator cuff strength improved significantly after a six-week ETER protocol for individuals with SAPS when compared to a control group performing a GE program. The experimental protocol emphasized training only the rotator cuff muscles responsible for external rotation and progressed participants based on strength improvements and not symptom reproduction. This symptom reducing exercise program may be of benefit to the rehabilitation programs for individuals experiencing SAPS. Moreover, focusing on the external rotators, as in this study, avoided painful impingement positions from overhead activity and did not perpetuate muscle imbalances (e.g. deltoid to rotator cuff) previously implicated in the etiology of SAPS. Lastly, the results of this study provide a basis for future research comparing different diagnoses as well as intervention groups.

REFERENCES
14. Bernhardsson S, Klinberg IH, Wendt GK. Evaluation of an exercise concept focusing on eccentric strength training of the rotator cuff for patients with...


ABSTRACT

Background: Assessment of foot posture, morphology, intersegmental mobility, strength and motor control of the ankle-foot complex are commonly used clinically, but measurement properties of many assessments are unclear.

Purpose: To determine test-retest and inter-rater reliability, standard error of measurement, and minimal detectable change of morphology, joint excursion and play, strength, and motor control of the ankle-foot complex.

Design: Reliability study.

Methods: 24 healthy, recreationally-active young adults without history of ankle-foot injury were assessed by two clinicians on two occasions, three to ten days apart. Measurement properties were assessed for foot morphology (foot posture index, total and truncated length, width, arch height), joint excursion (weight-bearing dorsiflexion, rearfoot and hallux goniometry, forefoot inclinometry, 1st metatarsal displacement) and joint play, strength (handheld dynamometry), and motor control rating during intrinsic foot muscle (IFM) exercises. Clinician order was randomized using a Latin Square. The clinicians performed independent examinations and did not confer on the findings for the duration of the study. Test-retest and inter-tester reliability and agreement was assessed using intraclass correlation coefficients (ICC2,k) and weighted kappa (Kw).

Results: Test-retest reliability ICC were as follows: morphology: .80-1.00, joint excursion: .58-.97, joint play: -.67-.84, strength: .67-.92, IFM motor rating: Kw -.01-.71. Inter-rater reliability ICC were as follows: morphology: .81-1.00, joint excursion: .32-.97, joint play: -.06-1.00, strength: .53-.90, and IFM motor rating: Kw .02-.56.

Conclusion: Measures of ankle-foot posture, morphology, joint excursion, and strength demonstrated fair to excellent test-retest and inter-rater reliability. Test-retest reliability for rating of perceived difficulty and motor performance was good to excellent for short-foot, toe-spread-out, and hallux exercises and poor to fair for lesser toe extension. Joint play measures had poor to fair reliability overall. The findings of this study should be considered when choosing methods of clinical assessment and outcome measures in practice and research.

Level of evidence: 3

Key Words: Assessment, examination, intrinsic foot muscles, manual therapy, repeatability
INTRODUCTION

Traumatic and overuse injuries of the ankle and foot are frequently incurred in sport, physical training, and the workplace. The most common lower extremity injury treated is the lateral ankle sprain, with more than two million individuals injuring their lateral ankle annually in the United States. Similarly, plantar fasciitis is a frequently occurring overuse injury in the foot that is responsible for more than one million ambulatory care visits in the United States per annum. Clinical practice guidelines recommend physical examination of the ankle-foot complex to include observation of foot morphology and posture, palpation, range of motion, test of joint play to assess ligamentous integrity, and strength in the assessment of these patients.

While test-retest and inter-rater reliability of some commonly utilized assessment measures of the ankle-foot complex have been studied, measurement properties for many others have yet to be established. The authors of a systematic review of ankle-foot examination articles published from 1966-2006 found that only a few studies rigorously assessed measurement properties such as reliability of ankle-foot posture, morphology, multisegmental joint mobility, strength, and motor function. A ramification of imprecise physical examination measurements is the inability to distinguish actual clinical change from change resulting from random error. Consequences of measurement uncertainty are decreased sensitivity, specificity, and prognostic accuracy when assessing impairment throughout the disease or injury course or when tracking effectiveness of therapeutic interventions. Reliability of new, innovative examination measures of multisegmented ankle and foot motion, strength, and motor control also need to be assessed. Novel measures of intersegmental mobility of the foot and neuro-motor function of the intrinsic foot muscles (IFM) have been suggested to be clinically important in the assessment of the foot functions of shaping, force attenuation and transmission, and postural control.

The purpose of this study was to determine test-retest and inter-rater reliability, standard error of measurement, and minimal detectable change of morphology, joint excursion and play, strength, and motor control of the ankle-foot complex in healthy, recreationally active individuals. Reliability of participant-reported task difficulty during short-foot and toe posture exercises were also assessed.

METHODS

Design

A reliability study was performed using a sample of convenience in which the independent variables were clinician (novice and experienced) and session (baseline and reassessment). Inter-rater and test-retest reliability, SEM, and MDC were assessed for each clinical measure of foot morphology, joint mobility, strength, and motor performance.

Participants

Data from 24 healthy, recreationally active adults aged 18-38 years were included (12 males, 12 females; mean age 21.5 ± 4.8 years; BMI 23.5 ± 2.9 kg/m²). Participant demographic information and self-report measures are detailed in Table 1. “Recreationally active” was defined as participation in some form of physical activity for at least 20 minutes per day, at least three times a week. Individuals were excluded if they had any history of ankle or foot sprain, fracture in the leg or foot, disability secondary to lower extremity neuromuscular functional impairment, neurological or vestibular disorders that affected balance, diabetes mellitus, lumbosacral radiculopathy, a soft tissue disorder such as Marfan or Ehlers-Danlos syndrome, any absolute contraindication to manual therapy, or were pregnant. Participants who met inclusion criteria provided informed consent and the study was approved by the Institutional Review Board. Figure 1 is a flowsheet illustrating recruitment, retention, and time points for this study.

Assessors

All participants were evaluated by two clinicians. The first clinician (Tester 1) was an athletic trainer (height = 162.6 cm, mass = 59.0 kg, surface area of the palmar hand = 159.0 cm²) with two years of clinical experience. The second clinician (Tester 2) was a physical therapist (height = 180.3 cm, mass = 88.5 kg, surface area of the palmar hand = 221.0 cm²) with 14 years of clinical experience and was a board certified
orthopaedic clinical specialist. Both clinicians were right-hand dominant and trained in morphologic assessment of the foot, goniometry, inclinometry, handheld dynamometry, gross motor assessment, and assessment of joint play and employed these skills regularly in practice.

### Procedures

Prior to participant recruitment, both clinicians reviewed assessment procedures and performed collaborative trial assessments together to ensure agreement on examination technique and interpretation. Each clinician performed the examinations independently and did not confer on the findings. Clinician order was randomized using a Latin-square. Due to the potential influence on foot morphology

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### Table 1. Participant Demographic and Self-Reported Measures

<table>
<thead>
<tr>
<th>Measure</th>
<th>Male (n=12)</th>
<th>Female (n=13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>23.3 (6.4)</td>
<td>19.8 (1.2)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>176.0 (6.9)</td>
<td>162.6 (12.1)</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>74.6 (9.4)</td>
<td>60.3 (9.0)</td>
</tr>
<tr>
<td>BMI</td>
<td>24.0 (2.0)</td>
<td>23.0 (3.5)</td>
</tr>
<tr>
<td>Godin Leisure Time Questionnaire</td>
<td>88.2 (24.6)</td>
<td>71.8 (26.7)</td>
</tr>
<tr>
<td>Foot and Ankle Ability Measure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADL</td>
<td>99.8 (0.6)</td>
<td>100 (0)</td>
</tr>
<tr>
<td>ADL SANE</td>
<td>99.8 (0.6)</td>
<td>100 (0)</td>
</tr>
<tr>
<td>Sport</td>
<td>99.8 (0.9)</td>
<td>99.5 (1.7)</td>
</tr>
<tr>
<td>Sport SANE</td>
<td>99.9 (0.3)</td>
<td>99.6 (1.4)</td>
</tr>
<tr>
<td>Identification of Functional Ankle Instability (IdFAI)</td>
<td>0.6 (1.4)</td>
<td>1.6 (2.4)</td>
</tr>
<tr>
<td>Tampa Scale of Kinesiophobia</td>
<td>16.0 (4.3)</td>
<td>15.4 (2.9)</td>
</tr>
<tr>
<td>Veterans RAND 12-Item Health Survey</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical Composite</td>
<td>56.6 (3.2)</td>
<td>58.0 (2.5)</td>
</tr>
<tr>
<td>Mental Composite</td>
<td>48.0 (0.8)</td>
<td>48.7 (1.2)</td>
</tr>
<tr>
<td>Physical Function</td>
<td>100 (0)</td>
<td>100 (0)</td>
</tr>
<tr>
<td>Role Physical</td>
<td>96.9 (7.8)</td>
<td>98.1 (6.9)</td>
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<tr>
<td>Bodily Pain</td>
<td>95.8 (9.7)</td>
<td>100 (0)</td>
</tr>
<tr>
<td>General Health</td>
<td>89.6 (16.7)</td>
<td>80.8 (11.0)</td>
</tr>
<tr>
<td>Vitality</td>
<td>68.8 (21.7)</td>
<td>59.6 (21.7)</td>
</tr>
<tr>
<td>Social Function</td>
<td>91.7 (16.3)</td>
<td>96.2 (9.4)</td>
</tr>
<tr>
<td>Emotional Role</td>
<td>99.0 (3.6)</td>
<td>94.2 (9.7)</td>
</tr>
<tr>
<td>Mental Health</td>
<td>79.2 (12.3)</td>
<td>67.3 (20.8)</td>
</tr>
</tbody>
</table>

### Time spent barefoot per day

<table>
<thead>
<tr>
<th>Time spent barefoot per day</th>
<th>Right</th>
<th>Left</th>
<th>Right</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-29 minutes</td>
<td>2 (16.7)</td>
<td>0 (0)</td>
<td>3 (23.1)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>30-59 minutes</td>
<td>2 (16.7)</td>
<td>3 (23.1)</td>
<td>3 (23.1)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>&gt; 60 minutes</td>
<td>2 (16.7)</td>
<td>3 (23.1)</td>
<td>3 (23.1)</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

### Foot Posture Index

<table>
<thead>
<tr>
<th>Foot Posture Index</th>
<th>Right</th>
<th>Left</th>
<th>Right</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highly Pronated</td>
<td>2 (16.7)</td>
<td>3 (23.1)</td>
<td>3 (23.1)</td>
<td>2 (15.4)</td>
</tr>
<tr>
<td>Pronated</td>
<td>3 (25.0)</td>
<td>4 (33.3)</td>
<td>6 (46.2)</td>
<td>3 (23.1)</td>
</tr>
<tr>
<td>Normal</td>
<td>4 (33.3)</td>
<td>3 (25.0)</td>
<td>2 (15.4)</td>
<td>6 (46.2)</td>
</tr>
<tr>
<td>Supinated</td>
<td>3 (25.0)</td>
<td>2 (16.7)</td>
<td>2 (15.4)</td>
<td>2 (15.4)</td>
</tr>
<tr>
<td>Highly Supinated</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

SD=standard deviation, cm=centimeters, kg=kilograms, BMI=body mass index, ADL=activities of daily living, SANE=single assessment numeric evaluation

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Figure 1. Flowsheet illustrating recruitment, retention, and study time points.
and intrinsic foot muscle strength, participants were asked the amount of time spent barefoot daily. Participants provided demographic information, health and injury history, and completed the Foot and Ankle Ability Measure (FAAM) Activities of Daily Living\textsuperscript{16} and Sport subscales,\textsuperscript{17} Identification of Functional Ankle Instability (IdFAI),\textsuperscript{18} Veterans Rand 12-item Health Survey (VR-12),\textsuperscript{19} and the Godin Leisure-time Exercise Questionnaire.\textsuperscript{20}

**Morphologic Foot Assessment**

Foot posture was assessed in standing using the Foot Posture Index–6 item version (FPI-6), a categorical measure of foot type that is based on five observations and one palpatory assessment.\textsuperscript{21} Measurements of total and truncated foot length, arch height, and foot width were performed using the Arch Height Index Measurement System (JAKTOOL Corporation, Cranberry, NJ) in sitting and standing.

**Joint Excursion Measures**

Joint range of motion measures of rearfoot dorsiflexion, plantarflexion, inversion, and eversion were performed using a 30.5-cm transparent double arm plastic goniometer (Merck Corporation, Kenilworth, NJ). Forefoot inversion and eversion was measured using a digital inclinometer (Fabrication Enterprises, White Plains, NY) (Figure 2a) First metatarsal dorsiflexion and plantarflexion were measured utilizing a custom measuring device consisting of two metal rulers bent to 90° described by Greisberg and colleagues\textsuperscript{22} (Figures 2b,c). The stationary arm of the device was constructed from a 16-cm metal ruler bent to 90-degrees. The moving arm of the device was cut to 10-cm (bent to 90-degrees at the 5-cm mark) and fastened to the stationary arm with two plastic zip ties and a rubber tensioner. First metatarsophalangeal flexion and extension were measured with a 17-cm double arm plastic goniometer with a semicircular scale (Upjohn Corporation, Kalamazoo, MI). The details to patient position and procedures for each joint excursion measure are outlined in Table 2. The total arc of motion within a plane was used for analysis of joint excursion.

**Joint Play Motion**

Proximal tibiofibular joint mobility was assessed for the presence or absence of hypomobility. Joint play was assessed using the 7-point Likert scale (0 = ankylosed, 1 = considerable hypomobility, 2 = slight hypomobility, 3 = normal, 4 = slight hypermobility, 5 = considerable hypermobility, 6 = unstable) developed for quantification of passive mobility intervertebral motion by Gonnella and colleagues.\textsuperscript{23} Details to patient position and procedures for each joint play measure are outlined in Table 3.

**Strength and Motor Function**

Muscle strength was assessed with the MicroFET2 digital handheld dynamometer (Hoggan Health

\textbf{Figure 2.} a. Measure of forefoot on rearfoot inversion/eversion excursion. b. Custom measuring device and c. illustration of measurement of first metatarsal dorsiflexion and plantarflexion.
### Table 2. Clinical Measures of Joint Excursion and Strength

<table>
<thead>
<tr>
<th>Measure</th>
<th>Instrument</th>
<th>Position</th>
<th>Description of Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rearfoot</td>
<td>DF/PF 30.5cm goniometer</td>
<td>Supine</td>
<td>Stationary arm: Midline lateral leg; Axis: Lateral malleolus; Moving arm: Lateral foot</td>
</tr>
<tr>
<td>Inversion/</td>
<td>Goniometer</td>
<td>Prone</td>
<td>Stationary arm: Midline posterior leg; Axis: Subtalal joint; Moving arm: Midline posterior calcaneus</td>
</tr>
<tr>
<td>Eversion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standing DF</td>
<td>Paper tape measure</td>
<td>Standing Lunge</td>
<td>The foot is cantilevered over the plinth edge. Rearfoot is manually stabilized by cupping and gripping the calcaneus. Inclinometer is aligned across the plantar metatarsal head. The forefoot is maximally inverted and everted on the rearfoot.</td>
</tr>
<tr>
<td>First TMT</td>
<td>Modified ruler</td>
<td>Supine</td>
<td>As described by Bennel (1998)</td>
</tr>
<tr>
<td>Hallux Flexion/Extension</td>
<td>17cm goniometer</td>
<td></td>
<td>Stationary arm: Midline lateral first metatarsal; Axis: Lateral metatarsal head Moving arm: Lateral proximal phalanx</td>
</tr>
<tr>
<td>Ankle DF</td>
<td>Handheld Dynamometer</td>
<td>Supine</td>
<td>Tested in neutral DF/PF. Force measured at the metatarsal heads. The shank was manually stabilized.</td>
</tr>
<tr>
<td>Inversion</td>
<td></td>
<td>Prone</td>
<td>Tested with foot and ankle in neutral. Force measured at the metatarsal heads. Shank was manually stabilized.</td>
</tr>
<tr>
<td>Eversion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial/Lateral Glide</td>
<td>C-grip</td>
<td>Side-lying</td>
<td>With the foot cantilevered over the plinth edge, the clinician stabilizes the shank and cups the calcaneus and talus using a C-grip. A medial or lateral directed force is applied through the calcaneus for assessment of inversion. A lateral or medial directed force is applied through the calcaneus for assessment of eversion.</td>
</tr>
<tr>
<td>Inversion</td>
<td>Passive Mobility Scale</td>
<td></td>
<td>The clinician palpates the joint line of the proximal tibiofibular joint as the patient actively cycles through DF/PF of the foot.</td>
</tr>
<tr>
<td>Eversion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial/Lateral Glide</td>
<td>C-grip</td>
<td>Side-lying</td>
<td>The foot is cantilevered over the plinth edge. Rearfoot is manually stabilized by using a C-grip around the calcaneus and talus. An inversion or eversion force is applied at the distal metatarsals.</td>
</tr>
<tr>
<td>Talar Anterior and Posterior Glide</td>
<td></td>
<td>Supine</td>
<td>The clinician contacts the anterior lateral malleolus using the thenar eminence of the mobilizing hand and applies an anterior-posterior force.</td>
</tr>
<tr>
<td>Inversion</td>
<td></td>
<td></td>
<td>With the foot cantilevered over the plinth edge, the clinician stabilizes the shank and cups the calcaneus and talus using a C-grip. A medial directed rotatory force is applied through the calcaneus for assessment of inversion; a lateral directed rotatory force is applied through the calcaneus for assessment of eversion.</td>
</tr>
<tr>
<td>Eversion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial/Lateral Glide</td>
<td>C-grip</td>
<td>Side-lying</td>
<td>With the foot cantilevered over the plinth edge, the clinician stabilizes the shank and cups the calcaneus and talus using a C-grip. A medial or lateral directed force is applied through the calcaneus for assessment of inversion. A lateral or medial directed force is applied through the calcaneus for assessment of eversion.</td>
</tr>
<tr>
<td>Abduction</td>
<td></td>
<td></td>
<td>The foot is cantilevered over the plinth edge. Rearfoot is manually stabilized by using a C-grip around the calcaneus and talus. An inversion or eversion force is applied at the distal metatarsals.</td>
</tr>
<tr>
<td>Adduction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forefoot</td>
<td></td>
<td>Hook-lying</td>
<td>With the foot flat on the plinth, the first cuneiform is manually stabilized. The base of the first metatarsal is gripped with the mobilizing hand and a dorsal force is applied. The procedure is repeated with a plantar directed force.</td>
</tr>
<tr>
<td>Hallux</td>
<td></td>
<td></td>
<td>The great toe is cantilevered over the plinth edge. The first metatarsal is manually stabilized. The base of the first proximal phalanx is gripped with the mobilizing hand; a distraction force is applied followed by a dorsal directed glide. The procedure is repeated with a distraction and plantar directed force.</td>
</tr>
</tbody>
</table>

DF = dorsiflexion PF = plantarflexion TMT = Tarsometatarsal

### Table 3. Clinical Measures of Joint Play Motion.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Instrument</th>
<th>Position</th>
<th>Description of Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shank</td>
<td>+/- hypomobility</td>
<td>Seated</td>
<td>The clinician palpates the joint line of the proximal tibiofibular joint as the patient actively cycles through DF/PF of the foot.</td>
</tr>
<tr>
<td>Distal tibiofibular posterior glide</td>
<td></td>
<td></td>
<td>The heel is cupped in the treating clinicians stabilizing hand. The clinician contacts the anterior lateral malleolus using the thenar eminence of the mobilizing hand and applies an anterior-posterior force.</td>
</tr>
<tr>
<td>Talar Anterior and Posterior Glide</td>
<td>C-grip</td>
<td>Supine</td>
<td>With the foot cantilevered over the plinth edge, the clinician stabilizes the shank and cups the calcaneus and talus using a C-grip. A medial directed rotatory force is applied through the calcaneus for assessment of inversion; a lateral directed rotatory force is applied through the calcaneus for assessment of eversion.</td>
</tr>
<tr>
<td>Medial/Lateral Glide</td>
<td>C-grip</td>
<td>Side-lying</td>
<td>The foot is cantilevered over the plinth edge. Rearfoot is manually stabilized by using a C-grip around the calcaneus and talus. An inversion or eversion force is applied at the distal metatarsals.</td>
</tr>
<tr>
<td>Inversion</td>
<td>Passive Mobility Scale</td>
<td></td>
<td>The foot is cantilevered over the plinth edge. Rearfoot is manually stabilized by using a C-grip around the calcaneus and talus. An inversion or eversion force is applied at the distal metatarsals.</td>
</tr>
<tr>
<td>Eversion</td>
<td>C-grip</td>
<td>Side-lying</td>
<td>With the foot cantilevered over the plinth edge, the clinician stabilizes the shank and cups the calcaneus and talus using a C-grip. A medial or lateral directed force is applied through the calcaneus for assessment of inversion. A lateral or medial directed force is applied through the calcaneus for assessment of eversion.</td>
</tr>
<tr>
<td>Abduction</td>
<td>C-grip</td>
<td>Side-lying</td>
<td>With the foot cantilevered over the plinth edge, the clinician stabilizes the shank and cups the calcaneus and talus using a C-grip. A medial or lateral directed force is applied through the calcaneus for assessment of inversion. A lateral or medial directed force is applied through the calcaneus for assessment of eversion.</td>
</tr>
<tr>
<td>Adduction</td>
<td>C-grip</td>
<td>Side-lying</td>
<td>With the foot cantilevered over the plinth edge, the clinician stabilizes the shank and cups the calcaneus and talus using a C-grip. A medial or lateral directed force is applied through the calcaneus for assessment of inversion. A lateral or medial directed force is applied through the calcaneus for assessment of eversion.</td>
</tr>
<tr>
<td>Forefoot</td>
<td>C-grip</td>
<td>Hook-lying</td>
<td>With the foot flat on the plinth, the first cuneiform is manually stabilized. The base of the first metatarsal is gripped with the mobilizing hand and a dorsal force is applied. The procedure is repeated with a plantar directed force.</td>
</tr>
<tr>
<td>Hallux</td>
<td>C-grip</td>
<td>Hook-lying</td>
<td>The great toe is cantilevered over the plinth edge. The first metatarsal is manually stabilized. The base of the first proximal phalanx is gripped with the mobilizing hand; a distraction force is applied followed by a dorsal directed glide. The procedure is repeated with a distraction and plantar directed force.</td>
</tr>
</tbody>
</table>

TMT = Tarsometatarsal MTP = Metatarsophalangeal DF = Dorsiflexion PF = Plantarflexion
Industries, West Jordan, UT). Details to patient position and procedures for each joint strength measure are outlined in Table 2 and illustrated in Figure 3. Strength measures were based on a single trial of a “make test” and reported in Newtons (N). In the case of an invalid trial (due to equipment difficulty, deviation from test position, or substitution motion), the participant rested prior to retesting to mitigate effects from fatigue. The IFM test was performed and graded using the scale (1=Poor; 2=Fair; 3=Satisfactory) described by Jam.13

Motor performance and participant’s rating of perceived difficulty were assessed during the medial longitudinal arch draw up maneuver (short-foot exercise), the toe-spread-out exercise, hallux extension, and lesser toe extension exercise. These exercises are employed clinically and have scant evidence to support their use in treatment of conditions of the foot and ankle.24–26 The measurement properties of novel assessments of motor performance and task difficulty during IFM exercises need to be established before these interventions can be tested empirically. Motor performance was assessed using a scale adapted from the gross motor assessment developed by Bérard and colleagues27 (0 = does not initiate movement or starting position cannot be maintained; 1 = partially completes the exercise; 2 = completes the exercise with compensations, slowness or obvious clumsiness; 3 = completes the exercise with a standard pattern). Perceived difficulty was assessed by asking the participant to rate the task using a 5-point Likert scale (1 = Very easy; 2 = Somewhat easy; 3 = Neutral; 4 = Somewhat Difficult; 5 = Very Difficult). The exercises were performed sitting barefoot, with the foot in contact with the floor. During the short-foot exercise, the participant was instructed to draw the medial longitudinal arch up while maintaining the metatarsal heads, toes, and heel in contact with the ground. This maneuver was performed correctly if there was an approximation of the calcaneus and first metatarsal head resulting in a shortening of the foot. The toe-spread-out exercise was performed sequentially by extending all the toes, followed by abduction, hallux flexion, and little toe flexion. Hallux extension was performed by extending the first metatarsophalangeal joint while maintaining the lesser toes (2-5) in contact with the floor. Lesser toe extension was performed by extending toes 2-5 while maintaining the hallux in contact with the ground. Video of the exercises can be accessed at https://goo.gl/ugffZ8. Patients were verbally instructed in the maneuvers and guided through a practice trial before assessment. Following instruction, the participant performed the exercise and motor performance was...
assessed. The participant was allowed a second attempt if motor performance was sub-optimal (rated < 3) on the first trial. Motor performance and rating of perceived difficulty were recorded immediately following each task.

**Statistical Analysis**

The level of significance was set *a priori* at *p* ≤0.05 for all analyses. *A priori* sample size estimation of 14 participants were needed based on two clinician measurements per variable, a reliability of ≥.70 considered desirable, an α = .05, and β = .20. Group descriptive statistics were calculated for participant demographic information and self-reported measures. Test-retest and inter-rater reliability of variables measured on a continuous scale or an ordinal scale with at least five items were assessed with intraclass correlation coefficients (ICC2,k), with >.75 interpreted as being excellent, .40-.75 as fair to good, and <.40 as poor. Measures with negative ICCs were interpreted as having systematic disagreement.

Linear weighted *k* statistics were used to assess test-retest and intertester agreement for measures of hypomobility in the proximal tibiofibular joint, motor performance during intrinsic foot exercises, and the intrinsic foot muscle test with agreement interpreted as almost perfect from 0.81-1.00; 0.41-0.60 as moderate; 0.21-0.40 as fair; 0.00-0.20 as slight, and < 0.00 as poor. Descriptive statistics, ICC, and *k* estimates were computed using Statistical Package for Social Sciences (SPSS) Version 23.0 (SPSS, Inc., Chicago, IL). SEM and MDC were calculated from the mean variance of bilateral measures and both clinicians from visit one and the mean of ICC values for test-retest reliability for both limbs measured by both assessors using Microsoft Excel for Mac Version 15 (Microsoft Corp., Redmond, WA).

**RESULTS**

**Morphologic Foot Measures**

Test-retest and inter-rater reliability was found to be excellent (.81-1.00) for the FPI and morphologic measures of foot length, truncated foot length, foot width, and dorsal arch height (Table 4). The mean FPI scores were consistent between assessors and between visits (within 1 point on a 25-point scale). SEM was 2 points (rounded to the next integer) and MDC was 5 points (rounded). Group means were consistent between assessors and laboratory

### Table 4. Reliability of Foot Morphologic Measures.

<table>
<thead>
<tr>
<th></th>
<th>Group Means (SD)</th>
<th>Inter-rater Reliability</th>
<th>Test-Retest Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Reassessment</td>
<td>Baseline</td>
</tr>
<tr>
<td></td>
<td>Tester 1 Test 1</td>
<td>Tester 2 Test 2</td>
<td>Tester 1 Test 1</td>
</tr>
<tr>
<td></td>
<td>Rt Lt RtLt</td>
<td>Rt Lt RtLt</td>
<td>Rt Lt RtLt</td>
</tr>
<tr>
<td></td>
<td>SEM MDC</td>
<td>SEM MDC</td>
<td>SEM MDC</td>
</tr>
<tr>
<td>Foot Length</td>
<td>25.3 25.2 25.2</td>
<td>25.1 25.3 25.3 25.2</td>
<td>.1 2</td>
</tr>
<tr>
<td>(cm)</td>
<td>(2.0) (2.0) (2.0)</td>
<td>(2.0) (2.0) (2.0) (2.0)</td>
<td></td>
</tr>
<tr>
<td>Truncated Foot</td>
<td>18.6 18.3 18.6</td>
<td>18.5 18.6 18.4 18.4</td>
<td>.2 .4</td>
</tr>
<tr>
<td>Length (cm)</td>
<td>(1.5) (.14) (.14)</td>
<td>(.15) (.15) (.15) (.16)</td>
<td></td>
</tr>
<tr>
<td>Foot Width</td>
<td>92.4 91.7 90.8</td>
<td>89.8 92 91.6 91.0</td>
<td>.1 .2</td>
</tr>
<tr>
<td>(mm)</td>
<td>(6.7) (6.7) (6.7)</td>
<td>(6.0) (6.7) (5.9) (6.7)</td>
<td></td>
</tr>
<tr>
<td>Dorsal Arch</td>
<td>6.5 6.5 6.6</td>
<td>6.6 6.6 6.6 6.7</td>
<td>.1 .2</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>(0.6) (0.6) (0.6)</td>
<td>(0.6) (0.6) (0.6) (0.6)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foot Length</td>
<td>25.8 25.7 25.6</td>
<td>25.6 25.8 25.7 25.6</td>
<td>.1 .2</td>
</tr>
<tr>
<td>(cm)</td>
<td>(2.0) (2.0) (2.0)</td>
<td>(2.0) (2.0) (2.0) (2.0)</td>
<td></td>
</tr>
<tr>
<td>Truncated Foot</td>
<td>19.1 18.7 18.9</td>
<td>18.8 19.1 18.8 18.9</td>
<td>.2 .4</td>
</tr>
<tr>
<td>Length (cm)</td>
<td>(1.5) (.14) (.14)</td>
<td>(.15) (.15) (.15) (.14)</td>
<td></td>
</tr>
<tr>
<td>Foot Width</td>
<td>94.9 94.1 92.8</td>
<td>92.3 94.8 94.9 93.0</td>
<td>.9 .25</td>
</tr>
<tr>
<td>(mm)</td>
<td>(6.9) (5.9) (6.9)</td>
<td>(6.3) (6.4) (6.2) (6.7)</td>
<td></td>
</tr>
<tr>
<td>Dorsal Arch</td>
<td>6.0 6.0 6.1</td>
<td>6.1 6.1 6.1 6.2</td>
<td>.1 .2</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>(0.6) (0.6) (0.6)</td>
<td>(0.7) (0.6) (0.7) (0.6)</td>
<td></td>
</tr>
<tr>
<td>Foot Posture</td>
<td>4.8 5.0 5.3</td>
<td>4.7 5.6 5.6 6.4</td>
<td>1.6 4.5</td>
</tr>
<tr>
<td>Index*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The Foot Posture Index scale ranges from -12 indicating highly supinated to +12 indicating highly pronated. A score of 0-5 is considered a “normal” foot. SD=standard deviation, SEM=standard error of measurement, MDC=minimal detectable change, Rt=right, Lt=left
visits for measures performed using the Arch Height Index instrument, with SEM ranging from 1-2 mm and MDC ranging from 2-4 mm.

**Joint Excursion Measures**

Measures of joint excursion had excellent reliability (.81-.97) in 67% of the measures performed by Tester 1 and in 83% of measures performed by Tester 2. Table 5 details the reliability of joint excursion measures of the ankle-foot complex. Group means for standing dorsiflexion were consistent between assessors and laboratory visits. The measure had low variability, resulting in a SEM of 7-mm and a 2-cm MDC. Goniometric and inclinometric measures were consistent between visits for each clinician, but group means were higher for Tester 1 for subtalar and forefoot frontal plane excursion as compared to Tester 2. Standard error for goniometric and inclinometric measures ranged from 4-6°, with MDC ranging from 12-15°. Mean first metatarsal excursion measures were relatively consistent between assessors and visits. There was greater variability observed in measurements performed by Tester 2 on both visits. Standard error for first metatarsal excursion measures was 1-cm, with a MDC of 4-cm.

**Joint Play Measures**

Test-retest reliability of joint play motion (.67-.1.00) varied widely between clinicians; with the more experienced clinician (Tester 2) demonstrating greater consistency (53% of measures good to excellent) compared the novice clinician (Tester 1) (28% of measures good to excellent). Inter-rater reliability was poor (-1.06-.39) in 73% of joint play measures (Tables 6 and 7). Group means were relatively consistent between sessions. When comparing clinicians, group means for Tester 2 were lower in many joint play measures. SEM ranged from 0.4-0.6, with a MDC of a full grade for all but two joint play measures.

**Strength Measures**

Reliability of strength measures of the ankle-foot complex were found to have excellent test-retest reliability (.76-.88) in 58% of the measures performed by Tester 1 and 92% performed by Tester 2. Table 8 details the reliability of strength measures of the ankle-foot complex. SEM and MDC for all measures sans ankle plantarflexion ranged from 18.0-23.6 N with a MDC of 49.8-65.5 N. Ankle plantarflexion was found to have a SEM of 41.6 and a MDC of 115.2 N.

**Rating of Perceived Difficulty and Measures of Motor Performance during IFM Exercises**

Repeatability of reported task difficulty was highest for the short-foot (.75-.90) and hallux extension exercises (.87-.96) and more variable during toe-spread-out exercise (.61-.82) and the lesser toe extension (.16-.50) (Table 9). Participants reported substantial decreases in perceived difficulty during the short-foot (2.1-2.4 to 1.9-2.0), toe-spread-out (3.1-3.9 to

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<table>
<thead>
<tr>
<th>Table 5. Reliability of Joint Excursion Measures of the Ankle-Foot Complex.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group Means (SD)</strong></td>
</tr>
<tr>
<td><strong>Baseline</strong></td>
</tr>
<tr>
<td>Tester 1</td>
</tr>
<tr>
<td><strong>SEM</strong></td>
</tr>
<tr>
<td>Standing DF (cm)</td>
</tr>
<tr>
<td>(3.9)</td>
</tr>
<tr>
<td>Talocrural DF/PF (deg)</td>
</tr>
<tr>
<td>(7.4)</td>
</tr>
<tr>
<td>Subtalar Inv/Ev (deg)</td>
</tr>
<tr>
<td>(12.2)</td>
</tr>
<tr>
<td>Forefoot Inv/Ev (deg)</td>
</tr>
<tr>
<td>(16.7)</td>
</tr>
<tr>
<td>First MT DF/PF (mm)</td>
</tr>
<tr>
<td>(2.9)</td>
</tr>
<tr>
<td>Hallux Ext/ Flex (deg)</td>
</tr>
<tr>
<td>(16.0)</td>
</tr>
<tr>
<td><strong>SD=standard deviation, SEM=standard error of measurement, MDC=minimal detectable change, Rt=right, Lt=left, DF=dorsiflexion, PF=plantarflexion, Inv/inversion, Ev/eversion, MT=metatarsal, Ext/extension, Flex/flexion</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Poor</th>
<th>Fair</th>
<th>Good</th>
<th>Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>Fair</td>
<td>Good</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

The International Journal of Sports Physical Therapy | Volume 12, Number 7 | December 2017 | Page 1141
2.9-3.2), hallux extension (2.6-3.0 to 2.2-2.6), and lesser toe extension (2.0 reported for both limbs to each assessor to 1.6-1.8) exercises from baseline to reassessment. The subjective rating reported to the clinicians was consistent (.76-.97) within session for the short-foot, toe-spread-out, and hallux extension exercises and highly variable for the lesser toe extension during baseline assessment (-.08-.00). Consistency of the patient reported difficulty for lesser toe extension improved during reassessment (.71-.93).
Similarly, agreement of clinician's rating of motor performance was fair to moderate (.51-.86) for the short-foot and toe-spread-out exercises and substantial (.62-.71) for hallux extension exercise. Test-retest agreement of lesser toe extension varied between clinicians, with poor to slight (-.01-.02) observed in Tester 1 and moderate to substantial (.46-.68) in Tester 2. The IFM test had slight to moderate (.17-.44) test-retest reliability. Similarly, inter-rater reliability was poor to moderate during baseline assessment (-.02-.50) that improved to slight to moderate agreement (.16-.56) on the second session. Rating of motor performance during hallux extension and lesser toe extension exercises improved from baseline to reassessment.

Table 8. Reliability of Strength Measures of the Ankle-Foot Complex.

<table>
<thead>
<tr>
<th>Group Means (SD)</th>
<th>Baseline Test</th>
<th>Reassessment Test</th>
<th>Inter-rater Reliability</th>
<th>Test-Retest Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tester 1</td>
<td>Tester 2</td>
<td>Tester 1</td>
<td>Tester 2</td>
</tr>
<tr>
<td></td>
<td>SEM</td>
<td>MDC</td>
<td>Tester 1</td>
<td>Tester 2</td>
</tr>
<tr>
<td></td>
<td>Rt</td>
<td>Lt</td>
<td>Rt</td>
<td>Lt</td>
</tr>
<tr>
<td>Ankle DF (N)</td>
<td>267.1</td>
<td>257.4</td>
<td>259.2</td>
<td>251.2</td>
</tr>
<tr>
<td>Ankle PF (N)</td>
<td>365.8</td>
<td>360.2</td>
<td>453.3</td>
<td>455.6</td>
</tr>
<tr>
<td>Ankle Inversion</td>
<td>196.6</td>
<td>197.0</td>
<td>237.6</td>
<td>251.6</td>
</tr>
<tr>
<td>Inversion (N)</td>
<td>194.0</td>
<td>191.5</td>
<td>234.3</td>
<td>222.0</td>
</tr>
<tr>
<td>Lesser Toe</td>
<td>112.3</td>
<td>111.8</td>
<td>142.7</td>
<td>144.7</td>
</tr>
<tr>
<td>Flexion (N)</td>
<td>103.9</td>
<td>110.4</td>
<td>121.5</td>
<td>135.5</td>
</tr>
</tbody>
</table>

SEM=standard error of measurement, MDC=minimal detectable change, Rt=right, Lt=left

Table 9. Reliability of Participant-Reported Task Difficulty and Measures of Motor Performance of Short-foot and Toe Exercises.

<table>
<thead>
<tr>
<th>Group Means (SD)</th>
<th>Baseline Test</th>
<th>Reassessment Test</th>
<th>Inter-rater Reliability</th>
<th>Test-Retest Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tester 1</td>
<td>Tester 2</td>
<td>Tester 1</td>
<td>Tester 2</td>
</tr>
<tr>
<td></td>
<td>SEM</td>
<td>MDC</td>
<td>Tester 1</td>
<td>Tester 2</td>
</tr>
<tr>
<td></td>
<td>Rt</td>
<td>Lt</td>
<td>Rt</td>
<td>Lt</td>
</tr>
<tr>
<td>Short-foot</td>
<td>2.2</td>
<td>2.4</td>
<td>2.4</td>
<td>2.1</td>
</tr>
<tr>
<td>Exercise†</td>
<td>(1.3)</td>
<td>(1.3)</td>
<td>(1.3)</td>
<td>(1.3)</td>
</tr>
<tr>
<td>Toe-spread-out</td>
<td>3.1</td>
<td>3.5</td>
<td>3.8</td>
<td>3.9</td>
</tr>
<tr>
<td>Hallux Extension</td>
<td>2.8</td>
<td>2.6</td>
<td>3.0</td>
<td>2.7</td>
</tr>
<tr>
<td>Lesser Toe</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.1</td>
</tr>
<tr>
<td>Flexion†</td>
<td>(1.0)</td>
<td>(1.1)</td>
<td>(1.0)</td>
<td>(0.5)</td>
</tr>
<tr>
<td>Muscle Test†</td>
<td>(1.0)</td>
<td>(1.0)</td>
<td>(0.8)</td>
<td>(0.8)</td>
</tr>
</tbody>
</table>

SEM=standard error of measurement, MDC=minimal detectable change, Rt=right, Lt=left

† Rated on a 1-5 Likert scale (1=very easy, 5=very difficult).
$^\dagger$ Rated using the motor scale described by Bérad. $^\dagger$
$^\dagger$ Rated by clinician using the scale described by Jam. $^\dagger$

The IFM test had slight to moderate (.17-.44) test-retest reliability. Similarly, inter-rater reliability was poor to moderate during baseline assessment (-.02-.50) that improved to slight to moderate agreement (.16-.56) on the second session. Rating of motor performance during hallux extension and lesser toe extension exercises improved from baseline to reassessment.

The International Journal of Sports Physical Therapy | Volume 12, Number 7 | December 2017 | Page 1143
DISCUSSION
The principal findings of this study were that reliability was excellent in all morphologic foot measures and rearfoot and hallux sagittal excursion, fair to good in rearfoot frontal plane excursion, poor to excellent in joint play motion with disparity between clinicians, and good to excellent in strength measures. Participant-reported difficulty and motor performance during short-foot and toe exercises had fair to excellent agreement, except for lesser toe extension and the IFM test which had poor inter-rater agreement on the baseline assessment.

Morphologic Foot Assessment
Morphologic measures of the foot using the Arch Height Index Measurement System and the FPI were found to be expedient and having excellent reliability. These findings are consistent with other studies investigating the reliability of Arch Height Index Measurement System and FPI. Butler and colleagues\(^3\) reported the test-retest reliability of the Arch Height Index Measurement System to be .96-.99 and inter-rater reliability to be .98-.99 for arch height, truncated foot length, and foot length. These measures may be utilized in isolation, or as part of a composite measures such as the arch height index\(^3\) or foot mobility magnitude,\(^3\) to quantify longitudinal or transverse deformation of the foot across loading. The MDC values were relatively small and ranged from 2-4 mm, which makes morphologic measurements suitable as a potential outcome measure in clinical practice or in research.

The FPI, which is comprised of five observations of foot morphology and one palpation of talar head position, had excellent test-retest and inter-rater reliability (.81-.86). While excellent test-retest reliability has previously been reported, the findings of excellent inter-rater reliability in this study were substantially higher than the moderate reliability found in prior study of the FPI.\(^3\)\(^7\)\(^8\) MDC of the FPI was five points (rounded to the next integer) and reflective of a full categorical shift in foot morphotype (i.e. normal to pronated foot type). Despite having excellent repeatability, the large magnitude MDC in this measure is a product of high variability of foot morphotype observed in this sample (and likely reflective of the population in general). While this measure may not be ideal for assessing changes to the foot in the short term, it may have clinical and research utility when studying morphologic changes to the foot over the lifespan. It is recommended that morphologic foot measures be considered as a clinical or research outcome measure to capture deformation of the foot across loading.

Joint Excursion Measures
Excellent inter-rater and test-retest reliability (.96-.97) was observed during standing lunge dorsiflexion. These findings are consistent with data presented by Bennell and colleagues.\(^3\) Reliability of goniometric measures of the rearfoot were the highest when anatomical landmarks used for alignment were readily identifiable and not obfuscated by soft tissue. Rearfoot sagittal plane excursion had excellent test-retest and inter-rater reliability (.81-.88). The midline of the lateral foot, lateral fibula, and lateral malleolus are easily identifiable and utilized to align the moving arm, stationary arm, and the axis of goniometer during sagittal measures of dorsiflexion. Reliability of rearfoot frontal plane excursion was fair to good (.53-.73) with variability of measurement likely attributed to error in identification and alignment with obscure landmarks such as the subtalar joint and vertical axis of the calcaneus.

Clinician dexterity likely contributed to joint excursion measurement error. Tester 1, who had smaller stature and hand size of the two clinicians, demonstrated side-to-side differences in test-retest reliability in forefoot frontal plane and first metatarsal sagittal measures (fair to good reliability in the left limb and excellent reliability on the right). Both measures require a degree of ambidexterity to simultaneously stabilize and move adjacent segments while holding the instrument. It is plausible that disparate inconsistency between left and right measures is attributed to the 28% less hand surface area in this assessor.

Differences in the magnitude of overpressure applied by the clinicians during first metatarsal excursion measurement likely affected inter-rater reliability. While test-retest reliability was good to excellent for first metatarsal excursion in both raters (.62-.90), inter-rater reliability was poor to fair (.32-.53). Disparities in the amount of applied overpressure and soft tissue deformation due to the pliability
of the metatarsal pads are the most likely contributing factors to the inter-test reliability observed in
this measure.

Standard error for goniometric and inclinometric measures were 4-6°, with a MDC of 12-15° for the
total arc of motion. For sagittal plane talocrural and first metatarsophalangeal measures, this equates to
10-15% of the total excursion. In frontal plane rearfoot and forefoot measures, this equates to a 25% of
the total excursion. MDC was 2-cm (15% total excursion) and 4-mm (25% total excursion) for weight-
bearing dorsiflexion and first metatarsal excursion, respectively. The relatively higher MDC in frontal
plane measures are likely attributed to measurement error (more so in the rearfoot) and normal variability in motion.

Joint excursion measures, to include novel measures of forefoot on rearfoot inversion, eversion and
first metatarsal dorsiflexion excursion, had good to excellent repeatability and small MDC values. These
measures may have utility when assessing effectiveness of intervention aimed at improving range of motion, such as manual therapy, in the clinical population.

**Joint Play Motion**

Test-retest reliability of joint play motion ranged from poor to excellent (-.67-.84). Inter-rater reliability was poor (-1.06-.39) in 73% of the joint play measures. The distal tibiofibular posterior glide, subtalar medial glide, forefoot inversion and adduction, and tarsometatarsal dorsal and plantar glides had the highest test-retest reliability. Joint play measures were highly subjective, relied on a clinician's perceived magnitude of displacement, and were likely susceptible to bias. MDC for joint play measures were found to be a full grade on the mobility scale for all but two measures.

The mobility scale proposed by Gonnella and colleagues was developed as a means of quantifying and improving passive intervertebral joint play motion assessment reliability. This scale, which was based on the 4-point mobility scale (immobile, hypomobile, normal, and hypermobile) developed by Kaltenborn and Lindahl, added qualifiers that differentiated varying degrees of hypomobility and hypermobility in the assessment scheme. The utility of these qualifiers is questionable during the assessment of small magnitude joint play motions in the foot and ankle. Future study comparing the reliability of both scales is warranted for assessment of joint play motion in the ankle and foot.

Lack of a clearly defined reference is likely to be deleterious to consistency in assessment of joint play motion. Gonnella and colleagues described the reference for the joint mobility scale as the “expected normal for the patient when age, body type, and activity level are considered.” Differences in patient phenotype and clinician interpretation of normality make this reference a moving target. In peripheral assessment of joint laxity, clinicians often use the contralateral joint as a reference for comparison. By doing so, a quandary arose during assessment that is likely to have impacted reliability. It was challenging to determine if the assessed joint was hypermobile with normal mobility in the referenced contralateral joint, or if the assessed joint was normal with hypomobility in the contralateral joint. This differentiation was difficult, even when a participant's morphotype and generalized joint laxity was considered. In the current study, measures were made independently without consideration for other clinical correlates that would otherwise provide context for the findings. Ambiguity due to a poorly defined reference made judging magnitude of joint play motion difficult and likely contributed to inconsistency in these measures.

Clinical experience and expertise is likely to influence test-retest reliability in joint play measures. While both clinicians had fair to good reliability at best, the experienced clinician demonstrating greater consistency (53% of measures good) compared the novice clinician (28% of measures good). The higher reliability in measures conducted by the experienced clinician may be a result of uniformity of examination technique or consistency in interpretation of examination findings. Joint play measurements have previously been shown to be influenced by clinician technique, such as grip and test style. Magnitude and direction of force applied and joint position has also been shown to influence joint displacement. Habitual motor patterns formed from years of practice are likely to be more consistent
in an experienced clinician between multiple test sessions. Pattern recognition, improved analytical thinking, and intuition are components of clinical expertise that are formed with time and practice. Greater consistency in interpretation of examination findings is also a likely consequence to clinical expertise.

While joint play motion assessment had primarily poor to fair reliability, it is not the standard of care to utilize these measures in isolation. While not ideal as a primary outcome measure, these assessments may have utility as a clinical correlate with other measures when developing a diagnosis and plan of care. When assessing response to treatment, a change of one full grade on the mobility scale when combined with increases in joint excursion measures, should provide the clinician and researcher with ample information regarding changes in osteokinematic and arthrokinematic motion. The wider implications of these findings are that joint play measures, such as the talocrural anterior glide, are used clinically in surgical decision-making. The talocrural anterior glide (anterior drawer test) is used in the assessment of mechanical laxity and serves as a primary indication for surgical stabilization of the ankle. To ensure diagnostic accuracy and avoidance of unnecessary treatment (and associated financial burden and risk), it is recommended that instrumented measures of joint laxity, specifically ankle arthrometry of joint play in all three planes of motion, be utilized in lieu of manual assessment if surgery is a consideration.

**Strength**

Test-retest reliability and inter-rater reliability of hand-held dynamometric measures were found to be good to excellent. These findings are similar to those observed in the same laboratory by Kelln and colleagues. While variability in motor performance is expected during a maximal isometric task and with differences in strength between assessing clinicians, the authors posit that stabilization of the proximal segments, use of mobilization strap to assist in resisting force, and testing at a consistent joint angle likely contributed to the repeatability and inter-rater reliability observed for these measures in this study. Kelln and colleagues were unable to assess the reliability of handheld dynamometry measure of plantarflexion due to the tester being overpowered during testing. Use of a mobilization strap with the handheld dynamometer allowed the assessors to test this muscle group with excellent consistency.

The SEM for all strength measures, sans plantarflexion, ranged from 18.0-23.6 N, with MDC ranging from 49.8-65.5N. Plantarflexion measures, which were substantially higher in magnitude, had a SEM of 41.6 N and a MDC of 115.2 N. The MDC observed during strength assessment, which was 20-25% of the measure, are likely attributed to the variability often observed during motor tasks.

These findings should be considered when assessing changes in strength in healthy individuals using handheld dynamometry. It is recommended that clinicians ensure consistency of test position, joint angle, and proper stabilization when using a handheld dynamometry. Use of a strap to support the dynamometer and assist in resistance may improve consistency by reducing dependency on a clinician's upper body strength.

**Motor Performance during Short-foot, Toe Exercises, and IFM Test**

Motor performance of the IFM short-foot and toe exercises in this study were assessed using a novel application of the scale developed by Bérard and colleagues. In the original instrument, the motor scale was developed to assess gross motor function in individuals with neuromuscular disease. Reliability of motor performance varied with task complexity, the number of joint segments moving, and the plane of motion. Excellent test-retest and inter-rater reliability was observed in the uniaxial, single plane motion of hallux extension. To contrast this finding, tasks that were more complex, multisegmented, or involved less discrete movement patterns (such as the short-foot exercise, toe-spread-out exercise, and the IFM test) had less consistency and demonstrated fair to good repeatability and inter-rater reliability. Motor performance during tasks involving drawing up of the medial longitudinal arch (short-foot and IFM test) were generally less reliable compared to tasks involving the toes. It is unclear if this a consequence of greater volitional control of the toes compared to the medial longitudinal arch or the subtlety
of motion during a short-foot maneuver. Small subtle motions may be harder to be distinguish by the assessor and contribute to error.

There were data to suggest evidence of motor learning occurring within and between assessment visits. Inter-rater reliability for the lesser toe extension exercise was poor on baseline assessment and improved to good on the latter visit. This finding was likely attributed to the participant’s unfamiliarity with the task and variable performance during baseline testing. By the time the second assessor evaluated motor performance during the baseline visit, the participant had performed the tasks multiple times and consequently adapted to the novel task. Motor performance ratings provided by both clinicians also improved between visits, with higher ratings of performance during reassessment.

**Rating of Perceived Difficulty during Intrinsic Foot Muscle Exercises**

Repeatability of perceived task difficulty was excellent for the short-foot and hallux extension exercises, good to excellent in the toe-spread-out, and poor to fair for lesser toe extension. Tasks which had the lowest test-retest reliability were also the most complex (toe-spread-out and lesser toe extension) and demonstrated the largest decrease in perceived difficulty from baseline to reassessment. A disparity in task difficulty between limbs during the lesser toe extension tasks was also observed, with the left limb demonstrating greater variability between sessions. Except for the short-foot exercise, reliability of perceived difficulty paralleled motor performance in three of the four tasks. There was a disconnect between perceived difficulty and motor performance during the short-foot exercise, with participants reporting low difficulty while performing the task inappropriately or with substitution.

Inter-rater reliability was excellent for perceived task difficulty during short-foot, toe-spread-out, and hallux extension exercises. The lesser toe extension task had poor inter-rater reliability during baseline testing, which was also observed during assessment of motor performance of the same task. The authors posit that these findings are attributed to a decrease in task difficulty resulting from repetition and improvement in motor strategies.

The MDC for rating of task difficulty was 1-point (rounded to the next integer) for the short-foot and hallux extension exercises and 2-points for the toe-spread-out and lesser toe extension exercises. The minimal 2-point change is attributed to the variability of difficulty with the toe-spread-out exercise and poor to fair test-retest reliability in the lesser toe extension exercise.

Rating of motor performance and perceived difficulty during short-foot and toe exercises may have clinical utility in assessing IFM function. When assessing baseline measures, it is recommended that patients are assessed immediately following instruction of the tasks and after they have had an opportunity to practice the task. This additional baseline measure may capture any immediate motor learning that may occur. Subsequent measures may be contrasted to both baseline measures to assess effect of intervention.

**Limitations**

The current study does present with some limitations. While the assessing clinicians had similar training, they had different levels of experience and anthropometric characteristics. It is unclear which of these factors was most contributory to the findings in this study and should be investigated in the future. While an equal number of healthy male and female participants were recruited in this study, foot morphotype was not controlled for and resulted in an unequal representation in the current study’s sample. Previous research has suggested a link between foot posture and mobility. Future reliability studies should consider foot morphotype as a potential delimitation. These findings should be interpreted with caution when determining the effect of treatment in the clinical population. Variability in joint mobility or neuromotor function resulting from a clinical condition may increase the SEM and MDC of the measures. Future research to establish reliability, SEM, and MDC in specific clinical populations is needed.

**CONCLUSION**

Measures of ankle-foot posture, morphology, joint excursion, and strength demonstrated fair to excellent test-retest and inter-rater reliability. Test-retest reliability for rating of perceived difficulty and
motor performance was good to excellent for short-foot, toe-spread-out, and hallux exercises and poor to fair for lesser toe extension. Joint play measures had poor to fair reliability overall. The findings of this study should be considered when choosing methods of clinical assessment and outcome measures in practice and research.

REFERENCES


ABSTRACT

**Background and Purpose:** While there is much discussion about tendinopathy in the literature, there is little reference to the less common condition of iliopsoas tendinopathy, and no documentation of the condition in runners. The iliopsoas is a major decelerator of the hip and eccentric loading of the iliopsoas is an important component of energy transfer during running. Eccentric training is a thoroughly researched method of treating tendinopathy but has shown mixed results. The purpose of this case report is to describe the rehabilitation of a runner with iliopsoas tendinopathy, and demonstrate in a creative eccentric-biased technique to assist with treatment. A secondary objective is to illustrate how evidence on intervention for other tendinopathies was used to guide rehabilitation of this seldom described condition.

**Case Description:** The subject was a 39-year-old female middle distance runner diagnosed with iliopsoas tendinopathy via ultrasound, after sudden onset of left anterior groin pain. Symptoms began after a significant increase in running load, and persisted, despite rest, for three months. The intervention consisted of an eccentric-biased hip flexor exercise, with supportive kinetic chain exercises and progressive loading in a return to running program.

**Outcomes:** The Copenhagen Hip and Groin Outcome Score, the Visual Analogue Scale, the Global Rating of Change Scale and manual muscle testing scores all improved after 12 weeks of intervention with further improvement at the five-year follow up. After 12 weeks of intervention, the subject was running without restriction and had returned to her pre-injury running mileage at the five-year follow up.

**Discussion:** The eccentric-biased exercise in conjunction with exercises addressing the kinetic chain and a progressive tendon loading program, were successful in the rehabilitation of this subject with iliopsoas tendinopathy. This case report is the first to provide a description on the rehabilitation of iliopsoas tendinopathy, and offers clinicians suggestions and guidance for treatment and exercise choice in the clinical environment.

**Level of Evidence:** 5

**Keywords:** running, tendon, tendon pathology, tendon loading

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INTRODUCTION
Tendinopathy is the term used to describe the clinical condition of tendon pain, swelling, impaired tendon performance and dysfunction, independent of pathology within the tendon that has developed as a result of acute or chronic overload.1–3 While tendinopathy is a common condition in the athletic population,4 its pathophysiology is still not fully understood.5 Tendinopathy is generally considered to encompass both inflammatory and degenerative processes.5,7,8 However, although inflammatory markers may be present, tendinopathy does not have a typical inflammation response, and expression of these markers occurs in response to cyclic load.5 In addition, the relationship between tendon pathology, pain and function is unclear.5 These mixed characteristics of tendinopathy present a challenge to clinicians, as understanding the timeline and sequence of pathology is important in determining the proper treatment. For example, it has been suggested that the most important aspect of a tendinopathy rehabilitation program is appropriate loading and progression to prepare the tendon to meet the demands of sport.9 According to the donut theory,5 an area of cell degeneration within a tendon is usually surrounded by healthy tissue, and rehabilitation should focus on increasing the tolerance of this healthy tissue to loading.5,9,10 However, concern has been raised as to when and how that load should be applied to the tendon4,5,9,11 given the risk of exacerbating the pathological state of the tendon.

A few models of tendon pathology have been proposed.11–13 The most recent model by Cook and Purdam,5,11 relates the stage of pathology to the corresponding clinical presentation. Although the relationship between pain, structure and function is unclear, this model is still useful as it provides the clinician with a framework within which to determine timing and type of interventions. It is interesting to note that clinical tendon staging in this model is based heavily on loading history, clinical presentation and age of the individual, which can easily be determined in the clinical setting.

Cook and Purdam5,11 caution against eccentric loading in the early stages of tendinopathy when the tendon is already being significantly loaded from acute bouts of athletic activity, and tendon cells are already upregulated. Rather, they suggest that eccentric exercise can have a positive effect in the degenerative stage when tendons are less irritable. It has also been recommended that during this stage, the athlete avoid the offending activity,14 or can perform walking/jogging once there is minimal pain.15,16 Exercise to address the kinetic chain and contralateral deficits may be performed throughout the continuum of tendon pathology as this will help to unload the tendon, improving success of rehabilitation.9,11

Eccentric exercise as a method of rehabilitation for tendinopathy has been heavily investigated in the literature, but has yielded conflicting results.15–33 Norregaard et al25 found no differences in improvement between eccentric and stretching exercises over a one year period. In a recent review Coupee et al34 concluded that eccentric exercises were not superior to other forms of exercise loading applied to patellar and Achilles tendons, and suggested that the direction of movement may not be as important as the load applied to the tendon. Other reviews, while reporting positive outcomes using eccentric exercise, were unable to establish its superiority over other forms of exercise.14,28,33

In contrast, Roos et al35 reported superior pain reduction in mid-portion Achilles tendinopathy and return to sport after 12 weeks of eccentric work when compared to splinting. A number of other studies have also shown positive results from eccentric exercise when compared to other forms of treatment.15,18,24,26,32 Two systematic reviews have reported eccentric exercise to demonstrate superior outcomes compared to other interventions in patients suffering from patella tendinopathy36 and Achilles tendinopathy.37

Although there is considerable literature investigating the effects of eccentric exercise on Achilles, wrist extensor, posterior tibialis, and patellar tendinopathies, there seems to be no studies that have investigated its effect on iliopsoas tendinopathy. This condition is rarely described in the literature. Blankenbaker et al38 found one case of iliopsoas tendinopathy in a cohort of 40 patients with snapping hips. Other reports of iliopsoas tendinopathy have been documented in patients with total hip replacements39,40 with an incidence of 4.3%.40 The author
of this study found no cases of reports in runners, whose prevalence of groin pain is as high as 18 percent. Whether it is a rare condition, or under- or mis-diagnosed under different names such as tendinitis, bursitis, or snapping hip syndrome, seems unknown.

Eccentric exercise may be an appropriate method to use in the rehabilitation of iliopsoas tendinopathy in runners, given the role of the iliopsoas tendon in energy transfer during running. During stance phase in running, the hip is rapidly extending. The iliopsoas contracts eccentrically to decelerate the hip, and in doing so, gathers potential energy as it elongates. This energy is then released during swing as the leg slingshots forward. Because of this action, it makes sense to train the muscle with an eccentric component in order to prepare the muscle for the demands it faces in running.

The rehabilitation program for a runner with iliopsoas tendinopathy should consider the pathophysiology of the tendon, the biomechanics of the kinetic chain during running, and the characteristics of the load placed upon the iliopsoas tendon. The purpose of this case report is to describe the rehabilitation of a runner with the rarely described condition of iliopsoas tendinopathy, and demonstrate a creative eccentric-biased technique to assist with treatment. A secondary objective is to illustrate how evidence on intervention for other tendinopathies was used to guide rehabilitation of this condition. The subject of this report was informed that her case would be submitted for publication, and agreed to the submission.

CASE DESCRIPTION

The subject was a 39-year-old female runner who ran an average of 17-20 miles per week. She was 5 feet 4 inches tall and weighed 110 pounds. She had no significant medical history. At the time of the initial examination, the patient had been running consistently three to four times per week for over 15 years with no cross training.

At the initial examination, the subject presented with complaints of left inguinal pain that began after a self-perceived difficult hill run in new shoes after not running for two weeks. After this incident, she described stiffness in the groin when starting a run, but had no pain once warmed up. She therefore continued to train and run. The pain would present after running and she occasionally could not lift her leg to get out of her car upon returning home after a run. The subject reported that pain was worse after faster runs and after runs on hills.

Initially, she had no pain at rest, but as she continued running she began experiencing pain during the day after prolonged periods of sitting, the onset of snapping in the groin at night while turning in bed, and sharp pain when rising in the morning. The pain eventually affected her ability to walk after being stationary for prolonged periods, but would decrease as she continued to walk. Beserol®, a muscle relaxer with an analgesic component, would decrease her pain when present, but would not prevent further episodes. Three months after the initial injury, she sought the services of a physician, received a diagnosis of iliopsoas tendinopathy confirmed by diagnostic ultrasound, and was referred to physical therapy. The subject’s primary goal was to return to running without pain.

Detailed hip and functional assessments were performed. A clinical running analysis on the treadmill was also done to observe technique. Asymmetries in postural alignment were observed in standing and during the running analysis. Significant findings are reported in Table 1. Physical findings of particular note include excessive anterior pelvic tilt, positive left Thomas and Ober tests for iliopsoas and iliotibial band tightness respectively, pain to palpation of the belly of the iliopsoas, and weakness in bilateral hip extension and abduction, left greater than right. Her running analysis revealed a bilateral over-stride with decreased hip extension and anterior pelvic tilt. A right Trendelenberg sign was also noted, with poor lumbo-pelvic-hip control in the transverse plane and an asymmetrical and decreased arm swing.

Outcome Measures

The following outcome measures were assessed at the initial evaluation, after 12 weeks of eccentric training and at the 5-year follow up (Tables 2 and 3, Figure 1).

Pain Assessment. The subject’s pain after a run was documented using a 10-point visual analog scale.
This is a 100mm line anchored by 0 (no pain) on the left and 10 (pain as bad as it could be) on the right. It has been found to be a valid, reliable and responsive assessment with a minimal clinically important difference of 2cm. The Global Rating of Change Scale (GROC). The subject's perception of overall improvement was measured using the GROC. This is a 15 point Likert scale that measures the patient's impression of her progress after a period of treatment. The scores range
from “a very great deal worse” (-7) to “a very great deal better” (+7). Zero indicates no change. The minimal clinically important difference has been established at three points.46

Hip and Groin Outcome Score (HAGOS). The HAGOS was used to measure six dimensions (subscales): Symptoms; Pain; Function in daily living (ADL); Function in sport and recreation; Participation in physical activities; and hip and/or groin-related quality of life. Each subscale is normalized to give a score out of 100, where 100 indicates no problems and 0 indicates extreme problems. It has been shown to be a valid, reliable and responsive tool with a minimal clinically important change of between 10 and 15 for the subscales in young to middle-aged patients with hip and groin pain.47

Manual Muscle Testing (MMT). MMT as described by Kendall48 was used to assess strength. The subject moved to a position in the direction of the movement to be tested (ex. hip abduction) and attempted to hold the position against gradually increasing pressure exerted by the clinician. The point at which the subject breaks the hold position determines the score of the strength test. The strength of the muscle is scored out of 5, where 0 means that there is no evidence of any muscle contraction and 5 indicates that the subject’s strength is normal and able to hold against strong pressure. A study by Aitkens49 found a significant correlation between quantitative isometric testing and MMT, although another study50 found good specificity but only moderate sensitivity (<75%) and diagnostic accuracy (<78%) of MMT. Yet, in the absence of more robust isokinetic/isometric dynamometers, MMT may still provide a reasonable representation of a subject's strength in the clinic.

Assessment and Staging of Tendinopathy

Clinical Impression 1

No ultrasound was available to visualize the tendon in the physical therapy clinic, and the physician did not provide sufficient detail to stage the tendinopathy. Using the clinical presentation proposed by Cook et al,11 it was established that the subject was in the tendon degenerative stage, and possibly had some reactive characteristics as well. This was determined based upon the chronicity of the subject’s problem (> 3 months), the length of time she had been running which could indicate chronic strain (>15 years), and the fact that she had repeated bouts of tendon pain, that subsided with rest, but returned with loading again. In addition, palpation revealed a painful and thickened left iliopsoas tendon compared to the right side. These signs are consistent with reactive on degenerative tendinopathy based on the continuum of tendon pathology.10

Figure 1. HAGOS Scores.
Intervention

Phase I-Load management and eccentric exercise

The subject was instructed to stop running, as running, even short distances (less than one mile) in the initial phases of rehabilitation, was the primary aggravating factor, possibly creating acute reactivity within the tendon. The cessation of the offending activity is in accordance with recommendations by Wasjelewski.

As it was determined that the tendinopathy was in the degenerative stage, the subject was placed on an eccentric program for the iliopsoas tendon. Because she had stopped running, pain had subsided, likely indicating reduced reactivity, so loading could be introduced. She was also prescribed exercises to address the asymmetries, muscle length deficits of the hip flexors, weakness of the hip abductors and hip extensors as well as lumbo-pelvic-hip control. Studies support concomitant strengthening and lumbo-pelvic stability work in runners to improve kinetic chain biomechanics and unload the affected tendon. Table 4 shows the specific exercises that were done for three sets of ten to fifteen repetitions performed twice weekly throughout the 12 weeks of therapy.

The eccentric-biased program consisted of one exercise, designed by the author to limit the amount of core control needed by the subject. This side-lying position was chosen because she was unable to safely perform supine or standing eccentric hip flexion without excessively extending her spine. In addition, the exercise had to be performed at home on a daily basis without the need for clinic/gym equipment.

To perform the novel eccentric-biased exercise, the subject assumed the right side lying position with a Perform Better® black monster band secured around the left ankle and the other end attached to a sturdy object behind her at about knee height. Her left hip was maximally flexed with the knee flexed as well. This start position (Figure 2) is similar to a running position. To start the exercise, the subject slowly extended the hip, controlling against the pull into hip extension provided by the monster band for a count of “3” while keeping the knee flexed, until the hip was fully extended (Figure 3). This was to allow isolation of the iliopsoas and place the rectus femoris at a mechanical disadvantage. In addition, this placed stretch on the iliopsoas at end range hip extension, which was appropriate for the subject, given her hip extension limitations per the Thomas test and running analysis (Table 1). Once at the end position (Figure 3), the subject made a quick concentric contraction to the count of “1” as she quickly flexed the hip against the resistance of the band to move the left hip into full hip flexion to the start position. The subject was cued not to arch her back and to keep her abdominals engaged in order to stabilize the spine against the wall. She was allowed to hold onto a sturdy object to increase her stability. The exercise simulated the energy transferring function of the iliopsoas during running in a semi running-specific position.
The subject was instructed to perform 3 sets of 15 repetitions of this eccentric exercise twice per day over the course of 12 weeks (Table 5). She was informed that this should reproduce her tendon pain to no more than 5/10 (moderate pain) on the VAS.10,14,26,53,54 This protocol is based upon research by Alfredson et al16 who showed improvements in pain and function with this dosage and it is a frequently used dosage in the literature.14,33 The strength of the band was increased as the exercise became less painful,16,18,25 taking care not to cause an exacerbation of the pathological state9 or pain greater than 5/10. The subject reported good compliance with this exercise at home.

**Phase II: Reintroduction of loading/Cross-training**

Two weeks after starting the eccentric program, the subject reported an improvement in symptoms. As her pain was now minimal, the subject was allowed to start a walking program provided there was no further increase in pain18,34,51 to help start to increase the load on the iliopsoas tendon. During this time, she also performed deep-water running once a week for forty-five minutes in order to help maintain her fitness, and 100m sideways hill repeats ranging from 5-8 repetitions on each side once a week to assist with gluteal strength, pelvic stability and fitness. No pain was experienced during these activities.
Phase III: Return to Running
Silbernagel et al.\textsuperscript{54} used a pain monitoring model to assist with return to sport activities. As recommended, the subject in this case study began to re-introduce running when her ADL's produced no more than 2/10 pain. This occurred five weeks after starting her eccentric work. She began a walk-run interval program (Table 6) once to twice a week with no fewer than three days in between sessions to allow for recovery of the tendon.\textsuperscript{10} She did this in combination with continued water running and sideways hill repeats during the non-run days. She experienced some increased groin pain and stiffness after her runs. Running time was progressed only when the pain was less than 2/10. During this time, she continued her rehabilitation program to address her other deficits (Table 4).

At the end of 17 weeks, the subject was running without restrictions and would only experience groin pain with increased pace faster than a 9-minute mile. Speed places increased load on the ilio-psoas tendon. At this point, she was discharged to a strength and conditioning coach with instructions to use the pain model to help guide her progression of speed, and continue her lumbo-pelvic-hip strengthening and stability training. At five years post discharge from physical therapy, the subject returned for a follow-up visit and the outcome variables were re-assessed (Tables 2 and 3, Figure 1).

<table>
<thead>
<tr>
<th>WEEK (after starting eccentric training)</th>
<th>WALK-RUN-WALK INTERVALS (mins)</th>
<th>SYMPTOMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>10-10-10</td>
<td>Bilateral groin pain</td>
</tr>
<tr>
<td>10</td>
<td>8-14-8</td>
<td>No groin pain. +Low back pain</td>
</tr>
<tr>
<td>11</td>
<td>5-20-5</td>
<td>Mild left groin pain only at night when turning in bed</td>
</tr>
<tr>
<td>12</td>
<td>25 min run</td>
<td>Mild left pain in groin and back</td>
</tr>
<tr>
<td>13</td>
<td>30 min run</td>
<td>No groin pain. +Back stiffness</td>
</tr>
<tr>
<td>15</td>
<td>5-hour hike</td>
<td>No pain</td>
</tr>
<tr>
<td>17</td>
<td>Unrestricted</td>
<td>Left groin pain with increased speed</td>
</tr>
</tbody>
</table>

OUTCOMES
Results of outcome measures at the initial assessment, after 12 weeks of eccentric training and at a five-year follow-up are presented in Tables 2 and 3 and Figure 1. After 12 weeks of eccentric training using the technique described, the subject reported her worst pain to be 2/10 down from 6/10 at initial assessment, a clinically meaningful change. This further decreased to 1/10 at the five-year follow up although this was not significant. The subject also reported that the pain she did get at the 12-week mark was less frequent after running and appeared primarily only after increasing speed and/or distance for the first time. This pain continued to decrease in frequency at the five-year follow-up and was at that time, quite infrequent, occurring only about once monthly. She had returned to the mileage she was running at prior to the injury.

The HAGOS scores increased as well during this time frame, with the exception of the physical activity subscale, which showed a decrease in performance at the 12-week mark. This is likely because she was not running at the distance she was when she was initially assessed due to her cessation of running and gradual return to running protocol. However, at the five-year follow up, all sub scales showed improvement from the initial assessment and the 12-week mark. Clinically significant changes were found in the symptoms, sport/recreational and quality of life categories at the 12-week follow up. The improvement from initial assessment to the five-year follow up was clinically significant in all of the subscales. The improvement in pain and function were also reflected in the GROC scores.
DISCUSSION

Iliopsoas tendinopathy has not been well described in the literature. This case provides an example of the rehabilitation of a runner with this diagnosis and presents a novel eccentric-biased exercise for treating the condition. The subject in this study actually showed improvement in pain within two weeks after beginning the eccentric exercise. Tendinopathies can take 6-12 weeks to show improvement. However, this short time to improvement is similar to the time reported by Cushman in his study of eccentric training in rehabilitating hamstring tendinopathy, and is possibly due to neural changes at this early period. The subject was also performing exercises to improve the kinetic chain. However, the speed with which the subject reported pain reduction makes it unlikely that the improvement could be attributable to kinetic chain changes as these usually take a longer period to become apparent. Further improvement in this subject was achieved by the end of 12 weeks of eccentric training. This improvement indicated that the technique and dosage used were probably appropriate.

The subject attempted resisted eccentric hip flexion in both supine and standing, but was unable to maintain a neutral spine, which could increase the risk of back injury and decrease the effectiveness of the exercise. Therefore, the eccentric-biased exercise chosen was designed to limit the amount of lumbo-pelvic stability required to perform the exercise, as this subject had deficits in lumbo-pelvic control and strength. In addition, the psoas is a spinal stabilizer as well as a hip flexor, and it was thought that the tendon could be loaded with greater resistance if the stability role of the muscle was reduced. The focus on the eccentric component was purposely done to increase the time under eccentric tension to take advantage of the neural benefits of eccentric contractions.

Although this was an eccentric-biased exercise, with the focus on the higher time under tension during the eccentric phase, it also had a concentric component. True eccentric strength training usually involves very high loads that can usually only be moved eccentrically, as higher loads are needed to capitalize on the neural efficiency of eccentric exercise. There may be concern that this eccentric-biased exercise with a concentric component may not eccentrically load the tendon enough to achieve gains.

As there is no literature on iliopsoas tendinopathy, an attempt to apply recommendations from other lower extremity tendinopathies was helpful. A systematic review by Malliaras et al concluded that there is "limited (Achilles) and conflicting (patellar) evidence that clinical outcomes are superior with eccentric-only loading compared with other loading programs..." Therefore, as other programs, such as the Silbernagel-combined loading program use both eccentric and concentric loading, it is possible that loads heavy enough to be only eccentrically tolerated, may not be necessary to elicit gains. Furthermore, in the clinical setting, when the patient’s symptoms are highly irritable, high load may not be tolerated.

Malliaras et al also stated that "clinical improvement is not dependent on isolated eccentric loading in Achilles and patellar tendinopathy rehabilitation." They also suggest that there is potential for benefit even with lower load eccentric training, given the possible neural and metabolic mechanisms of lower-load eccentric exercise. The review also recommended eccentric-concentric over isolated eccentric exercise, which therefore makes the technique proposed in this study a rational choice. In addition, some studies suggest that the important stimulus is that a load is placed upon the tendon, not the type of contraction. In fact, procollagen (a precursor to collagen) is upregulated, and therefore tendon protein synthesis is stimulated, regardless of contraction type.

Specificity of training muscle contractions is important, and in eccentric-only programs, there is a resulting problem of concentric weakness. Furthermore, there is discussion that all tendons are unique to their function and position and therefore may not respond equally to particular loading protocols. Each tendon’s loading environment should be considered, as they are each unique in their loading patterns. Running involves both concentric and eccentric contraction of the iliopsoas, and therefore training of the iliopsoas should include both types of muscle contractions. The exercise suggested in this study is performed in a semi-running-specific setting.
position that reflects the concentric and eccentric hip flexion that occurs in running. Although research on other tendinopathies has been applied to this case report, it is important to consider the unique loading environment of the iliopsoas. It is for these reasons that the author believes that this technique was appropriate for this patient.

Although the subject had stopped eccentric training after 12 weeks, further improvement was noted at the five-year follow up in her HAGOS scores. This is similar to the results obtained by van de Plas et al.\(^5\) five years after eccentric training for Achilles tendinopathy. The continued improvement of the patient in this case study could be attributed to the addition of strength and conditioning sessions which focused on improving asymmetries, and strength and stability of her lumbo-pelvic-hip complex. This outcome also supports the need to address the kinetic chain as discussed in recent literature.\(^9,11,51,52\) A holistic approach that includes the entire kinetic chain ensures that further unloading of the tendon may occur, as other structures, such as the gluteal muscles, may contribute more to running.\(^62,63\) This highlights the importance of continued load management in the long term, particularly since a decrease in pain is not necessarily reflective of tendon healing\(^5,53,64\) and therefore load management and improvement in load tolerance must continue throughout the patient’s athletic career.

Gains may also have occurred because the progressive return to running, gradually increased the load tolerance of the tendon, allowing the subject to continuously improve her activity. This is supported by the donut theory\(^5\) of strengthening the healthy tissue around the degenerative zones within the tendon with gradual exposure to load.

The eccentric-biased exercise was chosen as the intervention based on the staging of the tendinopathy on the continuum of tendon pathology proposed by Cook and Purdam.\(^11\) As the physician did not document the stage of the tendinopathy, this continuum was extremely helpful in determining the appropriate treatment based on the clinical presentation of this subject and her history of tendon load. Although, tendon pathophysiology is still unclear\(^2,5,6,13,65,66\) this continuum can be a vital tool for the clinician who does not have access to imaging techniques. Furthermore, imaging does not correlate well with pain, so it is important to attend to clinical symptoms in defining the stage of tendinopathy.\(^1\)

The dosage of the eccentric-biased exercise was based on the Alfredson protocol which is widely used in the literature.\(^10,18,25,26,67\) The subject was instructed to exercise into moderate pain, 5/10 on VAS which she tolerated well without increase in the reactivity of the tendon. However, she experienced increased groin pain upon re-introduction of running. Progression, therefore, was based upon pain response to help guide the return to running and avoid tendon re-injury. The pain monitoring model proposed by Silbernagel\(^10,54\) was useful in helping the subject progress her running safely without fear of re-injury, and can be a tool for clinicians progressing an athlete through rehabilitation and return to play. The pain monitoring model was also helpful in guiding recovery intervals. Using the recommendation that pain the morning after running should not exceed 5/10, she was able to increase her running time and frequency post discharge, and manage her symptoms. This speaks to the importance of patient education in the management of tendinopathy.

The subject experienced rare flare-ups post discharge. These occasional symptoms for this length of time at the five-year follow-up reflects the degenerative stage on the tendon pathology continuum.\(^5,11\) Despite the continued tendon pathology, the subject’s low pain level (1/10) at five years is not necessarily reflective of the structure of the tendon. This supports recent research showing that pain does not correlate well with tendon histology.\(^1,5,66,69\) According to Cook et al.,\(^5\) the subject has moved sideways along the continuum from a painful state with poor function to a pain-free state with good function, although degenerative changes are still present.

The research used to support this case study has come from studies on Achilles, patellar, rotator cuff and medial/lateral epicondyle tendinopathies. No empirical studies were found on subjects with iliopsoas tendinopathy. However, given the response of the subject to the treatment, it is possible that iliopsoas tendinopathy responds similarly to other lower limb tendinopathies. Nonetheless, attention should be given to the specific loading environment of the tendon during athletic performance.
A case report has several weaknesses that limit the strength of the results. This report is only on one individual’s condition and response to treatment and therefore cannot be generalized to the general population. This subject was exceptionally compliant and patient with her program. This was a lengthy program that also relied heavily on the subject understanding the process and being receptive to education, and performing activities and load management interventions on her own. This may not be appropriate for all patients with this condition. This case report was also written retrospectively, and therefore may be subject to recall bias. Further research on this condition in a larger population is recommended before such treatment is implemented in a broader scope. In addition, while this case report supports the use of eccentric-biased training (with a small concentric component) in the treatment of this patient with iliopsoas tendinopathy, it did not investigate or compare the use of other forms of loading to the iliopsoas tendon.

**CONCLUSION**

The results of this case report indicate that iliopsoas tendinopathy can improve with a multi-modal approach to load management to allow recovery of the tendon. This includes appropriate staging of tendon pathology to help drive the timing and choice of treatment. This report demonstrates that in the correct stages of pathology, eccentric-biased isolated exercise, kinetic chain improvements and subject education with a return to sport program that considers tendon load and recovery are components that can lead to a successful outcome. This is a case report on one subject with iliopsoas tendinopathy, and there is a paucity of literature on this condition. Therefore, further studies on iliopsoas tendinopathy are recommended.

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ABSTRACT
The purpose of this clinical commentary is to review the anatomy, etiology, evaluation, and treatment techniques for nerve entrapments of the hip region. Nerve entrapment can occur around musculotendinous, osseous, and ligamentous structures because of the potential for increased strain and compression on the peripheral nerve at those sites. The sequela of localized trauma may also result in nerve entrapment if normal nerve gliding is prevented. Nerve entrapment can be difficult to diagnose because patient complaints may be similar to and coexist with other musculoskeletal conditions in the hip and pelvic region. However, a detailed description of symptom location and findings from a comprehensive physical examination can be used to determine if an entrapment has occurred, and if so where. The sciatic, pudendal, obturator, femoral, and lateral femoral cutaneous are nerves that can be entrapped and serve a source of hip pain in the athletic population. Manual therapy, stretching and strengthening exercises, aerobic conditioning, and cognitive-behavioral education are potential interventions. When conservative treatment is ineffective at relieving symptoms surgical treatment with neurolysis or neurectomy may be considered.

Level of Evidence: 5

Key words: Anatomy, etiology, evaluation, hip, nerve entrapment, treatment

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BACKGROUND AND PURPOSE
Non-arthritic hip pain is an area of increasing interest, particularly in the field of sports medicine. Regional hip and pelvic pain can be difficult to diagnose and treat as symptoms can originate from osseous, capsulolabral, musculotendinous, and/or neurovascular structures. Intra-articular pathologies, such as labral tears and femoroacetabular impingement, and extra-articular pathologies, such as muscle strains and athletic pubalgia, have been clearly defined. However, nerve entrapments in the hip and pelvic region are sources of extra-articular symptoms that have not been well described.

Nerve entrapment can occur around musculoten-dinous, osseous, and ligamentous structures because of the potential for increased strain and compression on the peripheral nerve at those sites. The sequela of localized trauma may also result in nerve entrapment if normal nerve gliding is prevented. The mechanisms behind how peripheral nerve entrapment negatively affects nerve function is complex and thought to be related to local changes in vascular permeability, impairment of axonal transport, and the formation of edema. Individuals with nerve entrapment commonly complain of burning or lancinating type pain and/or paresthesia in the distribution of the involved nerve. It should be noted that neuralgia, a commonly used term, refers broadly to pain in the distribution of a nerve. Physical examination findings will vary depending on nerve function and can include impairments in sensation, reflexes, and/or motor function. Tinel’s sign can be positive and recreate symptoms when the location of entrapment is superficial. Palpation may reveal localized tenderness in the area of entrapment and provocative movements that stretch the involved nerve are likely to reproduce symptoms. Diagnostic testing can include anesthetic injection, magnetic resonance imaging, ultrasonography, electromyography, and nerve conduction velocity tests.

Identifying nerve entrapments in the hip and pelvic region can be difficult because of the similarity in symptoms and potential co-existence with other musculoskeletal conditions. In athletes, common nerve entrapments in this region include the sciatic, pudendal, obturator, femoral, and lateral femoral cutaneous nerves. In order to provide comprehensive treatment to young, active individuals, clinicians need to be aware of the potential location, clinical presentation, and treatment options for those with nerve entrapments in the hip region. The purpose of this clinical commentary is to review the anatomy, etiology, evaluation, and treatment techniques for nerve entrapments of the hip and pelvic region.

POSTERIOR NERVE ENTRAPMENTS
The sciatic and pudendal nerves are susceptible to entrapment in the posterior hip region. In the subgluteal space the sciatic nerve can be entrapped as it passes under piriformis and over the obturator, gemelli and/or quadratus femoris muscles. The sciatic nerve can be entrapped in ischiofemoral impingement between the ischium and lesser trochanter. Also at the level of the ischium, the proximal hamstring can be involved in sciatic nerve entrapment and is known as ischial tunnel syndrome. The pudendal nerve can be entrapped in several locations as it exits the greater sciatic foramen, travels over the sacrospinous ligament, traverses through the pudendal canal (also known as Alcock’s canal) formed by the obturator fascia and sacrotuberous ligament, and emerges inferior to the pubic bone to innervate the perineum and genitalia. The most common location of entrapment occurs in the space between the sacrospinous and sacrotuberous ligaments at the ischial spine. The obturator internus muscle may also compress the pudendal nerve medial to the ischium.

The specific location of pain may help to identify the involved nerve and location source of entrapment. While those with sciatic nerve entrapment can have symptoms anywhere along the distribution of the sciatic nerve in the lower extremity, pain specifically in the buttock may indicate sciatic nerve entrapment. Individuals with sciatic nerve entrapment in the subgluteal space often present with a history of direct gluteal trauma and difficulty sitting for more than 30 minutes. Symptoms from ischiofemoral impingement typically occur during gait, when transitioning from mid-stance to terminal stance as the lesser trochanter contacts the ischium. This impingement may cause injury to the quadratus femoris and involve the sciatic nerve.
ischial tunnel syndrome, the origin of the hamstring tendon can be thickened due to trauma or partial hamstring avulsion and entrap the sciatic nerve. Symptoms radiating down the posterior thigh into popliteal fossa aggravated by running, with knee extension and hip flexion at heel strike, may indicate entrapment of the sciatic nerve in the ischial tunnel. Pudendal nerve entrapment results in pain medial to ischium, including the penis, scrotum, labia, perineum, and/or anorectal regions. These symptoms are generally made worse when sitting, except when sitting on a toilet seat. The area medial to ischium is not under compression when sitting on a toilet seat unlike sitting on a flat hard surface. Prolonged periods of cycling may be associated with pudendal nerve entrapment. Friction created in the pudendal canal from the repetitive nature of pedaling or direct compression of the nerve between the nose of the bicycle seat and pubic bone make cyclists susceptible to pathology of the pudendal nerve and its terminal motor and sensory branches.

Physical exam for those with potential posterior nerve entrapments should include the seated palpation, seated piriformis stretch, active piriformis, ischiofemoral, and active knee flexion tests. The seated palpation test can be used to distinguish the source of entrapment based on location of tenderness. This test requires the patient to sit on the examiner’s hand while the examiner simultaneously palpates three locations in the posterior hip: 1) the subgluteal space, lateral to the sacrum, in the area of deep hip external...
rotators; 2) the ischium and hamstring origin, and 3) the soft-tissue medial to the ischium. The seated piriformis stretch (Figure 3) and active piriformis test (Figure 4) can be used to identify those with sciatic nerve entrapment in the subgluteal space. A positive active piriformis test or seated piriformis stretch was found to identify those with sciatic nerve entrapment with sensitivity and specificity values of 0.91 and 0.80, respectively, in subjects with posterolateral hip pain. The ischiofemoral impingement test assesses for reproduction of symptoms when the lesser trochanter contacts the ischium as the hip is moved into extension in an adducted and externally rotated position. The sensitivity and specificity of this test for identifying individuals with ischiofemoral impingement in subjects with posterior hip pain were 0.82 and 0.85, respectively.

The active knee flexion tests at 30° and 90° have been described for assessment of proximal hamstring tendon pathology and ischial tunnel syndrome. These tests are performed while the patient is seated and their knee positioned in 30° flexion (Figure 6-A) and then in 90° flexion (Figure 6-B) with the examiner palpating the ischial tunnel. The patient actively flexes their knee for five seconds against resistance in each position with a positive test being reproduction of symptoms. A positive active knee flexion test at 30° or 90° was found to identify those with proximal hamstring pathology with sensitivity and specificity values of 0.84 and 0.97, respectively. It can be difficult to differentiate proximal hamstring pathology from ischial tunnel syndrome as the two conditions often occur together, particularly in more chronic situations. In the author’s experience, ischial tunnel syndrome
often have a positive active 30° knee flexion test with reproduction of radiating symptoms, although there is no evidence to support this suggestion.

The physical examination for those with pudendal nerve entrapment is relatively benign with exception of pain reproduction. Careful palpation should be performed assessing for tenderness at the greater sciatic notch near the proximal aspect of the piriformis and medial to the ischium that may elicit symptoms from entrapment near the sacrospinous and sartorius ligaments, the obturator internus muscle, and pudendal canal. A transvaginal or transrectal examination performed by an experienced pelvic health practitioner may be necessary to rule out intrapelvic entrapment. A summary of the common locations of posterior nerve entrapments as well as key subjective findings and signs are presented in Table 1.

**ANTERIOR NERVE ENTRAPMENTS**

The obturator, femoral, and lateral femoral cutaneous are nerves that can be entrapped and serve as a source of symptoms in the anterior hip region. Although ilioinguinal, iliohypogastric, and genitofemoral nerve entrapment can occur, entrapment of these nerves is relatively rare, usually iatrogenic following surgery, and generally not directly related to sports or activity related injuries. The obturator nerve can be entrapped as it exits the obturator canal or more distally by fascia overlying the short adductor muscles. Entrapment of the femoral nerve can occur at the level of the inguinal ligament as it enters the femoral triangle. Entrapment of the femoral nerve can occur in the iliacus compartment or adductor canal and involve the saphenous branch. The lateral femoral cutaneous nerve is commonly entrapped where it perforates the inguinal ligament approximately 2 cm medial to the anterior superior iliac spine. Female gymnasts may injure this nerve from repetitive trauma associated with uneven bar activities. Another sport-related cause of lateral femoral cutaneous nerve entrapment is seen in scuba divers where the weight belt worn around the waist directly compresses the nerve.
A thorough physical examination should be performed in those with symptoms and a history suggestive of a nerve in the anterior hip region. Symptoms associated with obturator nerve entrapment include medial thigh symptoms aggravated by stretching into hip abduction and slight extension but not aggravated by resisted adduction and therefore inconsistent with adductor muscle involvement.20,25 The main clinical feature of patients with femoral nerve entrapment is quadriceps muscle weakness.29 Severe femoral nerve injury may produce quadriceps muscle atrophy and an absent patellar tendon reflex. Symptoms associated with femoral nerve entrapment are typically reproduced with movements of hip extension and knee flexion, such as with the Modified Thomas test position. A positive pelvic compression test and Tinel’s sign can be used to identify those with lateral femoral cutaneous nerve entrapment.30 The pelvic compression test involves applying a downward force to the pelvis with the patient's symptomatic side facing up in side lying position in attempts to reduce tension on the inguinal ligament and relieve the patient's symptoms. This test was found to have 0.95 and 0.93 sensitivity and specificity values, respectively, when compared to neurophysiologic testing.30 A summary of the common locations of anterior nerve entrapments as well as subjective findings and signs are also presented in Table 1.

CONSERVATIVE TREATMENT
Similar to diagnosing, treating those with nerve entrapment in the hip and pelvic region may be challenging as intervention strategies have not been well studied. Manual therapy, stretching and strengthening exercises, aerobic conditioning, and cognitive-behavioral education are potential interventions.2,31 A thorough examination and comprehensive treatment program should also assess for and direct treatment at abnormal movement patterns that effect the hip and pelvis. This would include abnormal kinematic motion secondary to osseous

Figure 6. A. Active Knee Flexion Test at 30°. B. The Active Knee Flexion Tests at 30° (Figure 6-A) and 90° (Figure 6-B) have been describe to assess for proximal hamstring tendon pathology and ischial tunnel syndrome.
pathologies, such as femoroacetabular and ischio-femoral impingement, as well as other soft-tissue causes of flexion and/or extension range of motion restrictions of the hip.

Neural gliding or mobilization is a manual therapy technique that attempts to improve neurodynamics by restoring the balance between the relative movements of the nerve and surrounding structures. Although there is limited evidence to support nerve mobilization for lower extremity entrapments, the hypothesized benefits from these techniques include facilitation of nerve gliding, reduction of nerve adherence, dispersion of noxious fluids, reduction of intraneural edema, increased neural vascularity, and improvement of axoplasmic flow. These techniques may also affect central mechanisms by decreasing nociceptive behavior in the spinal cord. Neural mobilization requires knowledge of the nerve pathway and movement that applies tension to the specific nerve. For example, sciatic nerve mobilization would combine movements of hip flexion, knee extension, and ankle dorsiflexion while femoral nerve mobilization would combine hip extension and knee flexion.

Manual therapy interventions in the form of soft-tissue mobilization can also be directed to musculotendinous structures affecting the nerve. Although there is limited evidence to support soft-tissue mobilization for lower extremity nerve entrapments, these techniques can address goals of increasing range of motion, reducing pain, decreasing swelling, increasing flexibility, and/or improving muscle performance. Traditional massage strokes of effleurage, petrissage, and deep friction can be included as soft-tissue mobilization techniques. Other techniques may include soft tissue mobilization in conjunction with active patient movement. Soft-tissue mobilization can also include the use of specialized instruments in treatment administration. These instruments used during assisted soft-tissue mobilization techniques attempt to induce biological changes to affect scar tissue and to stimulate the regeneration of soft tissues. These techniques may also try to mechanically mobilize tissues that are restricting nerve gliding.

### Table 1. Sites of Entrapment, Keys Signs and/or Symptoms with Nerves in the Anterior and Posterior Hip Region

<table>
<thead>
<tr>
<th>Involved Nerve</th>
<th>Common Site of Entrapment</th>
<th>Key Signs and/or Symptoms</th>
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<tbody>
<tr>
<td><strong>Posterior Nerve Entrapments</strong></td>
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<td></td>
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<tr>
<td>Sciatic</td>
<td>Priformis and obturator internus/gemelli complex</td>
<td>Positive seated piriformis stretch and/or active piriformis tests</td>
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<td></td>
<td>Proximal hamstring</td>
<td>Ischial tenderness</td>
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<td></td>
<td>Lesser trochanter and Ischium</td>
<td>Pain in the posterior thigh to the popliteal fossa aggravated with running</td>
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<td></td>
<td></td>
<td>Positive ischial femoral impingement test</td>
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<tr>
<td>Pudendal</td>
<td>Ischial spine, sacrospinous ligament, and lesser sciatic notch entrance</td>
<td>Pain medial to ischium</td>
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<tr>
<td></td>
<td>Greater sciatic notch and piriformis</td>
<td>Sciatic notch tenderness and piriformis muscle spasm and tenderness</td>
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<td></td>
<td>Alcock’s canal and obturator internus</td>
<td>Obturator internus spasm and tenderness</td>
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<tr>
<td><strong>Anterior Nerve Entrapments</strong></td>
<td></td>
<td></td>
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<tr>
<td>Obturator</td>
<td>Obturator canal</td>
<td>Pain in medial thigh</td>
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<td></td>
<td>Adductor muscle fascia</td>
<td>Aggravation with movement into abduction</td>
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<tr>
<td>Femoral</td>
<td>Beneath iliopsoas tendon</td>
<td>Reproduction of symptoms with modified Thomas test position</td>
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<td></td>
<td>Inguinal ligament</td>
<td>Quadriceps muscle weakness</td>
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<tr>
<td></td>
<td>Adductor canal</td>
<td>Pain in the anteromedial knee joint, medial leg, and foot.</td>
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<tr>
<td>Lateral Femoral Cutaneous</td>
<td>Inguinal ligament</td>
<td>Positive pelvic compression test</td>
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In addition to manual therapy techniques, stretching and strengthening exercises, aerobic conditioning, and cognitive-behavioral education have been shown to be valuable in the treatment of those with nerve entrapments in the hip region. Stretching, whether performed independently by a patient or performed by a physical therapist, attempts to relieve nerve compression by lengthening shortened musculotendinous structures. However, aggressive stretching can be irritating to the nerve and must be controlled in a slow and progressive manner. One specific exercise for the sciatic nerve involves the combined passive movements of hip flexion, abduction, and external rotation to symptoms provocation followed by movements of hip adduction, internal rotation, and extension. (Figure 10) Although there no evidence to support the technique, this movement combination is purported to mobilize the sciatic nerve in the deep gluteal region. Strengthening exercises can also be performed to facilitate proper load transfer between the lumbosacral spine, pelvis, hip, and lower extremity when alterations or deficiencies of these relationships have been identified. For those with chronic pelvic pain, non-symptom provoking strengthening and training of the pelvic floor muscles is recommended. Aerobic conditioning can be useful because of the general positive effect it has on overall pain management. Cognitive behavioral therapy may assist an individual to gain a sense of control over pain by providing an understanding of pain mechanisms and coping strategies.

**SURGICAL TREATMENT**

When conservative treatment, including injections, is ineffective at relieving symptoms associated with nerve entrapment, surgical treatment with neurolysis or neurectomy may be considered. Neurolysis involves surgical decompression and removal of adhesions that are causing the nerve entrapment. In cases where the nerve is being compressed by a hematoma, cyst, or bursa, surgical or percutaneous drainage may be
femoral cutaneous are potential causes of hip pain. A detailed description of symptom location combined with physical examination findings can be used to identify the site of entrapment. Although not well defined, conservative intervention strategies can include soft-tissue and nerve mobilization, controlled stretching and strengthening exercises, aerobic conditioning, and cognitive-behavioral education. Surgical treatment with neurolysis or neurectomy can be considered in those with recalcitrant symptoms.

CONCLUSION
Nerve entrapments in the hip and pelvic region are sources of extra-articular symptoms in athletes and have not been well described. Entrapment of the sciatic, pudendal nerves, obturator, femoral and lateral femoral cutaneous are potential causes of hip pain. A detailed description of symptom location combined with physical examination findings can be used to identify the site of entrapment. Although not well defined, conservative intervention strategies can include soft-tissue and nerve mobilization, controlled stretching and strengthening exercises, aerobic conditioning, and cognitive-behavioral education. Surgical treatment with neurolysis or neurectomy can be considered in those with recalcitrant symptoms.

REFERENCES
1. Schmid AB, Coppieters MW. The double crush syndrome revisited—a Delphi study to reveal current


