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<table>
<thead>
<tr>
<th>Page Number</th>
<th>Article Title</th>
<th>Authors</th>
</tr>
</thead>
</table>
In 2013, the APTA adopted an inspiring new vision, “Transforming society by optimizing movement to improve the human experience.” This new vision for our profession calls us all to action as physical therapists to transform society by using our skills, knowledge, and expertise related to the movement system in order to optimize movement, promote health and wellness, mitigate the progression of impairments, and prevent the development of (additional) disability.

Physical therapists (PTs) are too often identified by what we do, rather than by what we know as professionals. Although public recognition for physical therapist practice methods and outcomes is essential, understanding that PTs achieve these outcomes through clinical reasoning and practice that emanates from a distinct body of knowledge is crucial to our professional identity. Movement is a key to optimal living and quality of life for all people that extends beyond health to every person’s ability to participate in and contribute to society.

The guiding principle of the new vision is “identity,” and it can be summarized as “The physical therapy profession will define and promote the movement system as the foundation for optimizing movement to improve the health of society.” Defining and promoting the movement system as the core construct that integrates the expanse of the PT professions’ body of knowledge is no small task! Although much of the scientific literature related to physical therapy addresses human movement in both broad and detailed configurations, the actual description of the anatomic structures and interrelated physiologic functions of movement have not yet been described as a system. Over the last three years, the APTA has led efforts not only to define the “movement system,” but also to lay the building blocks for the future. As currently defined, the “movement system” represents the collection of systems (cardiovascular, pulmonary, endocrine, integumentary, nervous, and musculoskeletal) that interact to move the body or its component parts. (Figure 1) By articulating the PT’s unique role in diagnosing and determining interventions for movement system disorders, the overarching goal is to advance the profession towards the reduction of unwarranted variations in practice and, in turn, to achieve consistent positive outcomes for specific diagnoses to enhance the value of the services we provide. By better characterizing physical therapists as movement system experts, we seek to solidify our professional identity within the medical community and society.

To further the definition of the movement system and begin to explore applications of this vision, The Movement System Summit was held December 8-10, 2016, in Alexandria, Virginia. The summit brought together 100 thought leaders in the physical therapy profession with a primary goal of developing a proposed action plan for integrating the movement system concepts into physical therapist practice, education, and research. Representatives from the SPTS and IJSPT were active participants in this summit; participating in collaboration among individuals, sections, and throughout areas of practice to help guide the future. There were many positive take away points from this summit and several of these are currently in the process of being incorporated into the inner workings of IJSPT (as well as other physical therapy related journals). The IJSPT editorial team

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is committed to the integration of movement system language, a focus on the movement system, and furthering the educational, research, and practice agendas of the APTA by supportive actions and efforts offered by the journal. An example of this is the development of new suggested key words that could be utilized to assist in establishing MESH headings for facets of the movement system. Additionally the journal will seek to be a catalyst to provide specific guidelines on ways that new and innovative research can advance clinicians’ knowledge of the movement system. Look for more information in future issues as the movement system road map continues to unfold and your journal champions efforts to integrate the movement system into all aspects of physical therapist practice.

REFERENCE
ABSTRACT

Background: Anterior cruciate ligament (ACL) injury is common among females due to many anatomic, hormonal, and neuromuscular risk factors. One modifiable risk factor that places females at increased risk of ACL injury is a poor hamstrings: quadriceps (H:Q) co-activation ratio, which should be 0.6 or greater in order to decrease the stress placed on the ACL. Exercises that produce more quadriceps dominant muscle activation can add to the tension placed upon the ACL, potentially increasing the risk of ACL injury.

Hypothesis/Purpose: The purpose of this systematic review was to compare quadriceps and hamstring muscle activation during common closed kinetic chain therapeutic exercises in healthy female knees to determine what exercises are able to produce adequate H:Q co-activation ratios.

Study Design: Systematic Review

Methods: Multiple online databases were systematically searched and screened for inclusion. Eight articles were identified for inclusion. Data on mean electromyography (EMG) activation of both quadriceps and hamstring muscles, % maximal voluntary isometric contraction (MVIC), and H:Q co-activation ratios were extracted from the studies. Quality assessment was performed on all included studies.

Results: Exercises analyzed in the studies included variations of the double leg squat, variations of the single leg squat, lateral step-up, Fitter, Stairmaster® (Core Health and Fitness, Vancouver, WA), and slide board. All exercises, except the squat machine with posterior support at the level of the scapula and feet placed 50 cm in front of the hips, produced higher quadriceps muscle activation compared to hamstring muscle activation.

Conclusion: Overall, two leg squats demonstrate poor H:Q co-activation ratios. Single leg exercises, when performed between 30 and 90 degrees of knee flexion, produce adequate H:Q ratios, thereby potentially reducing the risk of tensile stress on the ACL and ACL injury.

Level of Evidence: 2a- Systematic Review of Cohort Studies

Key words: Anterior cruciate ligament, electromyography, hamstrings, quadriceps, resistance training

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*Note: Ms. Dedinsky, Ms. Baker, Mr. Imbus, and Ms. Bowman were students at Walsh University when this research was conducted.

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INTRODUCTION

Anterior cruciate ligament (ACL) injuries can be devastating to an athlete. The ACL is the primary restraint to anterior translation of the tibia on the femur, and is often injured in noncontact conditions with the foot planted on the ground. It is estimated that 70-90% of ACL injuries occur without contact in situations such as rapid change of direction, landing, and deceleration. Closed kinetic chain (CKC) ACL injuries are often reported with moments of reduced knee flexion angles, increased valgus collapse at the knee, and increased internal or external tibial rotation. The incidence of these injuries is believed to be 1 in 3,000 with approximately 100,000 ACL injuries occurring each year in the United States. Of the ACL injuries sustained in the United States annually, it is estimated that 38,000 are in females. Although males have a higher overall number of ACL injuries, females are said to be 4-8 times more likely to have an ACL injury when data is normalized for the amount of exposures. Many factors have been identified that place females at increased risk of ACL injury including hormonal, anatomical factors, and neuromuscular factors. Of particular interest are the neuromuscular risk factors because they are considered to be modifiable. Decreased strength of the quadriceps and hamstring muscles, decreased active hamstring stiffness, delayed hamstring activation, decreased knee joint proprioception, and decreased hamstring:quadriceps (H:Q) ratio are all neuromuscular factors that have been identified that place females at increased risk of ACL injuries.

Females are often found to be quadriceps dominant, indicating that they preferentially activate their quadriceps over their hamstrings during functional movements. This increases the tensile force placed on the ACL, increasing the risk for injury. Co-activation of the quadriceps and hamstrings is important to provide stability to the knee joint and reduce the amount of tensile force placed on the ACL. A common way to measure co-activation of the quadriceps and hamstrings is by calculating the H:Q ratio. H:Q ratios of 0.6 and greater have been reported to decrease the risk of hamstring and ACL injuries, and ratios closer to 1 indicate higher activation of the hamstring muscles, which aids the ACL in providing additional passive resistance to anterior translation increasing the stability of the knee. Therefore, H:Q ratios of greater than 0.6 are considered adequate, while those less than 0.6 are considered poor for this review. In order to reduce the risk of ACL injury, it is important to adequately train the hamstring muscles through exercises that produce adequate H:Q co-activation ratios.

Closed kinetic chain exercises (CKC) are important for functional movement patterns promoting co-activation of the quadriceps and hamstrings, and consequently are commonly used in training to prevent ACL injuries. Compressive forces experienced during weight bearing add to the stability of the knee joint, which are not experienced during open chain kinetic exercises (OKC). OKC encourage quadriceps dominance and promote increased tensile stress on the ACL. During closed chain knee extension, external torques are largest from 90 to 45 degrees of knee flexion, with the greatest extensor moment arm occurring between 20 and 60 degrees of knee flexion. The greatest flexor moment arm occurs between 50 and 90 degrees of knee flexion. CKC are commonly preferred to OKC in ACL prevention due to the combination of CKC tending to produce a higher H:Q ratio than OKC, as well as their functional strengthening benefits.

OBJECTIVES

Females are at an increased risk for ACL injuries partly due to the predominant activation of the quadriceps over the hamstrings, increasing the tensile strain on the ACL. Many ACL injuries occur during closed chain activities, compared to open chain activities, due to the increased muscular control needed to stabilize the knee. Therefore, CKC were chosen as the focus of this review. The purpose of this systematic review was to compare quadriceps and hamstring muscle activation during common closed kinetic chain therapeutic exercises in healthy female knees to determine what exercises are able to produce adequate H:Q co-activation ratios.

METHODS

Protocol and registration

The current systematic review was registered on PROSPERO with registration number: CRD42015029898.
Eligibility criteria
The following criteria were required for inclusion: 1) studies that assessed electromyography (EMG) activity in at least one quadriceps and one hamstring muscle, 2) studies that reported EMG activity for females, 3) studies where participants performed closed kinetic chain exercises, 4) studies that explicitly stated participants had healthy knees or no prior surgical history of the knee, 5) full-text articles available in English, and 6) human participants. Studies were excluded if they did not report female EMG activity separately from male data or if gender was not specified.

Information sources
PubMed, Scopus, CINAHL, SportDiscus, Web of Science, and PEDro electronic databases were searched in November 2015 and May 2016 for eligible articles relating to quadriceps and hamstrings EMG activity during exercise. A hand search was performed to complete the exhaustive search and include any other eligible articles.

Search
The search strategy for each searched database, approved by a Walsh University librarian, is listed in Appendix 1.

Study selection
All studies identified through the systematic search were retrieved and duplicates were removed. Two reviewers independently screened titles and abstracts for inclusion in the full-text review. A third party reviewer resolved any discrepancies. Full-text articles identified through the title and abstract screen were obtained and assessed by two independent reviewers for inclusion in the systematic review. A third party reviewer once again resolved any discrepancies.

Data collection process
Data collection was performed by two reviewers independently, and then cross-checked for accuracy. The participants' characteristics, the muscles studied, the exercises performed, and EMG activity of the quadriceps and hamstrings muscles were included in the review.

Data items
The following operational definitions were applied to studies for inclusion. Quadriceps was defined as one or more of the four quadriceps muscles (rectus femoris, vastus lateralis, vastus medialis, and/or vastus intermedius). Hamstrings was defined as any one of the muscles of the hamstring muscle group (biceps femoris, semitendinosus, and/or semimembranosus). The specific muscles researched in each study were noted when available. Closed kinetic chain exercises (CKC) were defined as exercises that involved weight-bearing where the distal segment was fixed against the ground. In order to be considered as healthy, the article had to specifically denote that participants were healthy or had no surgical knee history. Mean EMG activity, % maximal voluntary isometric contraction (MVIC), and H:Q ratio was recorded for each muscle studied. H:Q ratios that were greater than 0.6 were considered adequate, while those that were less than 0.6 were considered poor.

Risk of bias in individual studies
Risk of bias in individual studies was assessed using the Mixed Methods Appraisal Tool (MMAT). Two screening questions require that the study have a clear objective and addressed the current research question. Four additional questions are used to determine the quality of the study based on study design. Each paper was rated as 25% (*), 50% (**), 75% (***) or 100% (****) based on one criteria to all four criteria being met, with a higher percentage indicating higher quality. Quality assessment was performed independently by two reviewers, with disagreements being resolved by reaching a consensus.

Summary Measures
Primary outcome measures included %MVIC, mean EMG data, and H:Q ratio for closed kinetic chain exercises. For articles where H:Q ratio was not provided, the ratio was calculated from the mean %MVIC or mean EMG data provided by dividing %MVIC or mean EMG of hamstring muscles by %MVIC or mean EMG of quadriceps muscles, respectively.

RESULTS
Study Selection
PubMed, SportDiscus, CINAHL, Scopus, Web of Science, and PEDro electronic searches acquired 982
articles to be screened for inclusion. After duplicates were removed, 605 articles remained for screening. The title and abstract screen excluded 546 articles, leaving 59 articles for full-text screen. Fifty-one articles were excluded. One article was identified through a hand search, leaving a total of eight articles to be included in the final review. See Figure 1 for details.

**Study Characteristics**

Eight studies were included for the final review. Number of participants, mean age, mean height, and mean weight can be found in Table 1. Seven studies tested the dominant lower extremity, and one study tested the right lower extremity. The primary outcome was mean EMG in three studies, %MVIC in five studies, and H:Q ratio in three studies. H:Q ratio was calculated from mean % MVIC or mean EMG data by the authors, when not provided, in five studies. A total of seven different CKC exercises were analyzed throughout the eight included studies. Four studies used different variations of a two-legged squat and five studies used variations of a single-legged squat. A lateral step-up was analyzed in two studies, and the Fitter, Stairmaster® and slide board were all...
analyzed in one study. Placement of electrodes varied for each study, and muscles tested for each studied are described in Table 1.

Risk of Bias within Studies
Four studies received an overall quality rating of three stars (***) and four studies received an overall quality score of four stars (****) based on the MMAT criteria. Each of the four articles receiving three stars was due to the participant selection not being representative of the whole population being studied. Participants were either required to be under 170 centimeters tall, only Division I athletes, only DPT students, or only NAIA student-athletes. Table 2 presents quality assessment details from each study.

Results of Individual Studies
Mean EMG activity, % MVIC, and H:Q ratios are presented in Tables 3, 4, and 5, respectively. All exercises produced higher mean EMG muscle activation in quadriceps muscles versus hamstring muscles except for the squat machine exercise with posterior support at the level of the scapula, and the feet located 50 cm in front of the hips (21.1 ± 13.1 vastus lateralis; 26.6 ± 9.9 hamstrings). All exercises where % MVIC was reported, had higher quadriceps than hamstring activation (Table 4). The lowest % MVIC reported for the quadriceps was 25.9 ± 6.8 for the quarter squat, and the greatest quadriceps activation (seen in the vastus lateralis) was with the single-leg squat (116.2 ± 73.5). % MVIC values ranged from 9.2 ± 1.1 for the semitendinosus with...
a squat with the center of gravity placed behind the feet from 0 to 30 degrees of knee flexion\textsuperscript{22} to 41.3 ± 9.0 for a slide board exercise.\textsuperscript{18} The quarter squat exercise produced H:Q ratios that ranged from 0.17 to 0.61. The step-up exercise yielded similar H:Q ratios, ranging from 0.23\textsuperscript{19} to 0.61\textsuperscript{18}. A multitude of variations existed for the performance of the single-legged squat\textsuperscript{21,23,24} as well as two-legged squat,\textsuperscript{20-22,25} yielding a wide range of ratios. The Fitter (0.706), Stairmaster\textsuperscript{\textregistered} (0.629), and slide board (0.739) H:Q ratios were only analyzed in one study.\textsuperscript{18}

### DISCUSSION

#### Summary of Evidence

Many exercises included in this review were performed either with variations of the same exercise across studies or were only included in one study, limiting comparisons and the ability to perform a meta-analysis. The exercises included a variety of two leg, single leg, barbell squat, and body weight exercises. Overall, two-legged squats demonstrated poor H:Q ratios, with nearly all two-legged squat variations producing ratios less than 0.6.\textsuperscript{20-22,25} In two studies,\textsuperscript{20,22} knee flexion was 90 degrees or greater during the squat exercise, and another study instructed participants to not allow knee translation past the toes.\textsuperscript{21} The deep range of motion of these squat variations could possibly contribute to lower H:Q ratios. During the descent portion of the squat, quadriceps activity peaked between 80-90 degrees of knee flexion, due to the increased external torque from 45 to 90 degrees of closed chain knee flexion.\textsuperscript{4,26} Hamstring activity peaks between 30-80 degrees of knee flexion during the ascent portion of the squat.\textsuperscript{4,20} Hip angulation was not reported in these studies, but increased hip flexion during the squat increases hamstring activity and decreases tensile forces on the ACL.\textsuperscript{26} Squats into deep ranges

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<thead>
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<th>Study</th>
<th>Screening Questions</th>
<th>Quantitative Descriptive Quality Criteria</th>
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</thead>
<tbody>
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<td>Blanpied, 1999</td>
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<td>Y</td>
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<td>Nishiwaki et al., 2006</td>
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<td>Selection bias minimized during participant recruitment?</td>
<td>Exposure/intervention and outcome measurements are appropriate?</td>
</tr>
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<td>Zeller et al., 2003</td>
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Table 2. Quality Assessment

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The International Journal of Sports Physical Therapy | Volume 12, Number 1 | February 2017 | Page 8
reflected a quadriceps dominant exercise which can increase the tensile force on the ACL.

Two squat variations, the squat machine with support at the scapula and the feet in line with the hips, and the squat machine with support at the scapula and feet placed 50 cm in front of the hips, produced a H:Q ratio greater than 0.6.\textsuperscript{25} In this study, only 60 degrees of knee flexion was allowed. The squat machine with support at the level of the scapula and the feet placed 50 cm in front of the hips was the only variation of the squat that did demonstrate a H:Q ratio (1.26) that favored the hamstrings. By providing support at the scapula versus the hip, the moment arm for ground reaction forces to the hip was greater than the moment arm for ground reaction force to the knee. This increased the activation needed from the hamstrings acting as hip extensors, rather than the knee extensors to provide stabilization during the exercise.\textsuperscript{25} By placing the feet 50 cm forward as well, the moment arm for the hip remains greater than the moment arm for the knee. This further contributes to the need of the hamstrings to work as hip extensors, causing more activation of the hamstrings than the quadriceps.\textsuperscript{25}

Variations of the single-leg squat show promise as an exercise that produces an adequate H:Q ratio with some variations producing ratios greater than 0.6. Zeller et al and Hopkins et al both had poor H:Q ratios for a single-leg squat which may be attributed to the depth of the squat. Participants in the Zeller et al study were instructed to squat down as far as possible without losing their balance, and averaged

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<thead>
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<th>Table 3. Mean ± SD EMG Activity</th>
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<tbody>
<tr>
<td>Study</td>
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Note: Hip= support was located at hip level; Scap= support was located at the scapular level; I-L= the foot was in line with the hips; FF= the feet were located 50 cm in front of the line of the hip
\* = values reported as EMG (mV x sec x 10\textsuperscript{3}); \* * = values were not reported with a unit; \* * * = values were reported as EMG (mV); \* * * * = values were reported as total EMG (mV x sec)
\textsuperscript{VM} indicates vastus medialis muscle; \textsuperscript{VL} indicates vastus lateralis muscle; \textsuperscript{BF} indicates biceps femoris muscle; \textsuperscript{HM} indicates hamstring muscle group; \textsuperscript{RF} indicates rectus femoris muscle;
approximately 95 degrees of knee flexion, while participants in the Hopkins et al study only performed the single-leg squat to about 30 degrees of knee flexion. Performing a squat past 90 degrees may favor the quadriceps due to the increased external torque, while squatting only to 30 degrees does not allow the hamstrings to have optimal activation since the moment arm of the hamstrings is greatest from 50 to 90 degrees of knee flexion. Two studies, Youdas et al and Graham et al, performed variations of the single leg squat that produced H:Q ratios that were greater than 0.6. Participants in the Youdas et al study averaged approximately 45 degrees of knee flexion, while those in the Graham et al study averaged about 56 degrees of knee flexion. Youdas et al also encouraged forward trunk lean while performing the single-leg squat to increase tension on the hamstrings. This demonstrates that the degree of hip and knee flexion may play an important role in producing H:Q ratios that are considered appropriate, and not excessively quadriceps dominant.

Lateral step ups, performed in two studies, presented a similar situation as single-leg squats. Those performed with a 20.3 cm step with an average degree of knee flexion of 68.5 degrees, produced a H:Q ratio of 0.61, while those performed with a 10 cm step and an average knee flexion of 30 degrees, only pro-

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<td>Fitter</td>
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<td>15.9 ± 6.4&lt;sup&gt;HM&lt;/sup&gt;</td>
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<td>Slide Board</td>
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<td>Lateral Step-Up</td>
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<td>12.4 ± 2.2&lt;sup&gt;HM&lt;/sup&gt;</td>
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<td>Squat: CGF:30-60</td>
<td>54.7 ± 1.8&lt;sup&gt;VM&lt;/sup&gt;</td>
<td>13.9 ± 1.9&lt;sup&gt;HM&lt;/sup&gt;</td>
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<td>61.2 ± 1.6&lt;sup&gt;VM&lt;/sup&gt;</td>
<td>14.6 ± 1.8&lt;sup&gt;HM&lt;/sup&gt;</td>
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<td>37.7 ± 2.1&lt;sup&gt;VM&lt;/sup&gt;</td>
<td>10.3 ± 2.5&lt;sup&gt;HM&lt;/sup&gt;</td>
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<td>52.0 ± 2.4&lt;sup&gt;VM&lt;/sup&gt;</td>
<td>15.4 ± 2.8&lt;sup&gt;HM&lt;/sup&gt;</td>
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<tr>
<td>Lynn et. al, 2012</td>
<td>Squat</td>
<td>71.3 ± 51.5&lt;sup&gt;RF&lt;/sup&gt;</td>
<td>28.9 ± 27.0&lt;sup&gt;BF&lt;/sup&gt;</td>
</tr>
<tr>
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<td>Counter-balanced Squat</td>
<td>64.5 ± 45.0&lt;sup&gt;RF&lt;/sup&gt;</td>
<td>30.5 ± 28.9&lt;sup&gt;BF&lt;/sup&gt;</td>
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<tr>
<td>Zeller et. al, 2003</td>
<td>Single-Leg Squat</td>
<td>116.2 ± 73.5&lt;sup&gt;VL&lt;/sup&gt;</td>
<td>83.4 ± 14.5&lt;sup&gt;RF&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Note: CGO = the center of gravity was over the feet; CGF = the center of gravity was in front of the feet; CGB = the center of gravity was behind the feet; VM indicates vastus medialis muscle; VL indicates vastus lateralis muscle; BF indicates biceps femoris muscle; HM indicates hamstring muscle group; RF indicates rectus femoris muscle; ST indicates semitendinosus muscle group.
duced H:Q ratios between 0.23 and 0.39. This demonstrated the influence of hip and knee flexion angles to produce a H:Q ratio greater than 0.6.

The modified single leg squat produced a H:Q ratio that is considered to be adequate. Participants in this study were instructed not to allow their knee to translate over their toes. During the modified single leg squat, the non-dominant leg was placed on a 12 inch step, which allowed for some weight bearing through both lower extremities. It also allowed for the center of gravity to move posterior to that of a regular single-leg squat, increasing the demand placed on the hamstrings.

The Fitter, Stairmaster®, and slide board exercises all produced H:Q ratios that were greater than 0.6 indicating good co-activation of the hamstrings and

<table>
<thead>
<tr>
<th>Study</th>
<th>Exercise</th>
<th>H:Q</th>
</tr>
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<tbody>
<tr>
<td>Hopkins et. al, 1999</td>
<td>Unilateral Quarter Squat (Flexion)</td>
<td>0.17 BF/VL</td>
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<td>Unilateral Quarter Squat (Extension)</td>
<td>0.34 BF/VL</td>
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<td>0.19 BF/VM</td>
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<td>0.23 BF/VL</td>
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<td>Lateral Step-Up (Extension)</td>
<td>0.36 BF/VL</td>
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<td>Lateral Step-Up (Flexion)</td>
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<td>Lateral Step-Up (Extension)</td>
<td>0.39 BF/VM</td>
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<td>Blanpied et. al, 1999</td>
<td>Squat Machine: Hip: I-L</td>
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<td>Wall Slide: Hip: I-L</td>
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<td>Single Leg Squat (Labile)</td>
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<td>Graham et. al, 1993</td>
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<td>Stairmaster</td>
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<td>Lateral Step-Up</td>
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<td>0.14 ± 1.5</td>
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<td>0.20 ± 1.7</td>
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<tr>
<td>Zeller et. al, 2003</td>
<td>Counter-balanced Squat</td>
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Note: H:Q= Hamstrings:Quadriceps; BF/VL= Biceps Femoris/Vastus Lateralis; BF/VM= Biceps Femoris/Vastus Medialis; BF/RF= Biceps Femoris/Rectus Femoris; CGO= the center of gravity was over the feet; CGF= the center of gravity was in front of the feet; CGB= the center of gravity was behind the feet; *= Semitendinosus/Vastus Medialis Ratio; **= Biceps Femoris/Vastus Medialis Ratio
quadriceps. Average degrees of knee flexion were 42 degrees for the Fitter, 72 degrees for the Stairmaster®, and 55 degrees for the slide board.

The comparison of these exercises demonstrate the importance of the degree of knee flexion while performing CKC in order to produce H:Q ratios that are not disproportionately quadriceps dominant. The results of these studies suggest that approximately 42 to 72 degrees of knee flexion may be the optimal range to encourage adequate H:Q co-activation ratios to reduce tensile force on the ACL and reduce the risk of injury. This can be in part because the hamstring moment arm is greatest between 50 and 90 degrees of knee flexion, and the quadriceps moment arm is greatest between 20 and 60 degrees of knee flexion with the external torque being greatest from 45 to 90 degrees of knee flexion. Not allowing for excessive knee flexion may diminish the need for eccentric control of the hamstrings to slow knee flexion, while too much knee flexion increases the external torque placed on the knee, both contributing to quadriceps dominant activation patterns. Exercises that produce poor H:Q ratios may be best avoided during the early rehabilitation phase after knee injury, or when the goal of rehabilitation is to promote hamstring activation.

Limitations
The primary limitation of this review was the small variety of exercises that were studied and the multiple variations of the same exercise that were performed across research studies. Some H:Q ratios were calculated based on average %MVIC that was presented in the studies, and not by the original researchers, which may contribute to slight variations in actual H:Q ratios. Another limitation was the inability to include studies that did not separate male and female data. Finally, only studies that were available in English could be included for review. Further research is needed to analyze H:Q ratios in other common therapeutic exercises that utilize CKC.

CONCLUSIONS
There are a variety of exercises that are performed to promote quadriceps and hamstring muscle strengthening. Multiple factors, including hormonal, anatomical, and neuromuscular, contribute to which exercise is preferred to produce a H:Q ratio that is above 0.6 in order to avoid excessive quadriceps dominance and anterior tensile force on the ACL. These results suggest that exercises with an appropriate range of motion, approximately 42 to 72 degrees, may yield adequate H:Q co-activation ratios and may decrease tensile load on the ACL as described in previous literature.

REFERENCES
11. Holcomb WR, Rubley MD, Lee HJ, Guadagnoli MA. Effect of hamstring-emphasized resistance training...

APPENDIX 1. DETAILS OF SEARCH STRATEGY

PubMed Search Strategy

1. hamstrings[Text Word]
2. hamstring[Text Word]
3. hamstrings muscle[Text Word]
4. hamstring muscle[Text Word]
5. 1 OR 2 OR 3 OR 4
6. quadriceps muscle[MeSH Terms]
7. quadriceps muscle[Text Word]
8. quadricep muscle[Text Word]
9. quadriceps[Text Word]
10. quadricep[Text Word]
11. 6 OR 7 OR 8 OR 9 OR 10
12. electromyography[MeSH Terms]
13. electromyography[Text Word]
14. EMG[Text Word]
15. muscle activation[Text Word]
16. neuromuscular activation[Text Word]
17. co-activation[Text Word]
18. coactivation[Text Word]
19. co-recruitment[Text Word]
20. corecruitment[Text Word]
21. co-contraction[Text Word]
22. cocontraction[Text Word]
23. h/q[Text Word]
24. h/q ratio[Text Word]
25. h/q activation[Text Word]
26. h/q coactivation
28. maximal voluntary isometric contraction
29. maximum voluntary isometric contraction
30. 12 OR 13 OR 14 OR 15 OR 16 OR 17 OR 18 OR 19 OR 20 OR 21 OR 22 OR 23 OR 24 OR 25 OR 26 OR 27 OR 28 OR 29
31. resistance training
32. resistance training
33. therapeutic exercise
34. muscle strengthening
35. exercise therapy
36. exercise therapy
37. physical therapy
38. physiotherapy
39. exercise
40. open chain kinetic exercise
41. closed chain kinetic exercise
42. 31 OR 32 OR 33 OR 34 OR 35 OR 36 OR 37 OR 38 OR 39 OR 40 OR 41
43. 5 AND 11 AND 30 AND 42

CINAHL Search Strategy
1. (MH “Hamstring Muscles”) OR “hamstrings” OR “hamstring” OR “hamstring muscle” OR “hamstrings muscle”
2. (MH “Quadriceps Muscles +”) OR “quadriceps” OR “quadricep” OR “quadriceps muscle” OR “quadriceps muscle”
3. (MH “Electromyography”) OR “electromyography” OR “EMG” OR “muscle activation” OR “neuromuscular activation” OR “co-activation” OR “coactivation” OR “co-recruitment” OR “corecruitment” OR “co-contraction” OR “cocontraction” OR “h/q” OR “h/q ratio” OR “MVIC” OR “Maximal voluntary isometric contraction” OR “maximum voluntary isometric contraction”
4. (MH “Resistance Training”) OR “resistance training” OR (MH “Therapeutic Exercise”) OR “therapeutic exercise” OR (MH “Closed Kinetic Chain Exercises”) OR (MH “Lower Extremity Exercises”) OR (MH “Muscle Strengthening +”) OR “muscle strengthening” OR (MH “Open Kinetic Chain Exercises”) OR “exercise therapy” OR (MH “Physical Therapy”) OR “Physical therapy” OR “physiotherapy” OR (MH “Exercise”) OR “closed kinetic chain” OR “closed chain” OR “open kinetic chain” OR “open chain”
5. 1 AND 2 AND 3 AND 4

Web of Science Search Strategy
1. TOPIC: (hamstrings) OR TOPIC: (hamstring) OR TOPIC: (hamstring muscle) OR TOPIC: (hamstrings muscle)
2. TOPIC: (quadriceps) OR TOPIC: (quadricep) OR TOPIC: (quadriceps muscle) OR TOPIC: (quadricep muscle)
3. TOPIC: (electromyography) OR TOPIC: (EMG) OR TOPIC: (muscle activation) OR TOPIC: (neuromuscular activation) OR TOPIC: (co-activation) OR TOPIC: (coactivation) OR TOPIC: (co-recruitment) OR TOPIC: (corecruitment) OR TOPIC: (co-contraction) OR TOPIC: (cocontraction) OR TOPIC: (h/q) OR TOPIC: (h/q ratio) OR TOPIC: (h/q activation) OR TOPIC: (h/q coactivation) OR TOPIC: (MVIC) OR TOPIC: (maximum voluntary isometric contraction) OR TOPIC: (maximal voluntary isometric contraction)
4. TOPIC: (resistance training) OR TOPIC: (therapeutic exercise) OR TOPIC: (muscle strengthening) OR TOPIC: (exercise therapy) OR TOPIC: (physical therapy) OR TOPIC: (physiotherapy) OR TOPIC: (exercise) OR TOPIC: (closed chain kinetic exercise) OR TOPIC: (open chain kinetic exercise)
5. 1 AND 2 AND 3 AND 4

Scopus Search Strategy
1. (TITLE-ABS-KEY (quadriceps* )) OR (TITLE-ABS-KEY (quadriceps femoris*)) OR (TITLE-ABS-KEY (quads*)) OR (TITLE-ABS-KEY (quad* )) OR (TITLE-ABS-KEY (quadricep* )))
2. (TITLE-ABS-KEY (hamstrings*)) OR (TITLE-ABS-KEY (hamstring*))
3. (TITLE-ABS-KEY (resistance training) OR TITLE-ABS-KEY (open chain kinetic exercise) OR TITLE-ABS-KEY (closed chain kinetic exercise) OR TITLE-ABS-KEY (therapeutic
exercise) OR TITLE-ABS-KEY (lower extremity exercise) OR TITLE-ABS-KEY (muscle strengthening) OR TITLE-ABS-KEY (neuromuscular facilitation) OR TITLE-ABS-KEY (plyometrics) OR TITLE-ABS-KEY (exercise therapy) OR TITLE-ABS-KEY (physical therapy) OR TITLE-ABS-KEY (physiotherapy) OR TITLE-ABS-KEY (neuromuscular activation))

4. ((TITLE-ABS-KEY (electromyography) OR TITLE-ABS-KEY (emg) OR TITLE-ABS-KEY (electromyography feedback)))

5. 1 AND 2 AND 3 AND 4

**PEDro Search Strategy**

1. Knee EMG

**SportDiscus Search Strategy**

1. DE “QUADRICEPS muscle” OR DE “RECTUS femoris muscle” OR DE “VASTUS medialis”
2. DE “HAMSTRING muscle”
3. H/Q
4. H/Q ratio
5. H/Q activation
6. H/Q coactivation
7. DE “ELECTROMYOGRAPHY”
8. maximal voluntary isometric contraction
9. maximum voluntary isometric contraction
10. mvic
11. EMG
12. Muscle activation
13. Neuromuscular activation
14. Co-activation
15. Coactivation
16. Co-recruitment
17. Corecruitment
18. Co-contraction
19. Cocontraction
20. 3 OR 4 OR 5 OR 6 OR 7 OR 8 OR 9 OR 10 OR 11 OR 12 OR 13 OR 14 OR 15 OR 16 OR 17 OR 18 OR 19
22. closed kinetic chain
23. closed chain
24. open kinetic chain exercises
25. open kinetic chain
26. open chain
27. therapeutic exercise
28. muscle strengthening
29. DE “PHYSICAL therapy”
30. Physical therapy
31. physiotherapy
32. 21 OR 22 OR 23 OR 24 OR 25 OR 26 OR 27 OR 28 OR 29 OR 30 OR 31
33. 1 AND 2 AND 20 AND 32
ABSTRACT

Background: Iliotibial Band (ITB) syndrome is a troublesome condition with prevalence as high as 12% in runners. Stretching has been utilized as a conservative treatment. However, there is limited evidence supporting ITB elongation in response to a stretching force.

Purpose/Hypotheses: The purpose of this study was to describe the iliotibial band tensor fascia lata complex (ITBTFLC) tissue elongation response to a simulated clinical stretch in-vitro. The authors hypothesized that the ITBTFLC would undergo statistically significant elongation when exposed to a clinical-grade stretching regimen, with the majority of the elongation occurring within the proximal ITBTFLC region.

Study Design: Within subjects repeated measures in-vitro design.

Methods: The strain response of six un-embalmed ITBTFLCs to a simulated clinical stretch of 2.75% elongation was assessed. Four sets of array marks were placed along the length of the ITBTFLC. Photographic images were taken in resting position (with 1.0% in-situ elongation) and with an additional 2.75% elongation. Tissue elongation was compared between proximal, middle, and distal ITBTFLC regions.

Results: A paired samples t-test demonstrated a significantly longer ITBTFLC in the “stretched” versus resting condition ($p = 0.001$). Significant elongation was observed in the proximal (3.96mm (SD = 1.35); $p = 0.001$), middle (2.12mm (SD = 1.49); $p = 0.018$) and distal (2.25mm (SD = 1.37); $p = 0.01$) regions during the “stretched” versus the resting condition. A one-way ANOVA demonstrated a significant main effect for region ($p = 0.002$). The proximal region exhibited significantly greater elongation versus the middle ($p = 0.003$) and distal ($p = 0.007$) regions, with no significant difference between the middle and distal regions ($p = 0.932$).

Conclusion: The results of this study demonstrate that the ITBTFLC is capable of elongation in response to a clinically simulated stretch. The proximal ITB region underwent significantly greater elongation than the middle and distal regions and may be more likely to respond to “stretching” in clinical situations. Future investigation should assess the ITBTFLC load/deformation properties to determine whether a short-term clinically available stretch translates into permanent tissue elongation.

Key Words: Iliotibial band, iliotibial band syndrome, stretch, tensor fascia lata

Level of Evidence: III

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INTRODUCTION

Iliotibial Band Syndrome (ITBS) is a commonly identified clinical condition characterized by focal lateral knee pain, which is often experienced while running and cycling. The prevalence of ITBS is reported to be 12% in runners\(^1\) and comprises 15% of cycling overuse injuries,\(^2\) often resulting in pain levels sufficient to result in activity cessation. Despite the high prevalence and impact on activity participation, controversy persists regarding ITBS etiology, related causal mechanisms, and treatment approaches.

Iliotibial Band Syndrome is thought to originate from a variety of functional anatomical and activity related factors.\(^1\) Anatomical factors may include specific anatomical features and differences such as femoral neck angle, femoral torsion, and Q-Angle. Activity related factors such as overuse and activity load are thought to contribute to ITBS development and pain persistence.\(^1\) The iliotibial band (ITB) is a distal continuation of the fascia arising from the tensor fascia lata (TFL), gluteus maximus, and gluteus medius muscles.\(^3\) The ITB serves as a supportive fascial structure that proximally encapsulates the TFL muscle and spans from the iliac crest and gluteus maximus to Gerdy’s (anterolateral tibial) tubercle. The ITB is considered to be a lateral thickening of the circumferential fascia lata.\(^4\) The ITB longitudinal fibers are continuous with the fascial sheath completely enveloping the lateral thigh and adhere to the entire length of the lateral intermuscular septum that attaches onto the femur’s linea aspera, separating the anterior and posterior compartments of the thigh.\(^5\) The ITB is linked to the femur through obliquely oriented strands of dense, regular fibrous connective tissue.\(^5\) After coursing between the biceps femoris and vastus lateralis the ITB attaches to the lateral femoral condyle and sends lateral retinacular fibers to the patella.\(^6\) Deep to the ITB at the lateral femoral condyle, investigators describe the presence of a bursa,\(^7\) retro-fascial space,\(^8\) and a fat pad that is highly vascularized, containing Pacinian corpuscles and nerve fibers.\(^3,5,9\) Finally, the most distal fibers attach to the Gerdy’s (anterolateral tibial) tubercle.

The histologic structure of the ITB is consistent with tendinous tissue,\(^9\) where the amount of elastic fibers within the tendon is sparse.\(^5\) Despite diligent review of literature, no comprehensive report of the tensile properties of the ITB-TFL complex was found. However, a 1931 study examined cadaveric fascia lata tissue and reported that 8-10% elongation would lead to a structural “break”.\(^10\) Gratz likened the tremendous tensile strength of the fascia lata to “soft steel wire of similar weight”, yet with “unexpected degrees of elasticity”.\(^10\) Falvey et al\(^4\) showed that hip motion (hip flexion, knee flexion, and hip adduction) produced the most ITB strain, compared to straight leg raise or Ober’s test position, however, tensile properties of anatomically different regions of the ITB-TFLC in total were not assessed.

Changes in the structural characteristics and mechanical properties of the ITB have been described as substantial contributors to development and persistence of ITBS.\(^2,11-13\) Selected authors purport tissue dysfunction and aberrant biomechanics as causative factors in ITBS development.\(^14-16\) Orchard et al\(^17\) described ITBS as an impingement between the lateral femoral condyle and the ITB posterior margin at approximately 30 degrees of knee flexion just prior to heel strike while running. The impingement event was thought to occur as the distal ITB repetitively moved in an anterior-posterior direction over the lateral femoral condyle, producing friction.\(^1,17,18\) Conversely, Fairclough and colleagues\(^19\) challenged the notion of an anterior-posterior movement, and instead proposed that the ITB moves in a lateral to medial direction causing lateral knee compressive forces.\(^5\) These authors reported that a relative tensioning and relaxation of the anterior and posterior fibers occurs during knee flexion and extension, contributing to tissue microtrauma and subsequent symptoms.

Management strategies have been suggested for reducing ITB dysfunction and improving mechanics, with limited evidence as to their efficacy.\(^1\) Clinical stretching techniques have been discussed as a possible treatment component aimed at modifying tissue dysfunction. However, limited evidence has been published supporting the effect of stretching on mechanical changes and or symptoms.\(^12,20-22\) Doucette and Goble\(^23\) reported a correlation between ITBS symptom improvement and increased ITB flexibility as measured by the distance from the medial patella to the table during Ober’s position. Conversely, other investigators have suggested that ITB stretching is not beneficial for reducing symptoms on a long-term
Noehren et al suggested that increased closed chain hip adduction and internal rotation moments contribute to ITB syndrome and propose hip abductor strengthening as a management strategy. Grau et al observed decreased hip adduction in ITBS subjects while running and proposed hip abductor stretches as a treatment approach. Yet, none of these studies examined the actual mechanical effects of stretching on the ITB tissue.

To clarify the ITB stretching effect, Willet et al discovered that the mid-thigh ITB does not appear to be the exclusive constraint to hip adduction during the Ober's test, with the gluteus medius, gluteus minimus, and the joint capsule constraining adduction. While these investigators examined ITB behaviors that constrained hip adduction, no study has examined the elongation potential of the entire ITB-tensor fascia lata complex (ITBTFLC) during simulated clinical stretching elongation. Therefore, the purposes of this study were to: (1) determine if the in-vitro un-embalmed ITBTFLC elongates in response to clinical-grade longitudinal tension loading and (2) describe the elongation behaviors found in different tissue regions along its ITBTFLC length. The authors hypothesized that the ITBTFLC would undergo elongation when exposed to clinical-grade stretching loads, and that the majority of the elongation would occur at the proximal portion, which includes the TFL muscular fibers.

MATERIALS AND METHODS

Preparatory Procedures

Six right-sided ITBTFLCs were harvested from six unembalmed human cadavers (3 male and 3 female) with a mean age of 81.5 (SD ± 7.8) ranging from 73 to 92 years. Cadaver characteristics including cause of death can be found in Table 1. All cadavers were stored at 3.9°C prior to ITBTFLC removal. In order to establish the resting tension present in the intact cadaveric ITBTFLC, pre- and post-dissection length measures were conducted both with and without intermuscular septum dissection. On the cadaver's left lower extremity, the entire ITBTFLC was exposed and the resting length of the ITBTFLC was subsequently determined. The resting length was determined in the following manner: the dissecting investigator separated the ITBTFLC from the underlying structures by cutting the intermuscular septum. The investigators then located the most distal (inferior and posterior) prominence of Gerdy's tubercle and the most proximal insertion of the ITBTFLC into the iliac crest (posterior fibers). A pin was placed at each location and ITBTFLC length was measured using a tape measure to record the in-situ resting length of the ITBTFLC. Investigators then removed Gerdy's tubercle (with the pin in place) and the length between pins was measured again. The second investigator held the tubercle and the ITBTFLC in place with sufficient tension to remove slack while avoiding a detectable stretch. The average of three measures was recorded both before and after tubercle dissection. Following these measurements, the ITBTFLC was removed along with a small portion of the iliac crest.

The difference in ITBTFLC length between the pre- and post- Gerdy's tubercle dissection was divided by the original length (before dissecting Gerdy's tubercle from the tibia) and multiplied by 100% to calculate the ITBTFLC percent change in length after removing Gerdy's tubercle from the tibia under each of the two dissection methods. The following formula was used for this calculation:

\[
\%\Delta \text{Length} = \frac{\text{Length}_{\text{Original}} - \text{Length}_{\text{Gerdy's cut}}}{\text{Length}_{\text{Original}}} \times 100
\]

Table 1. Cadaver characteristics.

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>Age</th>
<th>Sex</th>
<th>Cause of Death and Comorbidities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>89</td>
<td>Female</td>
<td>Complications of vascular dementia, COPD</td>
</tr>
<tr>
<td>2</td>
<td>92</td>
<td>Male</td>
<td>COPD, CAD, CHF, CAV</td>
</tr>
<tr>
<td>3</td>
<td>76</td>
<td>Female</td>
<td>COPD, CAD, CHF, West Nile Virus, Post-Polio Syndrome, Adult Failure to Thrive</td>
</tr>
<tr>
<td>4</td>
<td>83</td>
<td>Male</td>
<td>CVA, HTN</td>
</tr>
<tr>
<td>5</td>
<td>73</td>
<td>Female</td>
<td>Pancreatic Cancer</td>
</tr>
<tr>
<td>6</td>
<td>76</td>
<td>Male</td>
<td>Failure to Thrive, Dementia, Crohn's Disease, prostate Cancer</td>
</tr>
</tbody>
</table>

COPD = Chronic Obstructive Pulmonary Disease, CAD = Coronary Artery Disease, CHF = Congestive Heart Failure, CAV = Cardiac Allograft Vasculopathy, CVA = Cerebrovascular Accident, HTN = Hypertension
This calculation represents ITBTFLC in-situ elongation and was used to “pre-tension”/mimic the in-situ length of ITBTFLC prior to the simulated “clinical stretching” protocol.

The in-situ “clinical stretch” elongation percent was calculated in a similar manner to the in-situ resting length (described above) by measuring changes in ITBTFLC length from resting position to full hip adduction in the frontal plane. Pilot testing involved one intact cadaveric specimen with the ITBTFLC exposed from the iliac crest to the distal insertion at Gerdy’s tubercle. The cadaver was positioned supine with the non-testing lower extremity in hip and knee flexion. Resting length of the ITBTFLC was then measured. The non-testing lower extremity was then flexed at the hip and knee and positioned over the testing leg with the foot positioned lateral to the testing side leg. One investigator stabilized the pelvis while a second investigator adducted the testing lower extremity with maximum force with force placement just distal to Gerdy’s tubercle. A third investigator re-measured the ITBTFLC length with maximal adduction in this position resulting in a 2.75% increase in ITBTFLC length compared to resting. This testing position was most similar to “Stretch A” as described by Fredericson and colleagues (2002). Based on the relatively benign nature of this stretching position and its similarity to actual clinical stretches, it is unlikely that this 2.75% elongation would produce injury.

Two custom-made clamping devices were fabricated using a commercially available two-part resin material with an abrasive surface secured to each side of the clamping devices to prevent specimen slippage. Once harvested, ITBTFLC specimens were stored at -18°C until 12 hours prior to data collection when they were transferred to a different storage device and held at 3.9°C. Four hours prior to data collection, each specimen was allowed to warm to room temperature (19.8°C). All specimens were carefully cleaned, removing adipose tissue and muscle fibers that could have interfered with visualization of the ITBTFLC or altered the mechanical properties of the tissue. Specimens were then lightly cleaned with a 70% isopropyl alcohol solution using a soft cloth. Specimens were excluded if observable abnormalities or damage was observed after they were cleaned. Specimens were placed flat on a hard surface and

![Figure 1. Placement of Marker Arrays in cadaveric ITBTFLC. M1 = Marker Array 1; M2 = Marker Array 2; M3 = Marker Array 3; M4 = Marker Array 4; IC = Iliac Crest; GT = Gerdy’s Tubercle.](image-url)
mal end of the TFL insertion at the iliac crest; and (4) Marker Array 4- distal marker positioned distal to marker 2, 50% of the distance from marker 2 to the most distal end of the ITB insertion at Gerdy’s Tubercle. Each of the three regions were anatomically unique, with the TFL present in the proximal region, the middle region being attached to the linea aspera via the intermuscular septum, and the distal region absent of muscle fibers and having less attachment to the linea aspera versus the middle region. Approximately 50% of the TFL resided between Marker Array 1 and Marker Array 3 with the other 50% falling proximal to Marker Array 3. Additionally, while the ITB in this area serves as an attachment to the gluteus maximus, all gluteus maximus fibers were removed prior to testing.

Investigators mounted each ITBTFLC specimen into a 10 kN material testing system (MTS; MTS Systems Corporation, Eden Prairie, MN, USA) using custom-made clamping devices. The ITBTFLC was mounted with the distal end in the upper bracket and the bony ends of the ITBTFLC just outside the clamping devices to further prevent material slippage (Figure 2). A 12.2-megapixel digital camera (Canon Rebel xsi eos 450D, 18-55mm zoom lens; Canon U.S.A., Inc) was used to capture images. The camera was placed approximately one meter from the plane of the ITBTFLC, with the focal point centered at the specimen’s midpoint.

Each specimen was mounted in the MTS to a predetermined (1%) in-situ elongation and an image was captured. This 1% strain was established through the calculation of the mean ITBTFLC length difference between intact Gerdy’s tubercle and cut Gerdy’s tubercle during specimen harvesting as described above. Once mounted in the MTS and pre-tensioned, the full length of the specimen was recorded. Next, the specimen was elongated at five mm/second to the simulated “clinical stretch” that equaled an additional 2.75% strain as determined by in-situ cadaveric pilot testing described above. This “clinical stretch” position was beyond the pre-tensioned 1% in-situ state and maintained by the MTS device for 40 seconds. Afterward, the tissue was returned to the in-situ resting length for an additional 40 seconds. The simulated stretch protocol was repeated an additional three times. During each stretch protocol, the length was maintained for 40 seconds to mimic a clinical stretch scenario. A second image was captured at the end of the fourth stretch cycle with the specimen still in the loaded position. After the image was captured, the investigator returned the ITBTFLC to the in-situ resting length. Images were imported into and analyzed using a custom MATLAB (The MathWorks, Inc, Natick, MA, USA) program designed to calculate: 1) overall ITBTFLC elongation; and 2) elongation for each ITBTFLC section. Marker locations were identified by the investigator in both images (pre-and post-stretch cycle) and region lengths were calculated with consideration to both vertical and horizontal change using marker coordinates. Elongation was then calculated by comparing pre- to post-stretch cycle region lengths.

**Statistical Methods**

All data were analyzed using IBM SPSS version 21.0 for Windows (IBM Corp. Armonk, NY). Descriptive
statistics were calculated to summarize the demographic characteristics of the sample. Skewness, kurtosis and the Shapiro Wilk test were used to establish data normality. A paired samples t-test was used to determine if a difference existed between the simulated in-situ length and the length after the simulated stretch protocol. A one-way ANOVA was performed to identify significant main effects for the ITB region. Tukey’s post-hoc pair-wise comparison was used to identify the locations of significant differences. Significance was set at $\alpha = 0.05$ for all statistical comparisons.

**RESULTS**

All variables were normally distributed as defined by meeting at least two of three criteria (Shapiro Wilk test p-value $>0.05$, skewness between -2 and +2 and kurtosis between -2 and +2). The ITBTFLC was significantly elongated ($t = -6.753$; $p = 0.001$) in the “stretched” condition (381.62 ± 39.58 mm, 95% CI 349.95 – 413.28) versus resting condition (373.03 ± 39.45 mm, 95% CI 341.46 - 404.60), representing an average elongation of 2.3% between the most proximal (M3) and distal (M4) regions. The one-way ANOVA demonstrated a significant main effect for ITBTFLC region [$F(2,15)=9.589$; $p = 0.002$]. The post-hoc pairwise comparison tests (Figure 3) demonstrated that the proximal region strain (4.45 ± 1.79% 95%, CI 3.01 - 5.88; includes the TFL) was significantly greater than the middle (1.42 ± 1.02%, 95% CI 0.60 - 2.24; $p = 0.003$) or distal (1.70 ± 1.00% 95% CI 0.9-2.49; $p = 0.007$) strain values, while there was no significant difference between the middle and distal strain values ($p = 0.932$). Average force required to produce 2.75% initial elongation of the initial specimen was 79.15 N ± 41.05. After the initial 40-second simulated stretch cycle, the average force was 61.81 N ± 34.13. Visual specimen inspection did not reveal obvious tissue damage resulting from the 2.75% elongation protocol.

**DISCUSSION**

Results of this in-vitro study demonstrate that the ITBTFLC complex is capable of undergoing elongation (mean: 2.3%, range:1.1-3.5%) during a clinical-grade longitudinal tension loading protocol, and that significantly greater elongation was found in the proximal region when compared to the middle and distal regions. Initial testing during ITBTFLC specimen harvesting demonstrated a 1% resting elongation in-situ and an additional 2.75% elongation during an in-situ simulated clinical stretch compared to in-vitro length. These same elongation values were used during the “simulated stretch” protocol. Although the outcomes of this study demonstrated greater elongation than those presented in the study by Falvey et al,4 which demonstrated a 0.23 ± 0.18% mean elongation during a maximum voluntary hip abductor contraction, both studies demonstrate minimal elongation in the ITB itself. While the proximal region (including the TFL) lengthened by 4.45% in the current study, the middle and distal regions elongated by only 1.42% and 1.7%, respectively. The presence of the TFL in the proximal region was likely a factor contributing to the greater elongation observed in this region in the current study, where the location of greatest deformation occurred at the apparent pathway of least resistance, localized in the TFL and its connection with the ITB. This may correspond with the transition from muscle tissue to dense, regular fibrous connective tissue in the specific area.5 Within the range of loads tested in the present study, the outcomes suggest that most elongation will occur in this (proximal) region versus other regions of persistent higher stiffness. While not statistically significant, the distal region lengthened slightly more than the middle region. Since the intermuscular septum was not present in the current study, speculation regarding the influence of
this ITBTFLC attachment on the elongation pattern in-vivo or in-situ is not possible and should be considered for further study.

Many different treatment options other than stretching have been suggested for use to increase ITB extensibility. These include, but are not limited to, osteopathic manipulative treatment techniques that include a counterstain technique, self-administered myofascial release techniques utilizing a foam roll, and myofascial release techniques that are manually applied by a therapist. However, any contemporary recommendation supporting the use of these approaches can only be based on clinical experience and speculative conclusions in the absence of rigorous clinical data. Future research should examine the mechanical, neurophysiological, and clinical impact of such strategies.

Stretching is a common intervention utilized to affect elongation of the ITB. Little consensus exists regarding the structural impact of ITB stretching on the actual tissues. Different investigators have suggested that ITB fibers can be stretched by observing decreased ITB width during a modified Ober's maneuver. While both studies found that in-vivo ITB width narrowed during the test, they did not examine actual ITB longitudinal elongation response. Other investigators have examined the effects of stretching on ITB longitudinal deformation in cadaveric specimens. Matsumoto et al. used cadaveric selective cutting to discover that ITB superficial fibers at the mid-thigh level create a notable constraint to ITB elongation under a stretching load. Using mid-thigh ITB strain-gauge measures in unembalmed cadavers, Falvey et al. observed less than five percent ITB deformation occurred during the Ober test and hip flexion-adduction-external rotation and questioned whether stretching produces appreciable clinical stretch or strain and, moreover, whether or not it is capable of producing a lasting ITB lengthening effect. However, these investigators focused their evaluation on the middle portion of the ITB, not the entire ITB length.

While ITBTFLC “stretching” has been shown to be clinically beneficial, based on the paucity of comprehensive ITBTFLC tensile strength data, it is difficult to determine where clinical stretching protocols fall relative to the load/deformation curve for this specific tissue. Clinical stretching protocols may produce tissue elongation that falls within the elastic range of tissue deformation, leading to temporary clinical benefits, however, more research is needed to definitively resolve this question. Additionally, it is unlikely that short term “clinical stretching” produces permanent ITB deformation and as a result, other factors such as neuromuscular control changes may contribute to perceived clinical benefits. Future in-vivo research should examine the effects of a long-term stretching program on ITB stiffness, thus allowing for longer termed effects such as collagen deposition and cellular level processes involved in tissue healing and regeneration.

Although the current study's findings are in agreement with those of Falvey et al. demonstrating minimal stretching of the ITB, these findings are in contrast to those of Frederickson et al. who suggested that three different ITB stretch positions resulted in considerable ITB lengthening. It is important to note that these authors measured lengthening using 3-D motion analysis in-vivo, which may have resulted in marker movement due to skin movement in relation to underlying bony landmarks. While these authors reported in-vivo ITB lengthening of 9.84-11.15% using surface markers, direct ITBTFLC elongation measurements using a simulated clinical stretch during limited pilot testing in preparation for the current study resulted in only 2.75% elongation. However, the pilot testing stretch procedure was similar to stretch “A” by Frederickson et al. which resulted in 9.84% elongation in their study. Based on analysis of data from the current study as well as the study by Gratz, it is likely that a deformation of 9.84-11.15% could result in clinically significant ITB tissue damage.

There are a few limitations to this study. Tissue properties may be slightly different for in-vivo versus in-vitro specimens; however, it is difficult to accurately assess the direct length of all three portions of the ITBTFLC in-vivo. While the tissue used for the present analysis was harvested from a specimen sample that was older than those individuals who would likely develop ITB pain, it is difficult to obtain cadaveric tissue samples from a younger population for testing. The inclusion of the TFL tissue in the current study limits the ability to apply the findings.
specifically to ITB tissue tensile properties in the absence of TFL elongation. Future studies should examine the ITB in the absence of the TFL to better understand the isolated ITB tensile properties. Moreover, future research should examine the influence of tensile properties in tissues surrounding the ITBTFLC. Finally, the cadaveric nature of this study does not allow for assessment of muscular tone influence on ITBTFLC elongation. Future studies should develop means to examine changes in stiffness and deformation within the ITBTFLC in vivo. Future studies should also examine the load deformation behavior of the ITBTFLC and the influence of the intramuscular septum on ITBTFLC behavior.

CONCLUSION
The results of the current study suggest that the ITBTFLC is capable of tissue elongation under normal physiologic loads that simulate a clinical stretching protocol. It is uncertain whether this “stretch” translates into sustained, clinically meaningful tissue elongation. Greater lengthening occurred in the proximal region of the ITBTFLC, suggesting that the proximal region (containing the TFL) is more likely to undergo elongation in response to a clinical stretch force when compared to the middle or distal regions. The increased lengthening response in the proximal region may be due to the presence of the TFL. Results of this study do not challenge the perceived clinical benefit of ITB stretching, but suggest that benefits may be related to changes at the level of the TFL as opposed to the ITB proper.

REFERENCES
8. Nemeth WC, Sanders BL. The lateral synovial recess of the TFL as opposed to the ITB proper.


ABSTRACT

Background: Dance performance requires not only lower extremity muscle strength and endurance, but also sufficient core stabilization during dynamic dance movements. While previous studies have identified a link between core muscle performance and lower extremity injury risk, what has not been determined is if an extended core stabilization training program will improve specific measures of dance performance.

Hypothesis/Purpose: This study examined the impact of a nine-week core stabilization program on indices of dance performance, balance measures, and core muscle performance in competitive collegiate dancers.

Study Design: Within-subject repeated measures design.

Methods: A convenience sample of 24 female collegiate dance team members (age = 19.7 ± 1.1 years, height = 164.3 ± 5.3 cm, weight 60.3 ± 6.2 kg, BMI = 22.5 ± 3.0) participated. The intervention consisted of a supervised and non-supervised core (trunk musculature) exercise training program designed specifically for dance team participants performed three days/week for nine weeks in addition to routine dance practice. Prior to the program implementation and following initial testing, transversus abdominis (TrA) activation training was completed using the abdominal draw-in maneuver (ADIM) including ultrasound imaging (USI) verification and instructor feedback. Paired t tests were conducted regarding the nine-week core stabilization program on dance performance and balance measures (pirouettes, single leg balance in passe’ releve position, and star excursion balance test [SEBT]) and on tests of muscle performance. A repeated measures (RM) ANOVA examined four TrA instruction conditions of activation: resting baseline, self-selected activation, immediately following ADIM training and four days after completion of the core stabilization training program. Alpha was set at 0.05 for all analysis.

Results: Statistically significant improvements were seen on single leg balance in passe’ releve and bilateral anterior reach for the SEBT (both p < 0.01), number of pirouettes (p = 0.011), and all measures of strength (p < 0.05) except single leg heel raise. The RM ANOVA on mean percentage of change in TrA was significant; post hoc paired t tests demonstrated significant improvements in dancers’ TrA activations across the four instruction conditions

Conclusion: This core stabilization training program improves pirouette ability, balance (static and dynamic), and measures of muscle performance. Additionally, ADIM training resulted in immediate and short-term (nine-week) improvements in TrA activation in a functional dance position.

Level of Evidence: 2b

Key Words: abdominal draw-in maneuver, core stability, dancers, pirouette, transversus abdominis
INTRODUCTION

Collegiate dance teams perform and compete with dance styles ranging from jazz, contemporary, hip-hop and classical ballet.¹ Their performance combines the grace and beauty of the art of dance, with the strength and endurance of a highly-trained athlete.² Different from competitive studio dance, collegiate dance teams perform cheers and dance routines at a number of athletic events, often on the sidelines of football and basketball games, and compete in regional and national competitions against other college programs across the country.¹ Competitive collegiate dancers are expected to perform a diverse repertoire of techniques; judged on the individual and team’s execution of difficult technical skills while performing with precision and synchronization.³ Each technical skill requires significant motor control, particularly of the extremities, but also spinal stability provided by the trunk musculature hereafter referred to as the core.³ The spine must be maintained in erect postures through multiple combinations of movement, including pirouette revolutions. Holding the spine in an erect, extended position is viewed positively by competition judges when looking at body alignment and movement, as well as helping to maintain the center of mass vertically over the point of support; however, too rigid a stance has also been shown to lead to early toppling during pirouettes, requiring instead that subtle accommodations be made for any loss of balance.⁴

Recently, interest in improving fitness of dancers both for improved performance and injury reduction has increased.⁵⁻⁶ Dance training programs have been identified as insufficiently preparing ballet dancers for the physical demands of performance⁷ and subsequently injury rates (approximately 82% incidence among professional contemporary dancers during a 12 month period⁸ and seeing a prevalence rate of 95% among professional ballet dancers⁹) reflect this, particularly injury to the low back.³,¹² Research has shown that professional ballet dancers appear to have reduced fitness levels in regards to muscle strength¹³⁻¹⁵ and aerobic capacity⁶,¹⁶⁻¹⁸ when compared to athletes from other sports. And, while improvements in fitness levels are associated with better technique across dance genre, results from the effect of fitness training are limited to ‘dance performance’ measures related to aesthetic aptitude.²⁰⁻²³

Kibler et al defines core stability as “the ability to control the position and motion of the trunk over the pelvis and to allow optimum production, transfer, and control of force and motion to the terminal segment in integrated athletic activities.”²⁴(p190) A diminished core stabilizing system, with delayed activation patterns has been shown lead to a higher incidence of lower extremity injuries²⁵⁻²⁷ and to produce low back injury.²⁸,²⁹ The core stability system, also referred to as the lumbopelvic-hip complex, provides a ‘corset-like’ tensioning to the trunk when activated, and is comprised of global and local stabilizing subsystems. The global stabilizing subsystem comprised of the erector spinae, rectus abdominis, external oblique and quadratus lumbarum muscles provides for larger trunk motions with the capability of producing rapid, powerful torques. The local stabilizing subsystem is comprised of the transversus abdominis (TrA), multifidus, internal oblique muscles that are located deep to the global system, and provide for dynamic segmental spinal stability. Also included in the contemporary thinking of elements of the core are the pelvic floor and hip (gluteal and rotary) muscles.³⁰ It has been well established that specific exercises may be selected to target the many muscles contributing to the core stabilizing system.³¹ McMeeken et al³² showed increases in TrA muscle thickness as measured by ultrasound imaging (USI) which correlates highly (ICC M-mode = 0.981) with electromyographic activity. Additionally, the TrA activates in a feed-forward anticipatory fashion prior to and during lower extremity movement.³³ This occurs to minimize (compensate for) perturbing forces on static posture and dynamic balance.³⁴ The improved activation that comes from a core stabilization exercise program targeting specifically TrA may be inferred to improve static and dynamic balance, as Zazulak et al³⁵ demonstrated deficits in core proprioception predicted knee injury risk for female collegiate athletes in a three-year prospective study (n = 140). USI has therefore been utilized to assess TrA muscle activation for muscular dysfunction and motor control errors³⁶ causing decreased biomechanical stability, and altering control of dynamic posture responses.³⁵ The abdominal draw-in manue-
ver (ADIM) is a commonly utilized motor control exercise for the TrA muscle.\textsuperscript{37,38}

Professional ballet dancers (n = 24), when compared to age and sex matched non-dancer control subjects (n = 24) demonstrated more accurate proprioceptive feedback about lower limb (hip, knee, and ankle) position in space as well as center of gravity in relation to base of support.\textsuperscript{39} These proprioceptive tasks are required in the functional activities of dance, including turning, static and dynamic single leg balance, gesturing, and many others. Evidence suggests that improved proprioception in dancers may result in improved performance.\textsuperscript{40} For instance, Lott and Laws’ suggest that turning should be done in a manner that allows a dancer to make subtle adjustments based on changes in the alignment of center of mass in relation to base of support during a turn. Alternatively, they found that a rigid bodied dancer would have to maintain his/her body at an angle that deviated less than one degree from pure center, a nearly impossible task, or loss of balance occurred. This implies that more important than merely trunk strength and endurance, sensorimotor control is essential in attaining sufficient core stabilization during dynamic dance movements. Further, numerous studies have demonstrated the TrA as the key dynamic modulator in controlling spinal stiffness by way of its linkage and direct tensioning to the posterior thoracolumbar fascia.\textsuperscript{41–43} Additionally, Urquhart and Hodges\textsuperscript{44} demonstrated the TrA to have a complex role in trunk rotation, with the upper region fascicles active during rotation ipsilateral, and middle and lower region fascicles during contralateral rotation. While not observed, it is this action that may be occurring, with the core muscles working both concentrically and eccentrically throughout dance (pirouette) techniques as the dancer is spinning. Improved proprioception and ability to make trunk adjustments (both in controlling stiffness and rotary movements that may occur during pirouettes, etc.) based on dynamic alignment may result in improved single leg balance (both static and dynamic) and which could translate to a greater number of successful turns. Therefore, it may be inferred, and it is this study’s hypothesis, that improved core stability will enhance dance performance.

While the physiological effects of exercise as an intervention are well documented to be mode, volume and intensity specific,\textsuperscript{45} what has yet to be determined is if an extended core stabilization training program will improve specific measures of dance performance. The purpose of this study was to examine the impact of a nine-week core stabilization program on indices of dance performance, balance measures, and core muscle performance in competitive collegiate dancers. Specifically, this study aimed to determine if a nine-week core stabilization training program improves measures of dance related maneuvers, including: 1) static balance in single leg for time in front passé releve with arms in first position, 2) dynamic balance in single leg using the star excursion balance test, and 3) maximum number of pirouettes performed. Significant improvements were predicted in all three. Secondary purposes were to examine 1) the immediate influence of ADIM training on the same specific dynamic dance maneuvers and whether TrA thickness changes would remain at post-training testing, and 2) the nine-week program training effect on measures of trunk and lower extremity muscle performance. It was predicted that TrA thickness changes would increase upon immediate training and remain upon post-test training. Finally, it was predicted that measures of trunk and lower extremity muscle performance would all improve with the exception of single leg heel raises as gastroc-soleus is commonly already trained by dancers at a high level, which was not part of the core stability exercise program.

METHODS

Subjects

Subjects were enrolled by sample of convenience and completed a nine-week training program that focused on core stability training of the trunk musculature in addition to routine dance training. Originally, 26 female college-aged dancers were recruited for this investigation. All subjects were all formal members with the official Western Carolina University (WCU) Dance Team. The Institutional Review Board of WCU approved this study and all subjects signed the consent form. One subject dropped out due to injury and the other left the dance team. Figure 1 shows the study flow diagram with inclusion
and exclusion criteria. Anthropometric and demographic data (M ± SD) for subjects (N = 24 females) was: age (years) (19.67 ± 1.09); height (cm) (164.3 ± 5.3); weight (kg) (60.3 ± 6.2); left leg length (cm) (86.25 ± 3.58); right leg length (cm) (86.33 ± 3.68); competitive dance experience (years) (9.30 ± 4.57) and Beighton generalized test of hypermobility (range = 0-9, mode = 7). Because the authors were most interested in examining the impact of the core stabilization training program on the number of pirouettes, a sample size estimate was derived based on the following pretest and posttest estimates: M_d = 1, SD_d = 1.5, alpha = .05 and power = .80. The estimated sample size was 20 subjects. Thus, the sample size of 24 exceeded this estimate.

**Instruments and Procedures**

This section presents tests and measures administered prior to the nine-week core stabilization intervention program. Dance performance and balance tests were administered including: number of pirouettes, single leg balance in passe’ releve position, and star excursion balance test, as well as muscle performance tests including: extensor endurance test, flexor endurance test, side bridge test, hip abductor strength, single leg hop, and single leg heel raise. Following instruction, selective recruitment of TrA was utilized to ensure appropriate performance of core activation prior to nine-week training, as this specific training can help to reorganize neuromotor control patterns in the central cortex to improve muscle recruitment patterns thereby resulting in increased activation levels. Included in the TrA activation measures is a brief description of the short bout of TrA activation training and subsequent TrA measures. The administration of these tests and measures during posttesting (four days following the nine-week core stabilization program) is also presented. The final section presents a brief description of the nine-week core stabilization program.

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**Figure 1.** Study flow diagram for subjects. Inclusion criteria = WCU dancer with valid physical on file and signed informed consent form. Exclusion criteria = <18 years old; history of spinal or abdominal surgery; current pregnancy; current low back pain; currently taking medications affecting balance.
Transversus Abdominis Activation Training and Testing.

A physical therapist with over 15 years of experience in USI capture of TrA conducted all TrA activation training and measurements. This TrA training program followed a previously established USI training protocol for TrA activation in healthy adults.48 US imaging visualization and measurement of TrA muscle was completed by using a portable ultrasound curvilinear transducer set at 5 MHz using M-mode (LOGIQ P5; GE Medical, Pleasanton, CA). Subjects were tested individually on all occasions for each of the four instruction conditions. Instruction conditions 1 and 2 took place prior to any ADIM training. First, mean TrA activation was captured via USI in standing (Figure 2a) with instructions to “relax” and then to “move into the position” (passe’ releve). Three trials were performed and TrA thickness was measured via USI by the physical therapist and averaged for relaxed standing and the dance position. USI measurements of TrA in upright positions have been deemed reliable during functional tasks.48,49 Testing condition 2 was the same as 1 with the exception that subjects were told to “activate their core” during the passe’ releve position. Again, three trials were performed and TrA thickness was captured for relaxed standing and the dance position with instructions to contract. Next, subjects received a short (15 minute) bout of TrA activation training in standing with ADIM that included instructor and USI feedback. Both written and verbal instructions of the technique were provided as part of training, along with diagrams of the muscles involved and the rationale for this technique to prevent injury. Subjects were shown their TrA muscle while at rest and when contracted via the USI video display and were told to use this continuous visual feedback to help them acquire the ADIM. The success of TrA contraction, as visualized by isolated TrA thickening beyond resting thickness, was reported by the physical therapist in the form of verbal feedback and US imaging. Training continued for 10 attempts, with subjects needing to obtain three consecutive successful isolated TrA contractions in order to continue. Subjects during testing condition 3 were told to stand with instructions “to relax” and then told to perform the dance position with instructions to apply the ADIM (“draw-in”); three trials were performed and mean TrA thickness was captured via USI. Four days following the nine-week core stabilization training program, testing condition 4 took place. Subjects in testing condition 4 were told to stand with instructions “to relax” and then told to “move into the dance position.” Unlike condition 3 the instructions for condition 4 did not include the phrase to “draw-in” but were cued prior to testing session to perform according to their previous training. During all instruction conditions no visual or verbal feedback was provided; testing order remained constant across positions and instructions for all subjects.

Percent change in transversus abdominis (TrA) activation was examined during relaxed standing and passe releve position prior to any ADIM training (without instructions, and self-selected triggering pattern with instructions to “activate” their core), immediately following ADIM training, and four days after the completion of the core stabilization training program. Percentage of change in TrA thickness was computed per trial using the standing relaxed TrA measurement as minimum thickness and the dance position as the maximum TrA thickness (cm) per trial for each of the 4 test sessions. Percentage of change scores were determined by \[\frac{\text{maximum thickness} - \text{minimum thickness}}{\text{minimum thickness}} \times 100\].50 Mean percentage of change scores were computed for each of the 3 trials performed for the four instruction conditions.

Dance Performance and Balance Testing

Pirouettes. Subjects were told to assume the front passé position on the preferred turning leg with instructions to “perform your maximum number of consecutive turns in the front passé position.” Subjects performed three trials each under instructions to: “use your preferred turning method”; “activate your core”; or “perform the draw-in that you just learned” (ADIM), respectively. Each full trial of each subject was recorded via an iPad, which was positioned at a height of 183 cm. Video recordings were analyzed in manual slow-motion using Dartfish Express with a grid overlay.51,52 Dartfish has been established as a valid and reliable tool to measure upper (ICC = 0.98)53 and lower extremity (ICC ≥ 0.91)54 motions. A dance expert trained two raters on coding of maximum number of rotations using a
standardized procedure; the raters were blinded to each other’s results. The observational instrument used to determine the maximum number of pirouettes included identifying the point during turning that the subject’s heel struck the floor, lost balance, or hopped out of the pirouette. The final pirouette closest to the quarter revolution was counted and recorded. Interrater reliability was obtained by these two raters scoring the maximum number of pirouettes turned per trial per condition on a sub-sample of 13 subjects. Acceptable rater reliability has been generally been deemed to be >0.75.46

Figure 2. A) Transversus abdominis activation and training, B) single leg balance in passé releve position, C) SEBT, D) extensor endurance test, E) flexor endurance test, F) hip abductor strength test.
Mean scores were formed per subject per rater on each of the three conditions during pretesting. Since raters and subjects were randomly selected intraclass correlation model 2 was utilized to examine interrater reliability. High intraclass correlation (ICCs 2, 3) coefficients were noted on mean scores for maximum number of pirouettes turned for all instruction conditions. ICC coefficients were: .946 (95%CI = .826 to .983) for their preferred turning method instructions; .909 (95%CI = .683 to .973) for “activate your core” instructions; and .991 (95%CI = .971 to .997) for with ADIM as instructed. Each rater scored all remaining trials of each subject per instruction condition. During posttesting only the ADIM condition was performed and measured. Trial mean scores formed per subject per instruction condition per rater were averaged for the two raters and utilized for descriptive data and data analysis.

**Single Leg Balance in Passé Releve position.** Control of static balance has been examined using the timed single leg balance in a variety of populations, and found to have acceptable intra and inter rater reliability (ICC > 0.90). The single leg balance test was administered in the front (jazz) passé releve position on the subjects’ preferred turning leg (Figure 2b). Subjects prior to each trial were told to “stand on your leg in front passé with arms in first position, when you have your balance, raise up to releve and balance as long as you can in this position.” During pretesting, subjects performed three single leg balance trials under each of the following instruction conditions: “raise up to passé releve”; “as you raise up to passé releve activate your core”; and “as you raise up to passé releve draw-in” (ADIM). During posttesting subjects were tested only under the latter instruction conditions. Balance time was scored at the point that they elevated into passé relevé until they came out of position. Balance time was recorded by research assistants in seconds per trial. Mean scores for the three trials were computed for each individual for each instruction condition during pretesting and posttesting.

**Star Excursion Balance Test.** Using a tape measure on the floor, each subject completed a modified Star Excursion Balance Test (SEBT) (Figure 2c) according to the methodology described by Plisky et al and Filipa et al. The SEBT has shown to have acceptable intra-rater reliability by Plisky et al (ICC = 0.82 – 0.87), and Gribble et al (ICC = 0.86 - 0.92). Notably, poor performance on the anterior reach of the modified SEBT (>4cm side to side difference) has been validated for predicting lower extremity injury. Standing on selected leg with tip of great toe in the center of the intersecting lines, subjects were asked to reach with the free limb in three directions: anterior, posteromedial, and posterolateral. Trial performances were recorded according to weight bearing limb and direction of reach. Subjects performed 10 trials on each limb for each of the 6 reach directions. The last four trials (7-10) were recorded by a research assistant and utilized for descriptive data and data analysis (maximal reach distance in cm). The maximal reach was normalized to the dancer’s leg length. This test was administered during pretesting and posttesting.

**Muscle Performance Testing**

**Extensor Endurance Test.** Subjects performed a back extensor endurance (Sörenson) test, which has been shown to be predictive and have discriminative validity for distinguishing between subjects with non-specific low back pain (ICC = 0.88) and those without (ICC = 0.83). Subjects were positioned prone on a bench with their lower body fixed to the platform by straps (gait belts) positioned around the pelvis, knees, and ankles (Figure 2d). Subjects were told to hold the upper body in a maintained horizontal position, with upper limbs held across the chest and hands on the opposite shoulders for as long as possible. The amount of time (seconds) subjects held this position was recorded by a research assistant and administered during pretesting and posttesting. Pretest and posttest scores were utilized for descriptive data and data analysis.

**Flexor Endurance Test.** Abdominal fatigue was assessed using the flexor endurance test according to McGill et al (test-retest ICC = 0.97) which has shown to be a valid measure in office workers with sub acute low back pain (endurance test time significantly reduced, p<0.05) in symptomatic subjects. The flexor endurance test required subjects to sit on a flat bench with knees and hips flexed to 90 degrees and toes strapped to the bench, arms folded across the chest, and their back to a support angled 60 degrees from the bench.
Prior to the back support being removed, subjects were instructed to maintain trunk position for as long as possible. The amount of time (seconds) subjects held this position was recorded by a research assistant. This test was administered during pretesting and posttesting.

**Side Bridge Test.** Lateral trunk musculature of each side was assessed using the side bridge test by McGill et al.\(^2\) (test-retest ICC = 0.99). Swain and Redding\(^2\) in an observational study of female dancers with (n = 11) and without (n = 6) low back pain found the side bridge test a valid tool for discriminating between symptomatic subjects (endurance test time significantly reduced, p<0.05). Subjects were positioned side lying on a bench with support arm flexed, knees and hips extended, and spine in neutral. Subjects were instructed to lift their pelvis off the bench and to hold their body in a straight line over the bench as long as possible. A research assistant recorded the amount of time (seconds) subjects held this position. This test was administered during pretesting and posttesting.

**Hip Abductor Strength.** Hip abduction strength was measured bilaterally using a handheld dynamometer, Micro FET 2 (Hoggan Scientific, Salt Lake City, UT) on each of the subjects' lower extremities as described by Fredericson et al.\(^6\) who determined the procedure has very good inter-rater reliability (ICC = 0.96), but has not been validated against a gold standard (e.g. isokinetic dynamometer). The dynamometer used a digital display that displayed the maximum static force (kg) used to “break” the maximum isometric hip abduction contraction and bring the tested leg back to the bench. Subjects were positioned side lying on a bench with hip abducted to 30 degrees (Figure 2f). Each subject performed three trials with 15 seconds of rest between trials. Each trial was recorded by a research assistant. Mean scores for the three trials were computed for each subject. This test was administered during pretesting and posttesting.

**Single Leg Hop.** Lower extremity hopping performance was assessed using a single leg hop test according to the method used by Munro and Herrington,\(^6\) Brumitt et al.\(^6\) and Reid et al.\(^6\) Munro and Herrington\(^6\) found the test procedure to have good reliability (test-retest ICC = 0.80). Brumitt et al.\(^6\) found single leg hop for distance test to be a valid predictor as female athletes with a greater than 10% side-to-side asymmetry between had a four-fold increase in foot or ankle injury. Reid et al.\(^6\) found the single leg hop test to be a valid performance outcome measure compared to self-reported lower extremity function on 42 adult patients undergoing rehabilitation after ACL reconstruction. Each subject stood on selected leg with distal edge of great toe flush with the starting line. Subjects were asked to hop as far as they could while landing softly on the same foot, maintaining their balance. Six trials were performed on each limb. The last three trials on each limb were recorded by a research assistant. Mean scores for the three trials per limb were computed for each subject. This test was administered during pretesting and posttesting.

**Single Leg Heel Raise.** The single heel raise to fatigue test was used to assess and measure the strength endurance of the gastrocnemius/soleus muscle complex. While the construct validity of the single leg heel raise has yet to be established, there is acceptable reliability (test-retest ICC = 0.96). The test was performed bilaterally and subjects were required to keep pace with a metronome set at 80 beats per minute. Subjects were instructed that they may lightly place their hands on ballet bars for balance purposes only but no weight was allowed to be placed through upper extremities to aid in the test. The test was only performed one time on each foot. A research assistant recorded the number of raises per leg. This test was administered during pretesting and posttesting.

**9-week Core Stability Program**
Subjects performed an intensive nine-week core stabilization training program designed by the authors specifically for collegiate dance participants. The program was multifaceted and contained components incorporating balance/dance posture, strength, endurance, and proprioceptive control of the core and lower extremity (Figure 3). The stabilization training content was distributed to each participant through video. The video was specifically designed for the study to provide step-by-step information regarding how to correctly perform each exercise. The video provided cues for correct timing for each
exercise, and prompting for the number of repetitions and sets. Subjects performed exercises three times per week (with the second author two times per week following dance practice and on their own one time per week) for 30 minutes per session. The second author (dance instructor) provided cuing and feedback to reinforce TrA activation during the core exercises and throughout technical skill training at practice. The protocol for the core stabilization program consisted of a progression of three levels with 5-7 exercises per level focusing on maintaining sensorimotor control while promoting activation and strengthening of 1) TrA and internal oblique, 2) lumbar multifidus, 3) gluteus medius, quadratus lumborum and external oblique, 4) gastroc-soleus, 5) whole body major muscle groups. The degree of difficulty for the exercises was derived from the Jeffreys core stabilization program. Initial level exercises involved static contractions in a stationary position progressing to slow movements. Second level exercises progressed from static contractions in unstable situations to dynamic movements in a relatively stable position. Third level exercises involved dynamic movements in unstable situations. When participants had completed an exercise level for three weeks they were progressed to the next level.

**Statistical Analysis**

All descriptive and statistical analyses were completed using IBM SPSS version 23 (IBM Corp. Released 2015. IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.). A one-way RM ANOVA to examine differences among the four instruction conditions was conducted on mean percentage of change scores for TrA thickness. Mauchly’s test of sphericity was examined, and degrees of
freedom were adjusted when appropriate. Effect size was partial eta squared ($\eta^2_p$). Post hoc paired t tests were conducted if applicable to examine differences in mean scores for percent change in TrA between all instruction conditions. Alpha was set at 0.05 for these tests.

To examine the impact of the nine-week core stabilization program paired t tests were conducted on pretest and posttest mean scores for: number of pirouettes turned for the ADIM instruction condition; mean time (seconds) for single leg balance in passé relevé position for the ADIM instruction condition; normalized reach (%) for modified SEBT for each limb and direction; mean time (seconds) for back extensor test; mean time (seconds) for flexor endurance test; mean time (seconds) for side bridge test per left and right side; mean hip abductor strength (kg) per left or right side; normalized distance (%) for single leg hop per left and right limb; and mean number of heel raises for single leg heel raise per left and right limb. Difference scores were computed for paired t tests measures and indicated no outliers and normality. Alpha was two-tailed for paired t tests and set at .05.

RESULTS

The one-way repeated measures ANOVA on mean percentage of change in TrA thickness among the four instruction conditions was significant (F 3,69 = 54.382, p < .001) and produced a large effect size $\eta^2_p = .703$. All post hoc paired t tests (df = 23) were significant for all possible comparisons of instruction conditions ($p < .001$). Importantly mean percentage of change in TrA thickness (M ± SD) significantly increased across the following four instruction conditions, respectively: from relaxed standing to the dance position without any instructions (20.4% ± 21.8%); from relaxed standing to the dance position with instructions to activate your core (41.6% ± 32.9%); from relaxed standing to the dance position with instructions to apply ADIM (after the short bout of ADIM training) (77.1% ± 39.5%); and from relaxed standing to the dance position with instructions to apply ADIM (four days after the nine-week core stabilization training program concluded) (115.2% ± 51.6%). Thus, a short bout of ADIM training in standing showed subjects significantly improved their ability to activate the TrA during the passé relevé position and improved their ability to do so over a long period of time.

Table 1 presents descriptive data and results of paired t tests for the dance performance, dynamic balance, and muscle performance measures. Result of paired t tests indicated the nine-week core stability training program showed significant improvements on the dance measures (i.e. pirouettes, single leg balance); dynamic balance measures (i.e. modified SEBT for right and left anterior); and muscle performance measures (i.e. abdominal flexor endurance test, side bridge test, back extensor endurance test, hip abductor strength, and left and right single leg hop).

Discussion

This within-subjects longitudinal study used a video-recorded, clinician directed and monitored core stabilization exercise training program intervention in order to determine its effect on measures of dance performance, balance and core muscle performance. As expected, the measures of core and lower extremity muscle performance were significantly improved from our core stability program. Measures of dance and balance performance also significantly improved. Following the nine-week training program, the primary study outcome of pirouettes was significantly improved under training to use ADIM. However, the lack of clinically significant effect for the number of pirouette turns (while significantly improved, there was less than a whole number improvement) may have been due to the nature of the task (e.g., selection of TrA may have been too complex for this skill and/or changes in muscle performance as a result of training). Alternatively, individual technique and ability may supersede TrA contribution to this complicated task. However single leg heel raise, common to dancers in their general workouts but not part of this core stability program, was not improved.

As predicted, percent change in TrA thickness was significantly greater during post-training ADIM, with post-hoc tests revealing the greatest significant improvement from baseline to post-training. These findings are consistent with previous literature examining the immediate effects of a ADIM training session on TrA activation in healthy adults, though it is important to note that measures of starting TrA
<table>
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<tr>
<th>Measure</th>
<th>Instructions/Protocol</th>
<th>Pretest</th>
<th>Posttest</th>
<th>p value</th>
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<tr>
<td><strong>Dance Performance and Balance Testing</strong></td>
<td></td>
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<tr>
<td>†Pirouettes (revolutions)</td>
<td>Relax Stance</td>
<td>2.40 (0.66)</td>
<td>Not Tested</td>
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<td>Self Activated</td>
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<td>Utilize ADIM</td>
<td>2.21 (0.63)</td>
<td>2.55 (0.81)</td>
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<td>6.37 (4.24)</td>
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<td>6.03 (5.04)</td>
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<td>Modified SEBT Normalized for leg length (%)</td>
<td>Right-Anterior</td>
<td>68.00 (0.05)</td>
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<td>94.77 (0.08)</td>
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<td>91.91 (0.11)</td>
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<td>68.59 (0.05)</td>
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<td>Back Extensor Endurance Test (sec)</td>
<td>88.34 (34.80)</td>
<td>104.80 (49.92)</td>
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<td>Abdominal Flexor Endurance Test (sec)</td>
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<td>Side Bridge Test (sec)</td>
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<td>30.83 (17.30)</td>
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<td>31.01 (17.27)</td>
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<td>Hip Abductor Strength (kg)</td>
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<td>13.75 (4.09)</td>
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<td>Single-leg Hop Normalized for leg length (%)</td>
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<td>125.02 (21.69)</td>
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<td>36.67 (9.54)</td>
<td>37.38 (8.81)</td>
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*Paired t tests df = 23; alpha two tailed. †Maximum number of pirouettes turned and single leg balance tests were in the front passé relevé with arms in first position.
thickness were higher than one previous study, which could reflect an elevated baseline of somatomotor control in collegiate dancing populations as compared to general populations. Although there was not a significant same-day improvement in single-leg balance or pirouettes, it is important to note that this may be attributed to dancers being in the cognitive phase of motor learning of the ADIM. This early phase of motor learning may have negatively affected dancers’ abilities to dual-task with applying new skill to previously mastered dance task. The finding of maintained TrA activation ability during a functional activity at nine weeks following a short ADIM training session are similar to a recent five-month longitudinal study where supine instructed TrA activation (ADIM) training translated to increased activation levels during standing, loaded tasks in asymptomatic subjects. Enhanced TrA thickness via ADIM scores for pretest and posttest over a self-selected pattern of activation indicate the value of US imaging biofeedback in TrA activation. The findings that TrA activation significantly improved from self-activation instructions to immediate post ADIM training indicated dancers were not aware they were not fully activating their TrA. A recent study also found no differences during self-activation instructions between young adults with and without prior ADIM training (without USI). That is, adults, when told to self-activate their TrA during standing and other upright functional loaded tasks did not vary regardless of their training history. This suggests direct observation of TrA via USI rather than a self-report of core activation training sans USI may be an important component of assessment and training. These findings of improved TrA activation and core muscle performance measures (flexor fatigue, extensor fatigue, and side bridge) are similar to a recent study by Hoppes et al in which subjects performed a eight-week core stabilization exercise program and improved TrA activation in neutral relaxed standing and with military body armor donned, and improved similar measures of core strength and endurance.

The authors also predicted that this nine-week core stabilization intervention would increase performance in dynamic balance. The SEBT has been used as an alternative, indirect measure of core stability because it is a measure of dynamic balance and postural control. Post-hoc testing revealed only significant improvements in two out of the six reach directions, which were left and right anterior reaching directions of the modified SEBT. These present findings are in slight contrast with Sandrey and Mittel, who found that a progressive, 30 minute per session six-week core stabilization training program significantly improved all directions of the SEBT in (N = 20) track athletes training 3x/week. However, upon closer examination, these authors used anteromedial, medial, and posteromedial directions with only the right leg, whereas the current study used anterior, posteromedial and posterolateral directions for both legs. Further analysis of the improvements in only these two directions in this population could be a result of the core stability program or the focus and training of specific, dynamic technical skills as a team. That is, preparation and take off of, and transition between leaps and jumps and dynamic control of leaps and jumps in the anterior direction. Regardless, as Pliskay et al have reported that > 4 cm side-to-side differences in anterior reach scores predicted injury status in various sports, the anterior reach improvement is valuable.

While this progressive exercise program targeted the lumbopelvic-hip region, some of the improvements are likely interacting as illustrated in Figure 2. For example, Garrison et al found that a strengthening program, specifically targeting hip muscles that included hip abductors of patients (n = 43) enrolled in a rehabilitation program following ACL reconstruction were able to improve sagittal plane dynamic balance (anterior direction of SEBT). This demonstrates the importance of hip abductors in stabilizing the pelvic-hip complex in maintaining balance while attempting lower extremity anterior reach. Furthermore, the FIFA 11+ injury prevention program is an internationally utilized multifaceted warm up program that has been shown to improve measures lower extremity function and prevent non-contact injuries in football (soccer). Similar to our program, the FIFA 11+ is comprised of exercises involving the core and lower extremity muscles that has been shown to improve dynamic balance (SEBT), static balance (single leg balance) and hop for distance.
This is the first study to examine the effect of a progressive multi-week core stabilization training program on measures of dance performance, dynamic balance, and muscle performance. Previously Angioi et al\textsuperscript{40} utilized a six-week conditioning program on contemporary ballet dancers and found improved select measures of fitness (lower extremity vertical jump, upper extremity press-ups and aerobic conditioning) and improved scores on a dance aesthetic competence test (developed by the author)\textsuperscript{85} with the exercise group (N=12) compared to a controls (N=12). Exercises were dissimilar to those in the current study program, as they were extremity focused and without specific core (TrA) activation training. Twitchett et al\textsuperscript{23} also examined the effect of an exercise program (10 weeks) on ballet dancers that did include one spinal strengthening exercise similar to the current study types of exercise, with the remainder of their program either extremity focused or aerobic in nature. They found their supervised, one-hour per week program improved in the intervention group (N=8) on qualitative scores of an aesthetic dance tool compared to controls (N=9). Likewise, Brown et al\textsuperscript{22} also focused on extremity training, and compared both plyometric training (N=6), and traditional weight training program (N=6), to controls (N=6) in eighteen college students enrolled in ballet or modern dance class. Intervention group subjects trained twice weekly for six weeks. While control subjects did not improve, both intervention groups improved in lower extremity indices of strength that relate to dance performance. However, dance specific indices were not measured. Furthermore, in a well-designed randomized study Koutedakis et al\textsuperscript{21} employed a 2-3x/week 12-week training program (intervention N=19, control N=13) and found significant improvements in lower extremity strength and flexibility, aerobic conditioning, and a qualitative dance rating based on performance of a choreographed dance routine. Exercise intervention was comprised of free weight training, running, cycling or swimming. Again, no specific core (TrA) training was included. Taken together, these studies have utilized a variety of aerobic conditioning, muscle strength and power training activities that have improved indices related to the specific training exercise (specific adaptation to imposed demand) and qualitative, aesthetic impression of dance performance. However, there remains a lack of studies that positively demonstrate improvement on objective dance indices as a result of specific, focused supplementary core stabilization training.

This study demonstrates that a nine-week core stabilization intervention may improve elements of dynamic balance and trunk musculature endurance in collegiate dancers. When considering administration of this intervention, it is important to acknowledge that collegiate dance team members and other athletes may have a higher baseline of exercise familiarity and tolerance than other non-athletes. Additionally, pretesting revealed a significant increase in TrA activation after a single session of training. Further, the increase noted between self-selected and immediately following ADIM training with USI demonstrated that dancers were not aware that they were not activating the TrA fully. This identifies a quick and effective method of educating subjects to create sensorimotor control in an effort to stabilize their trunk. Of importance is the capacity to differentiate between the ability of core muscle activation immediately upon instruction and the ability to utilize core activation during the subjects' activity (dance, athletics, functional tasks, etc.). Appropriate and specific applicable motor learning should be emphasized for each individual.

This study population was limited to young adult female collegiate dance team members who were not single genre (ballet, jazz) dancers; therefore, findings could only be generalized to this population. In addition, direct measurement of TrA activation was not possible during pirouettes. Thus, the ability of the researchers to monitor TrA activation during this dance maneuver was lacking.

**CONCLUSION**

An intensive nine-week training core stability program improved indices of dance performance, balance measures, and measures of core muscle performance. Testing revealed an immediate, significant increase in TrA activation after a single session of training, identifying a quick and effective method of educating dancers on core muscle activation. Additionally, ADIM training followed by a core stability program resulted in short-term (nine-week)
improvements in TrA activation in a functional dance position. Measures of trunk muscle endurance (extensor endurance, abdominal flexor endurance and side bridge tests), hip abductor strength and single leg hop were improved following our training program. Results for primary objectives of this study showed improvement in the dance related activity of pirouettes, the bilateral anterior reach directions of the modified SEBT and single leg balance performed in front passé relevé with arms in first position following a nine-week core stabilization training program.

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ABSTRACT

Background: Suspension training (ST) has been utilized over exercises performed on a stable surface to train multiple muscle groups simultaneously to increase muscle activation and joint stability.

Hypothesis/Purpose: The purpose of this study was to determine whether ST augments muscle activation compared to similar exercises performed on a stable surface.

Study Design: Cross-sectional study

Methods: Twenty-five healthy adults (male: 16; women: 9; BMI: 23.50 ± 2.48 kg/m²) had 16 pre-amplified wireless surface EMG electrodes placed bilaterally on: the pectoralis major (PM), middle deltoid (MD), serratus anterior (SA), obliques (OB), rectus abdominis (RA), gluteus maximus (GM), erector spinae (ES), and middle trapezius/rhomboids (MT). Each participant performed reference isometric exercises (Sorensen test, push-up, sit-up, and inverted row) to establish a baseline muscle contraction. Muscle activation was assessed during the following exercises: ST bridge, ST push-up, ST inverted row, ST plank, floor bridge, floor push-up, floor row, and floor plank. The root mean square (RMS) of each side for every muscle was averaged for data analysis. Multivariate analyses of variance (MANOVA) for each exercise with post-hoc comparisons were performed to compare muscle activation between each ST exercise and its stable surface counterpart.

Results: MANOVAs for all exercise comparisons showed statistically significant greater muscle activation in at least one muscle group during the ST condition. Post-hoc analyses revealed a statistically significant increase in muscle activation for the following muscles during the plank: OB (p=0.021); Push-up: PM (p=0.002), RA (p<0.0001), OB (p=0.019), MT (p<0.0001), and ES (p=0.006); Row: MD (p=0.016), RA (p=0.059), and OB (p=0.027); and Bridge: RA (p=0.013) and ES (p<0.0001).

Conclusions: Performing ST exercises increases muscle activation of selected muscles when compared to exercises performed on a stable surface.

Level of Evidence: 1b

Key words: Electromyography, muscle activation, stable surface exercise, suspension training exercise

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This research study was conducted at the Balance and Motion Laboratory of The School of Physical Therapy, Texas Woman’s University, Houston, TX.
INTRODUCTION
Suspension training (ST) is defined as having one or more straps connected to one or more anchor point(s) as the user is suspended from the handles of the straps by either their hands or feet, while the non-suspended pair of extremities are in contact with the ground. This type of training changes how the muscles are recruited due to the unstable base of support (BOS). The unstable BOS affects the human body via three routes: gravity, muscular force, and a “third factor”, which was described by Pastucha et al as “the force of physiological impact and deformation forces.” The cumulative effect of these forces is focused on a single point, the body's center of mass (COM). It is the position of the body's COM over its base of support that determines the stability of the body, and therefore the body's ability to perform any given action. STs are advertised as requiring additional muscle contraction to perform any given movement while utilizing the straps. This is purportedly achieved by forcing the primary (main agonist), secondary (assisting agonist), and stabilization (abdominal, lower back, and bracing) musculature to maintain the body's COM throughout a desired range of motion (ROM). The free-hanging straps allow for an unstable base of support during exercise, and result in a less stable base of support. Although there are a variety of studies that report the utility for STs for rehabilitation, physical fitness and wellness, few have comprehensively assessed the activation patterns of multiple muscle groups during functional exercises.

Suspension training was originally developed for use in the military in the 1990s, and has since been adapted for use by the general public. In theory, performing exercises with the suspension trainer should require greater muscle activation than the equivalent exercises performed without it, thereby potentially having a greater impact on strength, functional stability, and athletic performance. Battendorf et al propose that STs require increased muscle activation to perform any given task based on its ability to alter three mechanical properties: 1) size and location of the base of support; changing the size and location of the base of support (BOS) relative to the user's COM creates an unstable exercise platform requiring varied amplitudes of muscle activation to keep the user's center of mass (COM) over the BOS, 2) direction of the vector forces placed on the muscle groups; as the base of support changes in direction, the angles of the vector forces imparted to the muscle groups due to gravity are also changed which may change the pattern of motor recruitment, 3) the horizontal position of the COM relative to the anchor point determines the resistance/load of the exercise; STs are utilized by placing either the feet or hands into cradles attached to straps that are anchored to a fixed point that is above the cradles. The cradles, acting as bases of support may shift horizontally creating a pendulum effect that can alter the COM relative to the BOS horizontally which in turn, alters the gravitational vector and the loads placed on the working muscle groups. These principles have been theorized to be responsible for muscular loading/unloading during ST suspension training, but little evidence is available to fully support the efficacy of this claim.

Though there are a variety of claims regarding the utility of the ST to increase muscle activation, the evidence in the current literature is lacking. Recent studies by Snarr et al found increased muscle activation in pectoralis major and anterior deltoid when performing pushups in a ST when compared to pushups on the floor. Similar studies found that pushups performed in a ST elicited greater muscle activation of the rectus abdominis and latissimus dorsi. Limited scientific data is available on primary agonist, secondary agonist, and stabilization muscle activity measured simultaneously over several different exercise types. Therefore, the purpose of this study was to determine whether ST augments muscle activation compared to similar exercises performed on a stable surface.

METHODS
Study Design
A repeated measures design was utilized in a university laboratory setting equipped with a surface EMG, and a suspension trainer attached to a stable anchor point. The subjects performed a total of eight exercises during a single session: four using the TRX® suspension training system (Fitness Anywhere LLC, San Francisco, CA) and four equivalent exercises performed without the ST. The exercises were: push-
ups, inverted row, bilateral bridge, and a prone plank. After written consent was given, anthropometric measurements such as height, weight and abdomen skinfold thickness were taken with a stadiometer, standard bodyweight scale, and Lange skin-fold caliper (Beta Technology, Inc., Cambridge, MD), respectively. Each subject was equipped with a total of 16 wireless EMG electrodes (Mini Trigno; Delsys, Inc., Boston, MA). The electrodes were placed bilaterally (Figure 1) over the pectoralis major (PM), middle deltoid (MD), serratus anterior (SA), rectus abdominis (RA), obliques (OB), gluteus maximus (GM), erector spinae (ES), and middle trapezius (MT). The subjects performed the following exercises (Figure 2) in a random order, holding for five seconds each: isometric push-up, isometric sit-up, prone isometric trunk extension, and isometric inverted row to serve as a reference isometric contraction (RIC). After completion of the reference exercises, each subject performed the eight exercises in a randomized order.

Figure 1. Electrode placement for muscles of interest.

Figure 2. Isometric exercises chosen for reference isometric contraction (RIC).
The EMG signal was recorded throughout the entire performance of each exercise to compare muscle activation by means of normalized root mean square (RMS) between the ST and the counterpart non-ST exercise.

Subjects
Twenty-five subjects (16 men, 9 women; age: 27.24 ± 4.02 years; BMI: 23.50 ± 2.48) participated in this study after reading and signing an informed consent approved by the Texas Woman University's Institutional Review Board. Inclusion criteria for study participation were: 1) 18-35 years of age, 2) ability to read, speak, and write in English language, 3) no history of spinal, upper or lower extremity injury or surgery within the previous six months, and 4) abdominal skinfold measurement less than 34 mm to prevent impedance affecting EMG reading of abdominal muscles. This skinfold measure was selected arbitrarily to ensure subjects were below 24% body fat as percentages greater than this cut-off increase impedance of the EMG signal.

Procedures
After written consent was obtained, each subject completed the anthropometric measures and a total of 16 pre-amplified Ag wireless electrodes (Trigno, Delsys Inc., Boston, MA; Bandwidth: 450 ± 50 Hz > 80 dB/dec; overall channel noise: <0.75uV) were placed over muscles of interest. The electrodes were placed bilaterally on the pectoralis major, middle deltoid, serratus anterior, rectus abdominis, external/internal obliques, glutaeus maximus, erector spinae, and middle trapezius as described by Criswell (Figure 1). For the male subjects, skin hair was removed with an electric razor as necessary. To establish a reference isometric contraction (RIC) for the muscle groups of interest, each subject performed a 5-second reference body weighted isometric contraction without the ST in the following positions: push-up, inverted row, prone isometric trunk extension, and supine trunk flexion (Figure 2). It was decided to use an isometric reference contraction instead of a maximal isometric voluntary contraction due to the overestimation provided by the latter during typical muscle contractions performed during functional exercises. In addition, the authors wanted to replicate the positions, forces of exercises that are commonly done in the clinical environment. The push-up was used as reference for the pectoralis major, middle deltoid and serratus anterior. The inverted row was used for the middle trapezius while the prone isometric trunk extension test was used to assess the erector spinae and gluteal muscles. Lastly, the supine trunk flexion (sit-ups) was used to serve as reference for the rectus and oblique abdominis muscle groups. During the five-second reference contraction, the EMG data were collected with EMG Works® (Delsys Inc., Boston, MA) at a sampling rate of 2000 Hz and filtered through a Butterworth 2nd order band pass filter (cut-off frequency: 100-400 Hz, 160 dB/Dec.). The signal from each muscle of each side was averaged into one value to represent the muscle group bilaterally. The middle three seconds of each five-second epoch were considered for the reference isometric contraction (RIC). The order of performance of reference exercises was randomized for each subject with a one-minute rest break between each exercise.

Upon completion of the reference exercises, the eight exercises (four ST and four non-ST) were randomized and performed in succession with a rest period of three minutes between each. The TRX suspension training system was anchored to a metal frame and adjusted for each subject as follows: pushup (ST handles three inches above floor), inverted row (suspended user's upper body three inches above the ground), bridge (ST foot cradles three inches above the floor), plank (ST foot cradles three inches above floor) (Figure 3). The push-up and the inverted row were performed for five repetitions while the bridge and front plank were performed once with a 30-second isometric hold in an elevated position. For the female subjects, the ST push-up was modified as shown in Figure 4 which is a position commonly utilized for physical fitness tests administered in educational, military and various civil service settings. The data of interest used for statistical comparisons between groups were the third repetition for the push-up and inverted row, and the middle ten seconds for the bridge and front plank. The purpose for selecting the third repetition out of five for the push-up and inverted row was based on the assumption that the third contraction would be the one providing the most stable EMG signal. In this manner any
possible acceleration at the beginning of the exercise and deceleration and fatigue towards the last two repetitions was eliminated. The sampling rate and filtering processes were identical to those used to obtain the RIC. Once the data was trimmed to the time epoch of interest, the RMS signal for each muscle was normalized to its corresponding RIC.

Figure 3. Suspension training and floor exercises comparisons.

Statistical Analyses
Data were analyzed using SPSS® version 23 for Windows® (IBM Corp: Armonk, NY). Data were inspected to ensure normality and equality of variances between conditions was met. Means, confidence intervals and standard deviations for the RMS and RIC (%) were obtained for each muscle group. Given that the corre-
lation between variables for each exercise was greater than 0.70 a repeated measures multivariate analysis of variance (MANOVA) for each exercise was used to compare differences between muscle activation between conditions (ST vs Non-ST). Post-hoc analyses for each muscle using Bonferroni adjustments were performed when MANOVA was statistically significant (p ≤ 0.05).

RESULTS
The MANOVAs were statistically significant for each exercise; push-up (p = 0.01; R: 0.64), inverted row (p = 0.04; R: 0.43), bilateral bridge (p < 0.01; R: 0.70), and prone plank (p = 0.01; R: 0.66). Post hoc testing revealed that the ST version of the exercise increased the activation of the following muscle groups as compared to its counterpart exercise performed without the ST for the following exercises: plank: obliques (p = 0.021); pushup: pectoralis (p = 0.002), rectus abdominis (p < 0.0001), obliques (p = 0.019), rhomboids (p < 0.0001), erector spinae (p = 0.006); row: deltoid (p = 0.016), obliques (p = 0.027); bridge: rectus abdominis (p = 0.013), erector spinae (p < 0.0001). The differences found for the rectus abdominis with the row performed with the ST approached significance with p = 0.059. Tables 1.A to 1.D depict the results for each exercise.

Table 1. Comparisons of mean Root Mean Square (RMS) percent values for Suspension Trainer (ST) and floor plank exercises.

<table>
<thead>
<tr>
<th>Muscle Group</th>
<th>ST Mean ± SD 95% CI</th>
<th>Floor Mean ± SD 95% CI</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pectoralis major</td>
<td>36.53 ± 14.99</td>
<td>33.15 ± 12.85</td>
<td>.18</td>
</tr>
<tr>
<td></td>
<td>30.20 – 42.86</td>
<td>27.72 – 38.57</td>
<td></td>
</tr>
<tr>
<td>Middle Deltoid</td>
<td>113.99 ± 44.66</td>
<td>109.70 ± 36.70</td>
<td>.42</td>
</tr>
<tr>
<td></td>
<td>95.13 – 132.85</td>
<td>94.20 – 125.20</td>
<td></td>
</tr>
<tr>
<td>Serratus Anterior</td>
<td>71.47 ± 24.60</td>
<td>74.57 ± 22.19</td>
<td>.24</td>
</tr>
<tr>
<td></td>
<td>61.08 – 81.86</td>
<td>65.20 – 83.94</td>
<td></td>
</tr>
<tr>
<td>Rectus Abdominis</td>
<td>121.09 ± 118.98</td>
<td>74.94 ± 30.26</td>
<td>.07</td>
</tr>
<tr>
<td></td>
<td>70.85 – 171.33</td>
<td>62.16 – 87.72</td>
<td></td>
</tr>
<tr>
<td>Obliques</td>
<td>66.79 ± 24.12</td>
<td>54.63 ± 23.25</td>
<td>0.02*</td>
</tr>
<tr>
<td></td>
<td>56.60 – 76.98</td>
<td>44.82 – 64.45</td>
<td></td>
</tr>
<tr>
<td>Rhomboids/Middle Trapezius</td>
<td>42.53 ± 38.44</td>
<td>34.56 ± 10.87</td>
<td>.24</td>
</tr>
<tr>
<td></td>
<td>26.30 – 58.77</td>
<td>29.97 – 39.15</td>
<td></td>
</tr>
<tr>
<td>Erector Spinae</td>
<td>40.67 ± 16.45</td>
<td>41.28 ± 23.33</td>
<td>.85</td>
</tr>
<tr>
<td></td>
<td>33.73 – 47.62</td>
<td>31.43 – 51.14</td>
<td></td>
</tr>
<tr>
<td>Gluteus Maximus</td>
<td>46.10 ± 16.33</td>
<td>46.28 ± 18.82</td>
<td>.93</td>
</tr>
<tr>
<td></td>
<td>39.20 – 52.99</td>
<td>38.33 – 54.23</td>
<td></td>
</tr>
</tbody>
</table>

* Statistically significant increase in muscle activation after the post hoc analysis.
DISCUSSION
The objective of this study was to compare muscle activation between stable surface exercises and similar exercises performed using the ST. The main finding was that each ST exercise had at least one muscle group that showed a statistically significant increase in activation when compared to its equivalent exercise on the ground. Although surface EMG readings can be affected by body movements and other factors, this study's use of a RIC and standardization of joint angles/motions performed allows for the comparisons of muscle activation between conditions. The results of this study appear to indicate that the use of a ST will increase activation of several muscle groups when compared to similar exercises performed on a stable surface.

<table>
<thead>
<tr>
<th>Muscle Group</th>
<th>ST Mean ± SD</th>
<th>Floor Mean ± SD</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>95% CI</td>
<td>95% CI</td>
<td></td>
</tr>
<tr>
<td>Pectoralis major</td>
<td>115.07 ± 36.05</td>
<td>83.38 ± 30.03</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>Middle Deltoid</td>
<td>245.34 ± 112.98</td>
<td>84.37 ± 18.18</td>
<td>0.32</td>
</tr>
<tr>
<td>Serratus Anterior</td>
<td>91.81 ± 59.57</td>
<td>72.24 ± 21.99</td>
<td>0.11</td>
</tr>
<tr>
<td>Rectus Abdominis</td>
<td>93.90 ± 36.70</td>
<td>67.47 ± 25.26</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>Obliques</td>
<td>81.04 ± 60.14</td>
<td>52.80 ± 26.74</td>
<td>0.02*</td>
</tr>
<tr>
<td>Rhomboids/Middle</td>
<td>67.01 ± 23.50</td>
<td>46.53 ± 16.60</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>Trapezius</td>
<td>77.35 ± 23.05</td>
<td>82.86 ± 21.50</td>
<td>0.03*</td>
</tr>
<tr>
<td>Erector Spinae</td>
<td>54.52 ± 21.96</td>
<td>41.10 ± 15.96</td>
<td>0.01*</td>
</tr>
</tbody>
</table>

* Statistically significant increase in muscle activation after the post hoc analysis.

Table 2. Comparisons of mean Root Mean Square (RMS) percent values for Suspension Trainer (ST) and floor push-up.

<table>
<thead>
<tr>
<th>Muscle Group</th>
<th>ST Mean ± SD</th>
<th>Floor Mean ± SD</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>95% CI</td>
<td>95% CI</td>
<td></td>
</tr>
<tr>
<td>Middle Deltoid</td>
<td>168.98 ± 78.15</td>
<td>145.69 ± 65.00</td>
<td>0.02*</td>
</tr>
<tr>
<td>Serratus Anterior</td>
<td>47.14 ± 20.11</td>
<td>54.64 ± 29.82</td>
<td>0.18</td>
</tr>
<tr>
<td>Rectus Abdominis</td>
<td>67.41 ± 21.27</td>
<td>63.43 ± 18.94</td>
<td>0.05*</td>
</tr>
<tr>
<td>Obliques</td>
<td>40.56 ± 24.74</td>
<td>37.44 ± 20.39</td>
<td>0.03*</td>
</tr>
<tr>
<td>Rhomboids/Middle</td>
<td>77.35 ± 23.05</td>
<td>82.86 ± 21.50</td>
<td>0.20</td>
</tr>
<tr>
<td>Trapezius</td>
<td>67.62 ± 87.09</td>
<td>73.78 ± 91.94</td>
<td></td>
</tr>
</tbody>
</table>

* Statistically significant increase in muscle activation after the post hoc analysis.

Table 3. Comparisons of mean Root Mean Square (RMS) percent values for Suspension Trainer (ST) and floor row exercises.
The ST pushup was the only exercise that demonstrated a statistically significant increase in muscle activation for nearly all muscle groups tested. Snarr et al. had similar findings, when they reported increased activation of pectoralis major, anterior deltoid, and triceps brachii while performing ST pushup. One plausible hypothesis for this is that the ST pushup was the only exercise performed where the COM was directly over the unstable base of support (and farther away from the stable base), which may enhance activation of the tested muscle groups. STs are unique in that there are two BOS (one unstable and one stable), so as the COM gets closer over the unstable surface it is also getting further away from the stable surface, and vice versa.

Use of the ST increased the muscle recruitment of the pectoralis, rectus abdominis, obliques, rhomboids and erector spinae possibly due to a combination of decreased angular velocity and unstable BOS. Previous studies have shown that when a novel movement is introduced, the angular velocities required to perform the task are decreased which will allow for increased motor unit recruitment, particularly with concentric contractions. The EMG activity was assessed during the concentric phase of the ST push-up, which requires increased motor recruitment to perform the movement at a reduced angular velocity. Although the angular velocity was not the focus of this study, the subjects that were utilized had no previous exposure to ST and thus demonstrated reduced speed when performing these movements on the ST as compared to without it. The variations in point of stability as previously discussed requires altered magnitudes of motor recruitment based on the need to maintain the center of mass over a base of support that can shift directions based on the forces applied to it.

For the bridge exercise, there was a statistically significant increase in muscle activation for the rectus abdominis and erector spinae when using the ST. As previously discussed, distance of COM from the unstable arm will influence muscle activation for a given task. In the bridge exercise, the unstable surface (feet in straps) was further away from the user's COM, thereby decreasing the difficulty of the exercise. The bridge is a commonly used exercise to increase muscle endurance, strength and motor recruitment of the gluteal, hamstring, abdominal and trunk extensor muscle groups. The subjects reported increased levels of hamstring activity as compared to the gluteal muscle groups when the bridge was performed in the ST. This may be due to the necessity to control the anterior to posterior swing of the ST straps by activating the hamstrings during the bridge movement.

When performing the plank exercise with feet in the ST straps, all muscles tested in this study demonstrated an increase in activation compared to floor exercises, but only the obliques showed a statistically significantly greater RMS. While no studies to date have studied muscle activation in planks on a
ST, specifically with the feet in the unstable surface, core activation has been shown to increase when using a variety of unstable surfaces. Lehman et al.\textsuperscript{14} demonstrated a 20\% increase in core activation with push-ups performed with hands on a Swiss ball and Calatayud et al.\textsuperscript{18} found a statistically significant increase in muscle activation of the triceps, upper trapezius, lumbar erector spinae, rectus femoris and rectus abdominis, with the greatest change in the rectus abdominis when the push-up was performed on a ST. Despite limited research, one consideration for the practitioner would be holding the ST straps in the hands in a high plank position instead of performing the plank with feet in the straps. As mentioned above with the push-up, maintaining the center of mass directly over or closer to the ST straps tends to further increase muscle activation in all surrounding musculature. Thus, a practitioner can apply the strategy of altering body positioning to either assist the user or challenge them further.

With the inverted row, increased muscle activation was statistically significantly greater in the middle deltoid, obliques, and rectus abdominis. This again supports the hypothesis that providing an unstable BOS during an exercise may facilitate increased muscle activation, particularly at the spinal stabilizers. The inverted row has not previously been studied in regards to STs, but there are extensive published reports that discuss muscle activation patterns in the exercise on a stable surface. Mok et al.\textsuperscript{19} found abdominal musculature generally operated at <20\% of the MVIC during an inverted row performed at 45˚ angle. While the angle of incline could certainly be manipulated to increase muscle activation, the present study provides another alternative by using a ST. Additionally, further research could be conducted to determine if there is a difference in muscle activation between pushing exercises and pulling exercises on the ST. Calatayud et al.\textsuperscript{19} determined triceps brachii, pectoralis, and rectus abdominis muscle activation for a pushup on the floor is also less than 20\% MVIC. However, the addition of a ST could alter the demands on the muscle due to both the instability component and considering the pushup demands an eccentric contraction of the pectoralis major at the beginning of the exercise while the inverted row requires a concentric contraction of the middle trapezius.

Although an abundance of research has been conducted examining EMG activity of selected muscles during various exercises performed on unstable surfaces, few studies have examined the relative difference of similar exercises performed utilizing a ST. Furthermore, there is no literature currently available that looks at primary, secondary, and stabilization musculature over such a broad spectrum of muscle/exercise combinations simultaneously. Results from this study are consistent with findings from those found in Anderson et al.,\textsuperscript{20} where there was an increase in stabilization musculature EMG activity during body weight exercise when stability is challenged. Additionally, this study suggests that utilization of a ST alters the pattern of muscle recruitment. Thus, it appears that the muscles of the limbs must be activated to a greater extent to prevent unnecessary horizontal and diagonal movements.\textsuperscript{20} Surrounding musculature are then required to help stabilize the moving joint, in addition to performing the desired motion.\textsuperscript{13}

Due to the ability to load/unload the user, ST applications are extremely varied.\textsuperscript{3} The results of this study suggest that when body positioning is similar, a ST exercise will elicit greater stabilization muscle activation than its stable counterpart as found with the use of sEMG. While traditional unstable surface training is normally utilized to increase exercise difficulty, the TRX\textsuperscript{8} and other similar STs can be used to either increase or decrease muscular demand. This ability to gradually load/unload the user helps to progress the difficulty of the exercise at a selected degree of angulation each time, thus increasing specificity of training. STs also show great potential when applied to strength training. Typical strength training exercises, with the exception of Olympic lifts, are applied primarily in a single plane.\textsuperscript{21} Functionally, this is not very applicable as most physical activities are performed in multiple planes during any given movement.\textsuperscript{4} For athletes this is especially true, as there are often unexpected, high-load multidirectional vectors throughout the game of play. Given the inherent instability of STs, they can be utilized to train stabilization musculature, and more effectively mimic multidirectional loads that these athletes experience.

Although these results showed that suspension training elicits greater muscle activation than floor
exercises in some muscles, these results should be interpreted with caution. It has been documented that the EMG signal is not directly related to the number of muscle fibers activated limiting a direct measurement of neural drive.\textsuperscript{12} This is more evident during dynamic contractions where muscles are changing in length and there is a possibility of fatigue like in this investigation.\textsuperscript{12} However, EMG amplitude analyses are useful for approximating muscle activation when normalized to a reference contraction.\textsuperscript{22} Extrapolation of the results of this study to patients who are symptomatic or have other pathologies should be done with caution. It cannot be concluded that symptomatic individuals will demonstrate the same patterns of muscle activation as the asymptomatic individuals in this study. Additionally the results of this study only allow for speculation as to what underlying biomechanical principles are responsible for the increased muscle activation found using the ST. Results from this study can, however, be extrapolated for future research endeavors to potentially further isolate causal factors responsible for increased muscle activation when using STs. For example, exercises in future studies should be selected that minimize the available base of support and distance between COM and unstable hand straps; as these factors have been found to potentially contribute to increased muscle activation.

CONCLUSIONS
The results of this investigation showed an increased in muscle activation of several upper extremity and core muscles when exercises are performed using a suspension trainer. Such increases in muscle activation during ST were particular to each specific exercise based on positioning and loading of the straps. Future work is necessary to determine the effectiveness of ST in those suffering from upper extremity and lumbo-pelvic musculoskeletal disorders that could benefit from muscle stabilization interventions.

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ABSTRACT

Background/purpose: The growing volume of movement screening research reveals a belief among practitioners and researchers alike that movement quality may have an association with injury risk. However, existing movement screening tools have not considered the sport-specific movement and injury patterns relevant to soccer. The present study introduces the Soccer Injury Movement Screen (SIMS), which has been designed specifically for use within soccer. Furthermore, the purpose of the present study was to assess the intra- and inter-rater reliability of the SIMS and determine its suitability for use in further research.

Methods: The study utilized a test-retest design to discern reliability. Twenty-five (11 males, 14 females) healthy, recreationally active university students (age 25.5 ± 4.0 years, height 171 ± 9 cm, weight 64.7 ± 12.6 kg) agreed to participate. The SIMS contains five sub-tests: the anterior reach, single-leg deadlift, in-line lunge, single-leg hop for distance and tuck jump. Each movement was scored out of 10 points and summed to produce a composite score out of 50. The anterior reach and single-leg hop for distance were scored in real-time while the remaining tests were filmed and scored retrospectively. Three raters conducted the SIMS with each participant on three occasions separated by an average of three and a half days (minimum one day, maximum seven days). Rater 1 re-scored the filmed movements for all participants on all occasions six months later to establish the ‘pure’ intra-rater (intra-occasion) reliability for those movements.

Results: Intraclass correlation coefficient (ICC) values for intra- and inter-rater composite score reliability ranged from 0.66-0.72 and 0.79-0.86 respectively. Weighted kappa values representing the intra- and inter-rater reliability of the individual sub-tests ranged from 0.35-0.91 indicating fair to almost perfect agreement.

Conclusions: Establishing the reliability of the SIMS is a prerequisite for further research seeking to investigate the relationship between test score and subsequent injury. The present results indicate acceptable reliability for this purpose; however, room for further development of the intra-rater reliability exists for some of the individual sub-tests.

Keywords: Assessment, association football, kinematic, screening

Level of evidence: 2b
INTRODUCTION
The proliferation of movement screening research and its widespread use in professional soccer reveals a belief among practitioners and researchers alike that movement quality may have an association with injury risk. Movement quality is ill defined but relates to the ability of an individual to perform a given movement in a controlled manner while demonstrating good or acceptable technique. Exactly what constitutes good technique remains a topic of debate. While it is arguable that no ‘correct’ movement pattern exists for any given exercise there are certain characteristics that may be undesirable, such as restricted range of motion and an inability to control coordinated movements. The rationale behind movement screening is that such limitations may result in acute injuries or contribute to insidious overuse complaints.

Numerous screens exist; however, the supporting evidence with regard to both their reliability and association with injury varies widely in both volume and methodological quality. The majority of such research has focused on the Functional Movement Screen (FMS™), which has demonstrated good reliability but conflicting relationships with injury likelihood. The FMS™ was designed as a ‘general’ movement assessment tool and has been used within a wide range of sports and professional domains including the military and emergency services. In contrast, some screens such as the Landing Error Scoring System (LESS) have been designed with the intention of identifying those at an increased risk of a particular type of injury, for example, anterior cruciate ligament rupture. In addition, some have been designed for use within particular sports, for example, netball and rugby union. Despite the popularity of movement screening within professional soccer, no soccer-specific tool currently exists. The present study introduces the Soccer Injury Movement Screen (SIMS), which has been designed specifically for use with soccer athletes. The movements contained within the assessment were selected to reflect the most common sites (lower extremities) and types (strains and sprains) of soccer-related injury and hence they primarily tax the mobility and stability of the ankle, knee and hip joints in addition to the strength and flexibility of the surrounding musculature. When selecting the individual sub-tests, priority was given to movements previously proposed within the scientific literature as potentially associated with injury likelihood.

The efficacy of screening tests that seek to identify or predict which players will get injured has recently been questioned. In the context of sports-related injuries the idea that a single attribute such as movement quality for example, could be predictive is unlikely. As a result, the ultimate objective of the SIMS will be to investigate whether a causative relationship exists between movement quality and injury. Any potential relationship between movement quality and injury is unlikely to be substantial enough to justify the SIMS being considered ‘predictive’ but it may help inform the content of injury prevention programs by highlighting risk factors.

There is reason to expect that a causative relationship between movement quality and injury may exist since some authors have reported poor FMS™ scores preceding subsequent injury. However, numerous studies utilizing the same movement screening tool have not observed any link. The SIMS may eventually demonstrate a stronger association to injury risk than the FMS™ due to its more explicit scoring criteria (Appendix 2) focusing on specific aspects of each movement. Furthermore, the FMS™ includes movements targeting the upper limbs, which have limited relevance for soccer players, whereas the SIMS concentrates on the lower limbs only.

Before any prospective cohort studies can be conducted using the SIMS its reliability must first be established. The reliability of an assessment tool is of critical importance since it is a pre-requisite for test validity. Therefore, the purpose of the present study was to test the intra- and inter-rater reliability of the SIMS and determine its suitability for use in further research.

METHODS
Participants
Twenty-five (11 males, 14 females) healthy, recreationally active university students (age 25.5 ± 4.0 years, height 171 ± 9 cm, weight 64.7 ± 12.6 kg) agreed
to participate in the present study. Inclusion criteria required participants to be aged between 18-40 years of age, free of injury (any physical condition that precluded them from completing the assessment) and recreationally active. Information pertaining to the study protocol and requirements were provided for each participant before written informed consent was collected. The study was approved by the local ethics committee (ref number: 270/15, Ärztekammer des Saarlandes, Saarbrücken, Germany) and conformed to the Declaration of Helsinki.

Raters
Three raters carried out the SIMS in the present study; all possessed postgraduate sport science qualifications and had previous professional experience delivering movement assessments. In addition, Rater 1 was an accredited strength and conditioning coach with both the United Kingdom Strength and Conditioning Association (UKSCA) and the National Strength and Conditioning Association (NSCA). Prior to the present study all raters conducted pilot testing using the SIMS with 10 participants. The pilot testing incorporated two 2-hour sessions where raters reviewed the test instructions (Appendix 1), the scoring criteria (Appendix 2) and familiarized themselves with the camera positioning (Figure 1). In addition, three more two-hour sessions were conducted where raters practiced scoring video footage and discussed the interpretation of the scoring criteria. In total, rater training amounted to ~12 hours (10 classroom-based and two field-based).

Design
The present study utilized a test-retest design. Participants performed the SIMS on three occasions separated by an average of 3.5 days (minimum one day, maximum seven days). The SIMS contains five sub-tests: the anterior reach (AR), single-leg deadlift (SLDL), in-line lunge (ILL), single-leg hop for distance (SLHD) and tuck jump (TJ) (Figure 2). Raters 1 and 2 scored all participants whereas Rater 3 only scored 15 of the 25 (for reasons unrelated to the study). Raters scored two of the five movements (AR and SLHD) included in the SIMS in real-time on each occasion. The remaining three movements (SLDL, ILL and TJ) were filmed from both the frontal and sagittal planes using iPhone 4S devices (Apple Inc., California, USA) and scored retrospectively. These sub-tests were scored from video footage, as opposed to in real-time; to allow raters to view the movements in slow motion and increase the likelihood of identifying errors. A minimum of one week separated the scoring of participants’ filmed movements for occasions one, two and three respectively in an attempt to reduce the risk of rater bias (i.e. remembering the previous scores given). Scores for occasions one, two and three were compared within each rater to investigate ‘real-world’ intra-rater (inter-occasion) reliability. Scores were also compared between raters for each occasion to assess inter-rater reliability. Rater 1 re-scored the filmed movements for all participants on all occasions six months later to establish the ‘pure’ intra-rater (intra-occasion) reliability for those movements.

Soccer Injury Movement Screen (SIMS)
Detailed descriptions of each movement contained within the SIMS and associated scoring criteria are outlined in Appendices 1 and 2. The ILL is the same in its setup as when performed as part of the FMS™ albeit it is scored differently, while the tuck jump is
Figure 2. Demonstration cards that were shown to participants along with verbal instructions prior to test execution
A: anterior reach; B: single-leg deadlift; C: in-line lunge; D: single-leg hop for distance; E: tuck jump.
performed and scored exactly as described by Myer et al. A standardized five minute warm up was completed before each occasion and included dynamic bodyweight exercises (e.g. squats, walking lunges, hamstring walkouts, diagonal hop and holds). The assessments were performed outdoors on a hard, rubberized sports court during summertime in dry temperate weather conditions. Participants were instructed to wear tight fitting sports clothing and the same training shoes on each occasion. The five component movements were performed in sequential order starting with the AR followed by the SLDL, ILL, SLHD and TJ. Prior to each sub-test participants were read the test instructions (Appendix 1) verbatim and shown demonstration cards (Figure 2). Participants were then allowed three practice attempts for each sub-test where any obvious miscommunication or misunderstandings relating to how to execute the movements were clarified. Time to complete the assessment was 10-15 minutes per participant.

Each component movement was scored out of 10 points resulting in a theoretical maximum composite score of 50 when the score from each sub-test is summed. A higher score indicated poorer performance; hence, zero was the theoretical ‘best’ score while 50 was the ‘worst’. The AR and SLHD scoring criteria were objective in nature and were based on reach and jump distance respectively. In contrast, the SLDL, ILL and TJ relied on subjective assessment of movement quality. Raters were allowed to watch the clips of the filmed movements, both in real-time speed and slow motion, as many times as they deemed necessary to make an accurate judgment when scoring.

Statistical analyses
Descriptive data are presented as means ± standard deviation. Reliability statistics are accompanied with 95% confidence intervals (CI). Data were analysed using R statistics program (R Core Development Team 2014) and MedCalc for Windows, version 16.4.3 (MedCalc Software, Ostend, Belgium). Comparison of composite and individual sub-test scores between male and female participants was performed using the Mann-Whitney U statistic. Cohen’s $d$ effect size (ES) was also calculated to compare male and female participants and was interpreted as follows: ≤0.2, trivial; 0.21-0.60, small; 0.61-1.2, moderate; 1.21-2.0, large; 2.1-4.0, very large. Two way mixed model intraclass correlation coefficients ($\text{ICC}_{3, 1}$), weighted kappas (quadratic) and minimal detectable change (MDC) were used to determine the intra- and inter-rater reliability of the composite score. MDC values were calculated at both a 95% and 80% level of confidence in order to provide applied practitioners with the means to identify ‘true’ changes in test performance. Typically, MDC values are calculated to reflect a 95% confidence interval; however, this results in very conservative estimates of how much a test score has to change to be considered real and may be of limited usefulness in the applied setting where small improvements/demments in test performance can be meaningful. MDC values at lower levels of confidence (e.g. 80%) can be calculated and are useful to applied practitioners who may be willing to rely on more liberal estimates of test score changes. In addition, weighted kappas (quadratic) were used to determine intra- and inter-rater reliability of each individual subtest. ICC values were interpreted according to the following criteria: <0.40, poor; 0.40-0.59, fair; 0.60-0.74, good; ≥0.75, excellent. Similarly, weighted kappa values were interpreted according to the guidelines outlined by Landis and Koch: <0.00, poor; 0.00-0.20, slight; 0.21-0.40, fair; 0.41-0.60, moderate; 0.61-0.80, substantial; 0.81-1.00, almost perfect. Alpha was set at $p$≤0.05.

RESULTS
Composite scores were not significantly different between males (18.3) and females (15.3) (Table 1). Only the SLDL scores differed between genders (males = 4.3, females = 1.8) (Table 1).

$\text{ICC}_{3, 1}$, weighted kappa and MDC values for intra-rater (inter-occasion) reliability are presented in Table 2. Weighted kappa values for the individual subtests ranged from fair to substantial (0.35-0.77). With regard to the composite score, weighted kappa values were interpreted as substantial (0.63-0.68) while the ICCs were classified as good (0.66-0.72) for each rater.

$\text{ICC}_{3, 1}$ and weighted kappa values for inter-rater reliability are presented in Table 3. Weighted kappa values for the individual subtests ranged from mod-
erate to almost perfect (0.43-0.91). With regard to the composite score weighted kappa values ranged from substantial to almost perfect (0.78-0.81) while the ICCs were classified as excellent (0.79-0.86) for all three occasions.

Weighted kappa scores for ‘pure’ intra-rater (intra-occasion) reliability are presented in Table 4. The kappa values were evaluated as almost perfect for the SLDL (0.90) and ILL (0.85) while the TJ value was interpreted as substantial (0.73).

DISCUSSION
Overall, the present results indicate sufficient reliability for the SIMS to be considered useful for further research and applied practitioners alike. The intra-rater reliability of the SIMS composite score was classed as substantial and good for all raters based upon the weighted kappa and ICC scores respectively (Table 2). The MDC values calculated

### Table 1. Mean values (reported in arbitrary units) and comparison of test scores between males and females.

<table>
<thead>
<tr>
<th></th>
<th>Overall (n=25)</th>
<th>Males (n=11)</th>
<th>Females (n=14)</th>
<th>p-value</th>
<th>Male vs female effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite score</td>
<td>16.6 ± 4.9</td>
<td>18.3 ± 3.0</td>
<td>15.3 ± 5.8</td>
<td>0.080</td>
<td>0.6 (Small)</td>
</tr>
<tr>
<td>AR (mean ± SD)</td>
<td>1.7 ± 1.8</td>
<td>2.1 ± 2.3</td>
<td>1.4 ± 1.3</td>
<td>0.648</td>
<td>0.4 (Small)</td>
</tr>
<tr>
<td>SLDL (mean ± SD)</td>
<td>2.9 ± 2.1</td>
<td>4.3 ± 2.0</td>
<td>1.8 ± 1.5</td>
<td>&lt;0.01</td>
<td>1.4 (Large)</td>
</tr>
<tr>
<td>ILL (mean ± SD)</td>
<td>2.6 ± 1.5</td>
<td>2.5 ± 1.5</td>
<td>2.6 ± 1.6</td>
<td>0.825</td>
<td>0.1 (Trivial)</td>
</tr>
<tr>
<td>SLHD (mean ± SD)</td>
<td>4.1 ± 2.3</td>
<td>4.2 ± 1.9</td>
<td>4.0 ± 2.7</td>
<td>0.718</td>
<td>0.1 (Trivial)</td>
</tr>
<tr>
<td>TJ (mean ± SD)</td>
<td>5.4 ± 1.3</td>
<td>5.2 ± 1.0</td>
<td>5.5 ± 1.6</td>
<td>0.534</td>
<td>0.2 (Trivial)</td>
</tr>
</tbody>
</table>

Test scores drawn from Rater 1 on the third testing occasion. AR= anterior reach, ILL= in-line lunge, SLDL= single-leg deadlift, SLHD= single-leg hop for distance, TJ= tuck jump

### Table 2. Summary of intra-rater (inter-occasion) reliability values. Values in brackets represent the 95% confidence intervals.

<table>
<thead>
<tr>
<th></th>
<th>AR</th>
<th>SLDL</th>
<th>ILL</th>
<th>TJ</th>
<th>Composite score</th>
<th>ICC3.1 Composite score</th>
<th>MDC @ 95% confidence</th>
<th>MDC @ 80% confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rater 1</td>
<td>0.47</td>
<td>0.77</td>
<td>0.64</td>
<td>0.44</td>
<td>0.58</td>
<td>0.68</td>
<td>0.71</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>(0.17-0.77)</td>
<td>(0.67-0.87)</td>
<td>(0.52-0.77)</td>
<td>(0.26-0.61)</td>
<td>(0.43-0.73)</td>
<td>(0.54-0.81)</td>
<td>(0.52-0.85)</td>
<td>7.0</td>
</tr>
<tr>
<td>Rater 2</td>
<td>0.46</td>
<td>0.68</td>
<td>0.48</td>
<td>0.35</td>
<td>0.58</td>
<td>0.64</td>
<td>0.64</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>(0.22-0.69)</td>
<td>(0.55-0.81)</td>
<td>(0.30-0.66)</td>
<td>(0.15-0.55)</td>
<td>(0.44-0.72)</td>
<td>(0.49-0.80)</td>
<td>(0.54-0.85)</td>
<td>7.5</td>
</tr>
<tr>
<td>Rater 3</td>
<td>0.39</td>
<td>0.68</td>
<td>0.63</td>
<td>0.36</td>
<td>0.45</td>
<td>0.63</td>
<td>0.63</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>(0.02-0.77)</td>
<td>(0.55-0.81)</td>
<td>(0.49-0.77)</td>
<td>(0.11-0.61)</td>
<td>(0.26-0.65)</td>
<td>(0.45-0.80)</td>
<td>(0.38-0.86)</td>
<td>6.7</td>
</tr>
</tbody>
</table>

AR= anterior reach, ICC= intra-class correlation coefficient, ILL= in-line lunge, MDC= minimum detectable change, SLDL= single-leg deadlift, SLHD= single-leg hop for distance, TJ= tuck jump

### Table 3. Summary of inter-rater reliability values (between all three raters). Values in brackets represent the 95% confidence intervals.

<table>
<thead>
<tr>
<th></th>
<th>AR</th>
<th>SLDL</th>
<th>ILL</th>
<th>SLHD</th>
<th>TJ</th>
<th>Composite score</th>
<th>ICC3.1 Composite score</th>
<th>MDC @ 95% confidence</th>
<th>MDC @ 80% confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occasion 1</td>
<td>0.83</td>
<td>0.51</td>
<td>0.71</td>
<td>0.84</td>
<td>0.60</td>
<td>0.78</td>
<td>0.79</td>
<td>(0.72-0.95)</td>
<td>(0.35-0.66)</td>
</tr>
<tr>
<td></td>
<td>(0.33-0.84)</td>
<td>(0.50-0.79)</td>
<td>(0.41-0.75)</td>
<td>(0.86-0.97)</td>
<td>(0.35-0.65)</td>
<td>(0.70-0.87)</td>
<td>(0.58-0.92)</td>
<td>7.9</td>
<td>4.7</td>
</tr>
</tbody>
</table>

AR= anterior reach, ICC= intra-class correlation coefficient, ILL= in-line lunge, SLHD= single-leg hop for distance, TJ= tuck jump

### Table 4. Summary of intra-rater (intra-occasion) reliability values for video-taped movements. Values in brackets represent the 95% confidence intervals.

<table>
<thead>
<tr>
<th></th>
<th>SLDL</th>
<th>ILL</th>
<th>TJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rater 1</td>
<td>0.90</td>
<td>0.85</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>(0.86-0.95)</td>
<td>(0.80-0.91)</td>
<td>(0.62-0.83)</td>
</tr>
</tbody>
</table>
at an 80% level of confidence demonstrate that if a one-point increase or decrease in each sub-test were observed a ‘real’ change in composite score would have likely occurred. The inter-rater reliability was classified as substantial to almost perfect when considering the weighted kappa values and excellent according to the ICCs (Table 3). The SLDL sub-test was the only movement where a discrepancy in scores between males and females was apparent (Table 1). Male participants regularly cited hamstring inflexibility as a limiting factor during this task whereas female participants rarely mentioned this. Females generally display superior hamstring flexibility as compared to men.25 This difference in hamstring flexibility between males and females may potentially explain the gender difference in SLDL score observed in the present study.

The AR portion of the Y-balance test has previously been investigated as a risk factor with limb asymmetry >4 cm equating to a 2.3 – 2.7 times greater likelihood of non-contact injury among basketball and track and field athletes.26, 27 The scoring criteria used in this assessment (Appendix 2) required the rater to assign a score (0 – 10) based on the difference in reach distance between limbs. The reason for limiting the scoring range to a maximum of 10 points (a reach asymmetry of ≥10 cm) was to maintain equal weighting between all five sub-tests (each of which was scored out of 10). The scoring criteria were clearly objective for this sub-test and therefore did not directly assess movement quality. However, it was decided that the AR warranted inclusion in the SIMS regardless of not directly assessing movement quality, due to the promising evidence surrounding its relationship to injury.26, 27 The test reflects a number of physical qualities including neuromuscular control, strength and ankle stability: all of which are likely contributors to movement quality.1, 26, 27 Therefore, while this sub-test did not assess movement quality directly the variable that was measured (difference in reach distance) is likely a reasonable surrogate marker. Ankle injuries occur frequently within soccer therefore the anterior reach may be a promising tool for highlighting increased risk of such events.28 The intra-rater weighted kappa values for the AR ranged from fair to moderate (Table 2). In contrast, the inter-rater values ranged from moderate to almost perfect (Table 3). The difference between the intra- and inter-rater weighted kappa values suggests that the scoring criteria were clear but that a large proportion of the variation in the test scores stemmed from the participants and/or the influence of time between testing occasions. As such, additional participant familiarization with the test may help improve the intra-rater reliability.

While the SLDL is multifaceted in its demands, eccentric strength and flexibility of the hamstrings are clearly primary aspects of the movement due to the flexion of the hip with an extended knee on the standing leg. Both eccentric strength and flexibility of the hamstrings have been proffered as injury risk factors within soccer players.29, 30 Hence, the ability to perform the SLDL with a high degree of movement quality may indicate proficiency in these important attributes (hamstring flexibility and eccentric strength). The intra-rater SLDL weighted kappa values for each rater represented substantial agreement (Table 2) while the inter-rater reliability values ranged from moderate to substantial (Table 3). These findings suggest that while raters were very consistent in their scoring of the SLDL within themselves there is opportunity for improvement in the between-rater agreement. Such a scenario is somewhat inevitable when considering subjective scoring criteria; however, more detailed guidelines on what constitutes a movement ‘error’ may help improve consensus between raters in the future.

The ILL, or split squat, is a widely used exercise within soccer both during warm-up routines and resistance training sessions.31, 32 According to Cook et al.34 the ILL focuses on the “stresses simulated during rotational, decelerating and lateral type movements”. All of these movement patterns are frequently observed during soccer match play.34 The ability to perform this exercise correctly is important to ensure players do not use compensatory movements that potentially cause or exacerbate acute and overuse injuries. When performing the ILL the same test setup was used as with the FMS™; however, the scoring criteria utilized in the current research (Appendix 2) differed.33 The alternative scoring criteria were employed with the intention of explicitly outlining the potential movement flaws and hence enhancing clinical usefulness of the results. Both intra- and
inter-rater reliability of the ILL ranged from moderate to substantial (Tables 2 & 3). The weighted kappa values reported in the present investigation are in keeping with those observed in studies of the FMS™ version of the ILL.35-37 The more detailed scoring criteria adopted by the SIMS as compared with the FMS™ did not appear to adversely affect the reliability yet will provide practitioners with a clearer indication of where any potential movement dysfunction originates from.

It is important for soccer-specific movement assessments to incorporate explosive actions such as jumping and landing since they occur frequently during match play and often precede serious injury.34, 38 While bilateral, vertical drop jumps have long been used for injury risk stratification19, 40 many explosive soccer-specific actions are unilateral in nature and involve horizontal as well as vertical displacement (for example: kicking, changing direction and landing after a header).34 The scoring criteria for the SLHD were objective and incorporated both the jump distance and the between limb difference in jump distance (Appendix 2) with each of these aspects weighted equally. The precise distances that characterized the different scoring ranges were based on pilot testing conducted with recreationally active university students and therefore may not be applicable to professional or youth soccer players. Revised criteria may need to be established for higher-level athletes. The authors opted for objective, as opposed to subjective, scoring in this instance due to recent evidence suggesting jump distance as a risk factor for non-contact hamstring injury.41 While the intra-rater weighted kappa values ranged from fair to moderate the inter-rater values indicated almost perfect agreement between raters (Tables 2 & 3). The discrepancy between the intra- and inter-rater weighted kappa values suggests that a large proportion of the variation in the test scores stemmed from the participants and/or the influence of time between testing occasions rather than the application of the scoring criteria per se.

Allowing more jump attempts may increase the likelihood of maximum jump distance being reached and a plateau in performance occurring, which may in turn help improve reliability. On three occasions (for that occasion) participants recorded their best jump distance (for their last attempt. Similarly, 15 of the 25 participants recorded their best jump distances overall on testing occasion 3. In addition, 12 of the 25 participants scored by Rater 1 recorded their best between limb difference score on their third testing occasion. This demonstrates that incorporating a number of familiarization sessions on multiple days prior to testing may improve reliability for the same reasons highlighted previously (plateauing of performance). However, it should be remembered that the more attempts allowed and the more familiarization sessions performed the greater the potential for fatigue to influence test performance and the less practically feasible the assessment may become. There may be a trade-off between improved reliability and the feasibility of using the SIMS as a screening tool in the applied environment. A recent systematic review by Hegedus et al.42 assessed the methodological quality of studies exploring the reliability and validity of commonly used field-expedient screening tests such as the SLHD. They found no studies of satisfactory methodological quality reporting the reliability of the SLHD precluding comparison of the current results to previous findings.

The TJ assessment has been proposed as a field-expedient assessment of lower limb neuromuscular control.19 It is unique as an assessment of movement quality since it requires the participant to continuously perform plyometric vertical jumps for 10 seconds.19 While it is unlikely a player would replicate this precise activity during match-play the taxing nature of the test means it is likely to expose potentially injurious lower-limb movement patterns (particularly those associated with the onset of fatigue) that other, typically lower intensity assessments may not highlight. It has been suggested as a particularly useful tool for highlighting knee valgus movement during landing, which has been proposed as a risk factor for anterior cruciate ligament (ACL) injury.19, 43 Considering the long-term sequelae associated with ACL injury the authors judged the TJ worthy of inclusion in the SIMS.44, 45 Both the intra- and inter-rater weighted kappa values represented moderate agreement within and between raters (Tables 2 & 3). While this indicates accept-
able reliability the weighted kappa values calculated are lower than previously reported by Myer et al. However, Myer et al. only assessed 10 participants and so raters may have remembered the previous scores given, leading to recall bias. In addition, they scored the same video footage twice as opposed to scoring participants on two separate occasions. The scoring criteria (Appendix 2) are inherently subjective but reliability may be improved by adding some objective guidelines to certain scoring items. For example, one of the scoring items asks: “was there a pause between jumps”? This could potentially be changed to: “was there a pause, lasting longer than one second (or another defined time period), between jumps”? Such amendments may improve consistency of scoring within and between raters. However, future research is needed to assess the difference in reliability when objective instructions are given compared with when they are not.

In an effort to separate some of the sources of variation within the test-retest design, one rater scored all the filmed movements (SLDL, ILL and TJ) from each testing occasion twice. This removed the influence of variation in test performance stemming from the participants and revealed the ‘pure’ intra-rater, or intra-occasion, reliability. The weighted kappa values for the SLDL and ILL represented almost perfect agreement while the score for the TJ indicated substantial reliability (Table 4). These higher weighted kappa values (as compared to those reported in Table 2) are not surprising since they reflect only the variation in scoring associated with the rater. These results suggest that improvements in the ‘real world’ intra-rater reliability are more likely to arise from aspects related to the participants rather than the raters. Bearing this in mind, future strategies aimed at improving the intra-rater reliability of the SIMS further may include extended participant familiarization with the test and allowing them to read the scoring criteria. Explicitly explaining the scoring criteria for the FMS™ to participants elicited improved scores. This suggests that ambiguity related to what is being asked of participants during movement screening may influence their test execution and potentially contribute to variation in performance.

A number of limitations should be considered when interpreting the results of the present study. Perhaps most importantly, the pilot testing conducted to establish the scoring ranges for the SLHD (Appendix 2) were based on recreationally active university students’ scores. As such, it may be necessary to revise this aspect of the scoring criteria in the future if the SIMS is used with professional soccer players. Similarly, if the SIMS were to be utilized with youth soccer players then amendments to the scoring criteria may be necessary. In addition, the results presented here are from only 25 participants, which, is a relatively modest sample size for assessing reliability according to Terwee et al; however, the scores from three trials were included, rather than the usual two in an effort to improve the credibility of the conclusions. Furthermore, the raters represented a homogenous group. All were PhD students with postgraduate degrees in sport science. Further research may be needed to assess the reliability of the SIMS when conducted by other groups of raters, for example, undergraduate students or sports coaches.

CONCLUSIONS

Until now, no movement screen has been developed specifically for use among soccer players. The SIMS composite score demonstrated good to excellent intra- and inter-rater reliability. However, the intra-rater reliability of the individual sub-tests ranged from fair to substantial indicating scope for further improvement. Establishing the reliability of the SIMS is a prerequisite for further research seeking to investigate the relationship between test score and subsequent injury. The present results indicate at least acceptable reliability for this purpose.

REFERENCES


4. Padua DA, Marshall SW, Boling MC, et al. The Landing Error Scoring System (LESS) is a valid and


15. McCunn R, Meyer T. Screening for risk factors: If you liked it then you should have put a number on it. *Br J Sports Med.* 2016 [Epub ahead of print].


### Appendix 1. Description of the Soccer Injury Movement Screen (SIMS)

<table>
<thead>
<tr>
<th>Movement name</th>
<th>Rationale/perceived usefulness</th>
<th>Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-assessment</td>
<td>N/A</td>
<td>“For each exercise you have three practice attempts and three scored attempts on each leg. In the case of the tuck jump you have three practice jumps followed by the scored 10 second effort.”</td>
</tr>
</tbody>
</table>
| Anterior reach | - Provides an indication of ankle mobility (dorsiflexion)  
- Highlights limb asymmetry (ankle mobility and/or leg strength)  
- Provides an indication of single-leg control (e.g. motor control and balance) | “Remove your shoes. Place the big toe of your standing leg so it is touching the back of the taped line. Place hands on your hips. Reach the toes of the other leg as far along the measuring tape as possible – hovering around 5 centimeters off the ground. You must keep your standing foot in contact with the floor throughout, e.g. you cannot rise up on to your toes. Try to hover at the point of maximal reach for a couple of seconds to allow scoring. You must return to the start position for the attempt to be counted. Likewise, you must maintain balance throughout each attempt for the score to be recorded.”* |
| Single-leg deadlift | - Provides an indication of ability to simultaneously flex and extend at the hip with extended knees while maintaining neutral spinal alignment  
- Provides an indication of hamstring flexibility  
- Provides an indication of single-leg control (e.g. motor control and balance) | “Put your shoes back on. Tuck your t-shirt into your shorts. Stand on the middle of the cross, taped on the floor, and cross arms over your chest. Imagine a straight line between your head and your right heel. Try to hinge at the hip while keeping that line straight until parallel to the floor. Try to keep your standing leg (left) extended. Return to the start position with both feet touching the floor between each repetition.” Switch the words ‘right’ and ‘left’ when instructing the participant when testing the other side. |
| In-line lunge | - Provides an indication of ability to simultaneously flex and extend at the hip with flexed knees while maintaining neutral spinal alignment  
- Provides an indication of lower limb motor control and balance | As per instructions from Functional Movement Screen (Cook et al. 2006a) (see reference list for full article details). “Place your left toes so they are touching the back of the taped line. Place the heel of your right foot xx centimeters (as marked by instructor)** directly in front of your left foot. Hold the dowel behind your back gripping it with your left hand at your neck and your right hand at your lower back. Make sure the dowel is touching your head, upper back and buttocks. While maintaining an upright posture, descend into a lunge touching your left knee to the floor. Maintain contact with the dowel at the head, upper back and bum throughout. Return to the start position with knees fully extended between each repetition.” Switch the words ‘right’ and ‘left’ when instructing the participant when testing the other side. |
| Single-leg hop for distance | - Provides an indication of lower-limb unilateral power  
- Highlights limb asymmetry (lower-limb power and/or ankle stability and/or lower-limb eccentric strength)  
- Provides an indication of single-leg control | “Place the toes of the jumping leg so they are touching the back of the taped line. Jump as far as you can while still able to stick the landing on the same leg and hold your position to allow measurement. You must record three successful scored jumps on each leg and you will receive as many attempts as necessary to achieve this.” |
| Tuck jump | - Allows quick assessment of bilateral knee control during plyometric activity  
- Highlights limb asymmetry (lower-limb power and/or hip mobility) | As per instructions from Myer et al. (2008) (see reference list for full article details). “Stand on the middle of the cross taped on the floor with feet shoulder width apart. Upon signal from the tester, perform continuous vertical jumps on the spot for 10 seconds making sure to lift your knees towards your chest so that your upper thighs are parallel with the floor each time. Try to perform as many jumps as possible.” ** |

** If available, a slider device (e.g. Y Balance Test Kit™) can be used to perform the anterior reach.

** Foot placement is determined by measuring the distance from the floor to the tibial tuberosity (shin length).
calculate the score. Combine the scores for jump distance and jump symmetry to produce the final score out of 10. The maximum theoretical score achievable is 10 and this would represent a ‘poor’ score. In contrast, the theoretical minimum score is zero and this would represent a ‘good’ score.

### Scoring guidelines for the anterior reach and single-leg hop for distance (objective assessments)

#### Anterior reach
Measure the distance (in centimeters) from the start line to the most distal part of the foot of the reaching leg. Round to the nearest centimeter. Three repetitions are performed on each leg and reach distance should be recorded for each attempt. The maximum reach distances achieved by each leg should be used to calculate the difference between left and right. The maximum theoretical score achievable is 10 and this would represent a ‘poor’ score. In contrast, the theoretical minimum score is zero and this would represent a ‘good’ score.

<table>
<thead>
<tr>
<th>Difference in reach distance (cm) between legs</th>
<th>Test score</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
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<td>4</td>
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<td>6</td>
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<td>7</td>
<td>7</td>
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<td>8</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>≥10</td>
<td>10</td>
</tr>
</tbody>
</table>

#### Single-leg hop for distance
Measure the distance (in centimeters) from the start line to the heel of the jumping/landing leg. Round to the nearest centimeter. Three repetitions are performed on each leg and jump distance should be recorded for each attempt. Both jump distance and limb symmetry are taken into account when assigning a test score. The maximum jump distance achieved on each leg should be summed and used to calculate the score. Combine the scores for jump distance and jump symmetry to produce the final score out of 10. The maximum theoretical score achievable is 10 and this would indicate ‘poor’ movement quality. In contrast, the theoretical minimum score is zero and this would represent a ‘good’ score.

### Scoring guidelines for the single-leg deadlift, in-line lunge and tuck jump (subjective assessments)

- If an error occurs once and the rater judges it to be egregious then it should be scored as an error.
- If an error (but only to a minor extent) is observed once then it should not be scored.
- If the same error (but only to a minor extent) is observed twice then it should be scored as an error.

Defining specifically what constitutes “minor extent” or “egregious” is not possible. These judgments are left to the discretion of each individual rater. An important consideration is that raters are consistent in their judgments within themselves.

### Single-leg deadlift
The score for this test is based on the ‘movement quality’ criteria outlined below. Three repetitions are performed on each leg. The maximum theoretical score achievable is 10 and this would indicate ‘poor’ movement quality. In contrast, the theoretical minimum score is zero and this would represent a ‘good’ score.
The International Journal of Sports Physical Therapy | Volume 12, Number 1 | February 2017 | Page 66

Tuck jump
Mark a cross on the floor using tape (two 60cm strips that intersect). The score for this test is based on the ‘movement quality’ criteria outlined below. The maximum theoretical score achievable is 10 and this would indicate ‘poor’ movement quality. In contrast, the theoretical minimum score is zero and this would indicate ‘good’ movement quality. Myer et al. (2008) created the tuck jump assessment and any further clarification on scoring procedures can be sought from their original article (see reference list for full article details).

In-line lunge
The score for this test is based on the ‘movement quality’ criteria outlined below. Three repetitions are performed on each side. The maximum theoretical score achievable is eight and this would indicate ‘poor’ movement quality. In contrast, the theoretical minimum score is zero and this would indicate ‘good’ movement quality. Both legs are scored and the average of both right and left scores is assigned to the individual. To generate a score out of 10 multiply the fractional score out of eight by 10 e.g. if an individual displays four out of eight possible errors then the score out of 10 is: (4/8)x10 = 5. The reason for generating a score out of 10 is to maintain the same weighting between the five sub-tests.
ABSTRACT

Background: Brazilian Jiu-Jitsu (BJJ) athletes can be divided into two combat styles: pass fighters (PFs) and guard fighters (GFs). Flexibility of the posterior chain muscles is highly necessary in these athletes, especially in GFs. On the other hand, isometric strength of the trunk extensors is required in PFs. Handgrip strength is important in holding the kimono of the opponent, and symmetrical lower-limb strength is important for the prevention of injuries due to the overload caused by training.

Purpose: The aim of this study was to compare the biomechanical profiles of BJJ athletes with different combat styles using the following outcome measures: flexibility, trunk extensor isometric endurance, postural balance, handgrip isometric endurance and lower-limb muscle strength.

Methods: A cross-sectional study was conducted using 19 GFs and 19 PFs. The sit-and-reach test was used to evaluate the flexibility of the posterior chain muscles. The Biodex Balance System® was used to evaluate balance. A handgrip dynamometer and a dorsal dynamometer were used to evaluate handgrip and trunk extensor endurance, respectively. Quadriceps and hamstring strength were evaluated with an isokinetic dynamometer at 60°/s.

Results: No differences were observed between groups in terms of flexibility, balance, handgrip isometric endurance or quadriceps and hamstring strength; however, PFs (81.33) showed more isometric trunk extension endurance than GFs (68.85) ($p = 0.02$). Both groups had low values for hamstring/quadriceps ratio.

Conclusion: No significant biomechanical differences were observed between PFs and GFs.

Keywords: Jiu-Jitsu, martial arts, muscle strength, postural balance

Level of Evidence: 2b
INTRODUCTION

Jiu-Jitsu is a martial art that requires a variety of movements, such as flexion, extension, torsion and traction mechanics and center-of-mass displacement.\(^1\) This style of martial art appeared in Brazil after World War I and has undergone several modifications and adaptations, giving rise to Brazilian Jiu-Jitsu (BJJ), a fighting sport that has gained popularity around the world following the rise of the Ultimate Fighting Championships (UFC). The main techniques in BJJ are grappling, projections, transitions, chokes, and submissions.\(^2\)\(^,\)\(^2\)

BJJ athletes can be divided according to their combat styles into pass fighters (PFs) and guard fighters (GFs). The guard position is considered the essence of Jiu-Jitsu. The traditional position is the closed guard (Figure 1A), where the fighter has his/her back in the mat with legs wrapped around opponent, and he/she can take advantage to launch submissions. He/she can also be in a defensive position. Other guard positions have been created during the BJJ history, such as the spider guard (Figure 1B), De La Riva guard (Figure 1C), and butterfly guard (Figure 1D).\(^3\) The PF attempts to pass the guard of his/her opponent in order to score points or secure dominant positioning, while the GF defends the guard and reacts from this position. Some athletes prefer to choose one combat style and training based on the key aspects of that specific style.\(^4\)

BJJ requires certain physical attributes, such as flexibility, postural balance, isometric endurance, and muscle strength.\(^5\) An appropriate level of flexibility is necessary to allow joint mobility, thus avoiding limitations during the execution of techniques and the learning of specific drills. Athletes who prefer training from various guard positions require more posterior chain flexibility, especially hip flexibility. In contrast, PFs need more strength in the trunk extensors because GFs force them into trunk flexion.

Upper-limb isometric endurance is essential for good performance in BJJ athletes because most techniques require hand-gripping and grappling.\(^6\) Hand-grip strength is necessary to hold the opponent's

**Figure 1.** Types of guard position. (A) Closed guard (B) Spider guard (C) De La Riva guard (D) Butterfly guard.
kimono (i.e., uniform), requiring athletes to develop muscle endurance. Symmetrical strength in the lower limbs is essential because BJJ requires long and intense training that causes joint overload, mostly on the knees. Thus, adequate strength of the muscles that contribute to the stability and support of this joint is needed, particularly in the quadriceps and hamstrings because optimal ratios strength in these muscles contribute to a decreased risk of knee injuries. Dynamic postural stability and control of center of mass displacement are parameters that influence both guard defense and attack techniques.

Some studies regarding physiological demands and aerobic capacity in BJJ athletes have been published. Other studies regarding morphological adaptations (body composition and somatotype) have also been reported in the literature. To date, only one study has compared the biomechanics of combat style in BJJ athletes, and this study evaluated the fundamental movement competency with Functional Movement Screen (FMS®). No reports have examined strength, flexibility and balance in BJJ athletes.

The purpose of this study was to compare the biomechanical profiles of BJJ athletes with different combat styles (GF vs. PF) using the following outcome measures: flexibility, trunk extensor isometric endurance, postural balance, handgrip isometric endurance and lower-limb muscle strength.

**METHODS**

**Experimental Approach to the Problem**
A cross-sectional study was conducted from January to July of 2014. A total of 38 BJJ athletes were divided into two groups for assessment. Nineteen GFs comprised the first group, and 19 PFs comprised the second. The combat style was considered the independent variable, while flexibility, isometric endurance, postural balance, and muscle strength were the dependent variables of the study.

**Participants**
This study was submitted and approved by the Research Ethics Committee of the Federal University of Ceará (protocol n° 230/2011), and the research participants signed a written informed consent form. The sample size was calculated prior to the testing, using a significant difference of 20% for the flexibility outcome, with an estimated standard deviation of 8 centimeters. A significant difference of 20% was also chosen for the strength of the trunk extensors, with an estimated standard deviation of 36 kgf. A power of 80% and a level of significance of 5% were chosen for this calculation, thus resulting in a sample size of 20 individuals for each group.

All the athletes were professionals, over 18 years old and had competed in international-level competitions. The athletes were selected by convenience from a professional team specialized in this sport. Athletes with recent musculoskeletal injuries (i.e., within the last six months) and those who had undergone trauma or orthopaedic surgery in the last 12 months were excluded.

The groups presented similar anthropometric data, ages and practice durations. Only two athletes were left handed, and they were both GFs. Twelve PFs and seven GFs were blue belts (Table 1). The experience in BJJ is ranked according to the color of the belt of the fighters. Blue belts are the least experienced, whereas purple, brown, and black belts are the most experienced levels.

**Procedures**
A self-report questionnaire was utilized to investigate anthropometric characteristics, motor dominance, injury history and preferred combat style of the athletes. Then, the biomechanical tests were performed.

The athletes were assessed using the following outcome measures: posterior chain muscle flexibility, postural balance, isometric trunk endurance, isometric grip strength, and isokinetic thigh muscle strength. The reliability of the tests used has been analyzed previously.

The sit-and-reach test was performed in the Wells bench (Sanny®, Brazil) for the assessment of posterior chain muscle flexibility. The subject was positioned in a seated position, with the knees fully extended, the feet touching the bench, and the hands overlapping each other. The protocol consisted of the subject executing three repetitions, and the highest result was used for statistical purposes.
The Biodex Balance System® (BBS) (Biodex Medical Systems, Shirley, NY), which is commonly used to evaluate dynamic postural stability, was utilized for the postural balance assessment. This device measures the degree of inclination over each axis during the tests. The test was performed using the single-leg protocol, and the athletes were positioned with the tested knee at a 10-degree flexion angle and the contralateral limb at a 90-degree flexion angle. The arms were crossed at the level of the chest, and the eyes were directed toward the screen of the device, which was adjusted according to the height of each athlete. At the beginning of the trial, the athlete was instructed to maintain balance. This assessment was repeated three times for each limb, and each repetition lasted twenty seconds, with a 10 second rest interval. The level of stability of the platform of the BBS varied from Level 6 (more stable) to Level 2 (less stable) without any visual feedback to the subject. The Overall Stability Index, Antero-Posterior Stability Index, and Latero-Medial Stability Index (as calculated and provided by the BSS) were assessed.

Isometric dynamometry was utilized to assess muscular endurance and strength during the handgrip and trunk extension tests. Both muscle groups were assessed using the Maximum Voluntary Isometric Contraction (MVIC) protocol with three intermittent isometric contractions, as well as a 30-second isometric contraction test. A hand dynamometer (DM-100, Miotec®, Porto Alegre, Brazil) and a back dynamometer (DD-200, Miotec®, Porto Alegre, Brazil) were used. In order to assess handgrip strength, the athlete was asked to position the elbow at a 90º of flexion and squeeze the dynamometer with maximum effort. Three repetitions of five seconds were performed with an interval of 10 seconds between repetitions. In the same position, the athlete was asked to squeeze the dynamometer with maximum effort during 30 seconds for the assessment of endurance. For the evaluation of trunk strength, the athlete was asked to flex the trunk from a standing position, grasp the bar of the back dynamometer with both hands and then lift the bar with maximum effort. Three repetitions of five seconds were performed with an interval of 10 seconds between repetitions. In the same position, the athlete was asked to lift the bar for 30 seconds for the assessment of endurance. The data were sampled at 400 Hz using a Miotool 400 device interface (Miotec®). In order to evaluate muscle strength was recorded the peak force and to evaluate muscle endurance was recorded the average force during each trial.

The assessment of the quadriceps femoris (Q) and hamstrings (H) was performed using a Biodex® (Biodex Medical Systems, Shirley, NY) isokinetic dynamometer. Athletes warmed-up on a stationary bicycle for five minutes. The seat was adjusted so that the hip would remain at an 85-degree flexion angle, and the axis of the device was aligned with the lateral intercondylar notch. Next, the subjects were positioned in the dynamometer with belts fastened at the torso, abdomen, and tested thigh in order to prevent undesired movements. The lever arm of the device was placed 20 mm above the medial malleolus. The selected protocol consisted of concentric contractions at 60º/s for five repetitions. The device was calibrated for each subject, starting from a fully flexed knee position and ending in a fully extended knee position, whereas the reference point was a 90-degree knee flexion angle. The lower limb was weighted for standardization purposes. After the initial procedures, the subject was instructed to perform five flexion and extension movements at a submaximal intensity in order to finish the warm-up and familiarization. To compare the groups, it was used the following variables: the symmetry index of strength between limbs and the agonist/antagonist ratio.

**Statistical Analyses**

SPSS 17.0 was used with a significance level of 5%. The data distribution was analyzed with the Kolmogorov-Smirnov test. The independent t-test and chi-square test were utilized to compare the groups.

**RESULTS**

The groups were homogeneous regarding weight, height, BMI, and duration of sports practice (Table 1). No athletes were excluded from the initial sample. There were no significant differences between the groups in terms of flexibility (p=0.089) (Table 1). However, a difference was observed in the isometric endurance of the trunk extensors (p=0.02); the PFs showed higher values. No statistical differences were observed for peak isometric handgrip strength and trunk extension (Table 2), postural stability (Table 3), or isokinetic variables (p > 0.05) (Table 4).
### Table 1. Sample characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>PF</th>
<th>GF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>23.2±15.6†</td>
<td>22.58±5.4†</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>83.26±6.9†</td>
<td>77.53±11.9†</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.73±0.05†</td>
<td>1.74±0.1†</td>
</tr>
<tr>
<td>Time of Practice (years)</td>
<td>5.20±4.2†</td>
<td>6.66±3.9†</td>
</tr>
<tr>
<td>Posterior Flexibility (cm)</td>
<td>34.84±7.4†</td>
<td>36.47±11.4†</td>
</tr>
<tr>
<td>Dominance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>19 (100%)</td>
<td>17 (89.5%)</td>
</tr>
<tr>
<td>Left</td>
<td>0</td>
<td>02 (10.5%)</td>
</tr>
<tr>
<td>Graduation (Belt color)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>0</td>
<td>01 (5.3%)</td>
</tr>
<tr>
<td>Blue</td>
<td>12 (63.2%)</td>
<td>07 (36.8%)</td>
</tr>
<tr>
<td>Purple</td>
<td>03 (15.8%)</td>
<td>06 (31.6%)</td>
</tr>
<tr>
<td>Brown</td>
<td>01 (5.3%)</td>
<td>03 (15.8%)</td>
</tr>
<tr>
<td>Black</td>
<td>03 (15.8%)</td>
<td>02 (10.5%)</td>
</tr>
<tr>
<td>Total</td>
<td>19 (100%)</td>
<td>19 (100%)</td>
</tr>
</tbody>
</table>

† mean ± standard deviation. PF: pass fighter; GF: guard fighter.

### Table 2. Comparison of balance variables between the groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Mean ± SD</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Stability DL</td>
<td>GF</td>
<td>6.65±3.26°</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>5.12±1.59°</td>
<td></td>
</tr>
<tr>
<td>Overall Stability non-DL</td>
<td>GF</td>
<td>6.34±3.37°</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>5.01±1.51°</td>
<td>0.15</td>
</tr>
<tr>
<td>Antero-Posterior Stability DL</td>
<td>GF</td>
<td>4.04±2.40°</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>3.01±1.02°</td>
<td></td>
</tr>
<tr>
<td>Antero-Posterior Stability non-DL</td>
<td>GF</td>
<td>3.51±1.94°</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>3.20±1.08°</td>
<td></td>
</tr>
<tr>
<td>Medial-Lateral Stability DL</td>
<td>GF</td>
<td>4.35±2.74°</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>3.29±1.06°</td>
<td></td>
</tr>
<tr>
<td>Medial-Lateral Stability non-DL</td>
<td>GF</td>
<td>4.57±2.94°</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>3.20±1.70°</td>
<td></td>
</tr>
</tbody>
</table>

PF: pass fighter; GF: guard fighter; DL: Dominant limb; Non-DL: Non-Dominant Limb. SD: standard deviation.

### Table 3. Comparison of variables of isometric muscle strength between groups (reported in Kilogram)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Mean ± SD</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak isometric handgrip strength DL</td>
<td>GF</td>
<td>56.64±20.73</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>56.31±20.99</td>
<td></td>
</tr>
<tr>
<td>Peak isometric handgrip strength Non-DL</td>
<td>GF</td>
<td>55.33±19.74</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>53.61±20.49</td>
<td></td>
</tr>
<tr>
<td>Handgrip isometric endurance DL</td>
<td>GF</td>
<td>32.58±10.67</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>34.54±15.44</td>
<td></td>
</tr>
<tr>
<td>Handgrip isometric endurance Non-DL</td>
<td>GF</td>
<td>32.32±10.78</td>
<td>0.91</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>32.78±13.97</td>
<td></td>
</tr>
<tr>
<td>Peak trunk extension isometric strength</td>
<td>GF</td>
<td>116.08±22.61</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>123.61±30.70</td>
<td></td>
</tr>
<tr>
<td>Trunk extension isometric endurance</td>
<td>GF</td>
<td>68.85±12.09</td>
<td>0.02*</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>81.33±19.13</td>
<td></td>
</tr>
</tbody>
</table>

Significant at 5% level. PF: pass fighter; GF: guard fighter; DL: Dominant limb; Non-DL: Non-Dominant Limb. SD: standard deviation.
DISCUSSION

In general, biomechanical differences among BJJ athletes with different combat styles were not observed. The only difference found was that PFs showed more isometric trunk extension endurance than GFs, which is plausible considering the movements involved in the most prevalent techniques of this combat style.

Flexibility

Most of the athletes showed higher flexibility levels than the average population in the same age level according to the standard levels proposed by the Canadian Standardized Test of Fitness (CSTF), which is also reported in the scientific literature, as being the way of knowledge that involves methodic and organized investigation for its operations in searching results that confirm or annul hypothetical propositions.

There were no differences in flexibility between the groups in this study. The authors hypothesized that GFs would have higher flexibility in the posterior chain muscles, such as: spinal paraspinals, hamstrings and calves muscles. Posterior chain flexibility is extremely important for Jiu-Jitsu athletes, particularly GFs. It was hypothesized that GFs would present more flexibility because they spend most time of the fight in supine position with hips flexed trying to create space for a submission. However, it must be noted that Jiu-Jitsu is a dynamic sport and even an athlete with a preferred combat style must sometimes resort to other combat strategies, so that GFs occasionally need to fight in standing position, which is common for PFs.

Isometric muscle endurance

The fact that PFs exhibit higher trunk extension isometric muscle endurance than GFs was the only statistically significant difference found, which is comprehensible if the biomechanics of the techniques that are most prevalent in this combat style are considered. The authors purpose that PFs require extreme trunk extensor muscle endurance because GFs spend most of the fight time trying to pull PFs to the ground in submission attempts. This difference is clinically important because a Jiu-Jitsu match can last up to 15-25 minutes.

No studies comparing trunk extensor muscle strength in PFs and GFs were found. However, a descriptive study of Jiu-Jitsu athletes concluded that these athletes exhibited higher trunk extensor isometric muscle strength as compared with judokas. These differences between athletes who utilize different fighting styles was not assessed in the current study, as the current study compared fighting styles within Jiu-Jitsu instead of comparing with other fighting modalities.

No significant difference was found between the groups regarding isometric variables for muscular endurance and peak handgrip strength. However,
one study demonstrated a significant difference in relation to handgrip strength in the intermittent isometric contractions test. This test consisted of performing three repetitions of a five-second handgrip with an interval of one minute between repetitions. The athlete was oriented to keep the shoulder adducted alongside the body, with the elbow in 90° of flexion and forearm and wrist in neutral position. The athlete was in a seated position with hips and knees in 90° of flexion and feet on the ground. It was observed that the Jiu-Jitsu athletes showed greater strength in the left hand, although hand dominance was not considered in this study. It is important to consider that study compared athletes with sedentary subjects, while a comparison between two groups of athletes with similar levels of strength and isometric muscular endurance was performed in the current study, with no significant differences between the groups being expected. Another study conducted by Vidal Andreatto et al. found a significant difference in handgrip endurance when athletes were wearing the kimono. In addition, the authors found a decrease in maximum isometric handgrip strength in both the dominant and non-dominant extremities after fights.

Jiu-Jitsu athletes exhibit higher handgrip strength values in the dominant hand when compared to rowers, aikido athletes, and non-athletes, as well as higher handgrip strength values in the non-dominant hand when compared to aikido athletes and non-athletes (p<0.05). These results seem to be reasonable because Jiu-Jitsu is a sport that requires holding maneuvers, so that repeatedly demanding handgrip strength. The results of the current study did not show any significant differences between groups, likely because the comparison was made between athletes of the same sport, and as already mentioned, the development of muscle strength and endurance in both combat styles is necessary.

Postural Stability
The athletes in the current study had no significant differences in dynamic postural stability. These results were expected because these athletes participated in the same sport and all had similar balance demands. No previous studies analyzing the dynamic postural stability of Jiu-Jitsu athletes were found. To date, only one study verified differences in postural control involving martial artists. This study found that black belt martial artists presented greater postural control than sedentary people.

Due to a lack of evidence, similarities between judo and Jiu-Jitsu were considered for this discussion. Judokas have better dynamic balance than non-athletes, while amateur judokas and dancers have better stability with open eyes than high-performance judokas, professional dancers and controls. For stability with eyes closed, only the judokas presented good results. However, another study using the BBS to evaluate balance did not find significant differences between judokas and non-athletes, despite the fact that they mentioned static and dynamic postural balance as crucial for defense and attack.

Isokinetic Muscle Strength
No studies analyzing the isokinetic muscle strength of the knee extensors and flexors in Jiu-Jitsu athletes were found. One study aimed to assess the strength of the knee extensors and flexors in judokas. When assessed using an isokinetic dynamometer at 90°/s, 180°/s, and 240°/s, judokas demonstrated a higher peak torque for the extensors and flexors of the supporting leg than those of the attacking leg (p<0.05). The agonist/antagonist ratio was normal in both limbs in the aforementioned velocities. In the current study, the athletes of both groups exhibited lower results than the normative values for the agonist/antagonist ratio (i.e., 60% in slow velocities: 60°/s to 180°/s – and 80% in high velocities: 300°/s to 450°/s). These results suggest that both groups had muscular imbalances considering agonist/antagonist ratio, demonstrating hamstrings deficits. Regarding the peak torque of the knee extensors and flexors, no significant differences among athletes with distinctive combat styles were observed.

Some authors have attempted to compare various styles of combat and verify the anthropometric and morphological characteristics of PFs and GFs. A study conducted by Baéz noted that PFs exhibit more mesomorphic bodies than GFs (ectomorphic), because PFs must assume more positions that require muscle strength during the fight, such as, staying over the knees to pull the opponent. PFs also need more strength due to being continuously trying to pass the guard of the opponent. A study performed
by Boscolo et al. did not find differences in joint mobility, stability, proprioception, strength and flexibility when comparing different combat styles.

The study design was a limiting factor because the cause and effect relationships were evaluated at same time. Therefore, authors suggest conducting a prospective cohort study to examine the causality between combat style and biomechanical variables. Another limitation is the fact that the assessment was conducted in only one professional team of BJJ, reinforcing that findings must be interpreted with caution because findings may be unique to the training and performance of that specific team.

CONCLUSION
No significant biomechanical differences were found between BJJ athletes with two different combat styles. PFs exhibited greater trunk extensor muscle endurance than GFs, while all other parameters were not different between groups. Even given a preferred combat style, BJJ athletes must practice and be prepared for a variety of situations, and this may be the reason there are no substantial biomechanical differences between athletes.

Clinical Relevance
In general, athletes and coaches choose a fighting style based on the biomechanical characteristics of the individual because they believe that physical factors are crucial in choosing the fighting style that will be developed by each athlete. However, this study showed no differences between athletes with a preference for the guard style and those with a preference for the pass style. Therefore, the choice of fighting style need not be influenced by these factors.

What is known about the subject
There are few studies comparing Brazilian Jiu-Jitsu athletes with different fighting styles, and most are of low methodological quality. The current evidence indicates that there may be physiological, morphological, and functional differences between these athletes. However, no study to date has compared the biomechanical characteristics of these athletes.

What this study adds to existing knowledge
In general, no significant biomechanical differences were found between BJJ athletes with the two above-mentioned combat styles. The specific training required for a given fighting style is not associated with biomechanical differences, regardless of the athlete’s preference.

REFERENCES


ABSTRACT

Background: Foam rollers, or other similar devices, are a method for acutely increasing range of motion, but in contrast to static stretching, do not appear to have detrimental effects on neuromuscular performance.

Purpose: The purpose of this study was to investigate the effects of different volumes (60 and 120 seconds) of foam rolling of the hamstrings during the inter-set rest period on repetition performance of the knee extension exercise.

Methods: Twenty-five recreationally active females were recruited for the study (27.8 ± 3.6 years, 168.4 ± 7.2 cm, 69.1 ± 10.2 kg, 27.2 ± 2.1 m²/kg). Initially, subjects underwent a ten-repetition maximum testing and retesting, respectively. Thereafter, the experiment involved three sets of knee extensions with a pre-determined 10 RM load to concentric failure with the goal of completing the maximum number of repetitions. During the inter-set rest period, either passive rest or foam rolling of different durations (60 and 120 seconds) in a randomized order was employed.

Results: Ninety-five percent confidence intervals revealed dose-dependent, detrimental effects, with more time spent foam rolling resulting in fewer repetitions (Cohen’s d of 2.0 and 1.2 for 120 and 60 seconds, respectively, in comparison with passive rest).

Conclusion: The results of the present study suggest that more inter-set foam rolling applied to the antagonist muscle group is detrimental to the ability to continually produce force. The finding that inter-set foam rolling of the antagonist muscle group decreases maximum repetition performance has implications for foam rolling prescription and implementation, in both rehabilitation and athletic populations.

Level of evidence: 2b

Keywords: Fatigue; performance; self-manual therapy; self-myofascial release
INTRODUCTION
When producing a net joint moment, the net external force applied to the joint is proportional to the force generated by the agonist muscle minus that of the antagonist.\(^1\) Essentially, greater antagonist activation reduces net force output, but is necessary for maintaining appropriate joint stability.\(^1\) Thus, greater net joint moments could potentially be achieved by inhibiting the co-activation of the antagonist muscle.

Static stretching of the agonist muscle group, especially of long duration, has been repeatedly shown to impede neuromuscular function\(^2\), including the repetition performance in resistance exercise.\(^3\)–\(^5\) Hypothetically, stretching the antagonist muscle group could therefore cause inhibition of the antagonist and thus augment the net joint moment, as the latter represents the difference between the moment generated by the agonist and antagonist, respectively.\(^1\) Three recent studies have indeed shown that to be the case.\(^6\)–\(^8\) Sandberg et al.\(^8\) showed that stretching the antagonist muscle group results in greater net knee extension moment production during isokinetic knee extensions at fast velocities, in addition to improvements in vertical jump height and power. However, investigators did not note any differences in electromyography (EMG) amplitude in vastus lateralis and biceps femoris muscles between static stretching and passive rest conditions. Similarly, Paz et al.\(^7\) did not observe any differences in EMG amplitude of pectoralis major, latissimus dorsi, biceps brachii, and triceps brachii muscles, but noted improvements in repetition performance during the seated row exercise following proprioceptive neuromuscular facilitation (PNF) stretching of the shoulder adductors. Lastly, Miranda et al.\(^6\) observed a superior effect of antagonist static stretching of pectoralis major compared to passive rest on repetition performance of the seated row exercise. Furthermore, stretching of the pectoralis major resulted in statistically greater latissimus dorsi and biceps brachii activation during the exercise.

Foam rollers, or other similar devices, are a method for acutely increasing range of motion (ROM), but in contrast to static stretching, do not appear to have detrimental effects on neuromuscular performance of the treated muscle group, as determined from net joint moments during maximum voluntary isometric contractions.\(^9\) A typical resistance training session may involve exercises of both agonist and antagonist muscle groups, or, in some cases, they may even be paired, a technique known as antagonist paired sets.\(^10\) Stretching the antagonist muscle group seems to increase the performance of the agonist muscle group.\(^6\)–\(^8\) However, stretching the antagonist muscle group may also have a detrimental effect on the performance of subsequent exercises for the aforementioned antagonist muscle groups. This issue may be avoided by using foam rollers, or similar devices, during the inter-set rest period. Therefore, the purpose of this study was to investigate the effects of different volumes of foam rolling (60 and 120 seconds) of the hamstrings during inter-set rest periods on repetition performance of the knee extension exercise.

METHODS
Subjects
Twenty-five recreationally active females (Table 1) were recruited for the study. The same population of subjects was used before in a different experiment.\(^11\) Females were recruited both out of convenience and to help narrow the gender disparity in sports and exercise medicine research.\(^12\) An a priori sample size calculation (\(\eta^2 = 0.34; \beta = 0.95; \alpha = 0.05\)) using G*Power\(^13\) found that six subjects would be adequate; however, in order to increase statistical power, 25 were recruited.\(^14\) Anthropometric data included body mass (Techline BAL – 150 digital scale, São Paulo, Brazil) and height (stadiometer ES 2030 Sanny, São Paulo, Brazil). Subjects were included if they had been involved in resistance training program for at least one year prior to the experiment and had experience with the knee extension exercise. Participants were free from any functional limitation or medical condition that could have compromised their health or confounded the results of the study. During the ten-day period of data collection, the subjects were instructed not to engage in any lower body resistance training exercise or other strenuous activity. Prior to the study, all participants were provided verbal explanation of the study and read and signed informed consent and Physical Activity Readiness Questionnaire.\(^15\) All
procedures were in accordance with Declaration of Helsinki and the study was approved by the Institutional Review Board of University Hospital Clementino Fraga Filho of the Federal University of Rio de Janeiro (57023616.7.0000.5257/16).

**Procedures**

**Ten repetition maximum testing**

Ten repetition maximum was determined similar to Maia et al. Participants were sat on a knee extension machine (Selection Line Leg Extension, Technogym, Cesena, Italy), with the lumbar spine in contact with the back support, and ankle in slight dorsiflexion. Range-of-motion was between 100 degrees of knee flexion and full extension (0 degrees). Participants initially performed a standardized warm up consisting of two sets of fifteen repetitions of knee extensions with approximately 50% of normal training load. After the warm up, ten-repetition maximum testing was performed. For the first trial, subjects increased their warm up load by 100% and adjusted the load as needed in the subsequent trials. Execution of the knee extension exercise was standardized by not allowing pauses between concentric and eccentric portions of the lift. A maximum of three trials were allowed per testing session, separated by three minutes of passive rest. Testing was then repeated on another day at least 48 hours later (retest). The higher load between the two testing days was considered as the 10 RM load. The 10 RM load was confirmed by calculating the intraclass correlation coefficient. In an effort to minimize the margin of error, the following strategies were adopted: a) all subjects received standardized instructions about the exercise technique and data collection, b) subjects received feedback as to their technique and were corrected if and when appropriate, and c) all subjects were always verbally encouraged. The knee extension apparatus used for 10 RM testing and during the experimental sessions was the same (Selection Line Leg Extension, Technogym, Cesena, Italy).

**Foam Rolling**

Foam rolling was performed using The Grid Foam Roller (Trigger Point Technologies, 5321 Industrial Oaks Blvd., Austin, Texas 78735, USA), which is composed of a hard inner core enclosed in a layer of ethylene vinyl acetate foam. This kind of foam roller has been shown to produce more pressure on the soft tissue than those made out of polystyrene foam. Foam rolling was performed bilaterally in a seated position while maintaining the knees extended but relaxed. The subjects were instructed to propel their body backward and forward on the foam roller, between ischial tuberosity and popliteal fossa in fluid, dynamic motions, while trying to exert as much pressure on the foam roller as possible. The pace of rolling was not controlled for.

**Figure 1. Foam rolling start position at ischial tuberosity (A) and foam rolling end position at popliteal fossa (B).**

**Table 1. Subject characteristics.**

| Age (years) | 27.8 ± 3.6 |
| Height (cm) | 168.4 ± 7.2 |
| Body mass (kg) | 69.1 ± 10.2 |
| BMI (m²/kg) | 24.2 ± 2.1 |
| RTE (months) | 23 ± 6.6 |
| Knee Extension 10RM (Test) (kg) | 70.7 ± 11 |
| Knee Extension 10RM (Retest) (kg) | 71.4 ± 11.2 |

BMI = Body Mass Index; RTE = Resistance Training Experience; ICC= Intraclass Correlation Coefficient for 10 RM test and retest
is recognized that this reduces internal validity, as the effects may potentially be pace-dependent, not controlling the pace also enhances ecological validity of the findings, as this kind of procedure better represents situations in practice.

**Experimental protocol**

During the experimental sessions, participants performed knee extensions to concentric failure with the pre-determined 10 RM load. A four-minute rest interval was employed between each consecutive set. Both the order of visits (PR and FR) and different foam rolling volumes (FR60 and FR120) were randomized in a randomized, counterbalanced fashion. For both conditions, three sets were performed with four minutes of rest between each set. The PR condition was performed with passive rest, and the FR condition was performed during the rest period between the sets. Both FR conditions were performed in the same day, following a 10-minute break between protocols to avoid fatigue.18,19 The number of repetitions in each set, and in total, was recorded for each condition.

**Experimental Approach to the Problem**

A randomized within-subject design was used. Subjects visited the laboratory on four occasions during a ten-day period with at least forty-eight hours between visits. During the first two visits, the subjects underwent a ten-repetition maximum (RM) testing and retesting, respectively. Following 10 RM testing, two experimental sessions followed in a randomized order, which included: 1) passive rest (PR), 2) in a randomized order, foam rolling for 60 seconds (FR60) and foam rolling for 120 seconds (FR120). Each experimental session consisted of three (PR condition) and six sets (FR condition) of knee extensions with 10 RM load to concentric failure, interspersed by four-minute rest intervals, during which FR or PR were performed with the goal of completing the maximum number of repetitions.

**Statistical analyses**

In order to identify within-set, between-protocol differences, 95% confidence intervals (CI) of the differences between each protocol were calculated.20 Normality of the differences was ensured using the Shapiro-Francia test. Rather than traditional null hypothesis statistical testing, 95% CI were used in order to prevent dichotomous interpretation of the results,21,22 to increase the likelihood of correct interpretation,21 and to allow for a more nuanced and qualitative interpretation of the data.23 For differences with a 95% CI that includes zero, the observed difference cannot be concluded to be due to chance alone; in other words, the observations are statistically different from one another when the 95% CI of differences does not include zero. Additionally, Cohen’s $d$ effect sizes were calculated using the formula $d = \frac{M_d}{s_d}$, where $M_d$ is the mean difference and $s_d$ is the standard deviation of differences. This calculation differs slightly from traditional Cohen’s $d$ calculations, in that this formula better represents within-subject differences, whereas the traditional Cohen’s $d$ formula is better for between-subject comparisons.24–26 Cohen’s $d$ effect-sizes were defined as small, medium, and large for 0.2, 0.5, and 0.8, respectively.27 The combination of effect-sizes and 95% CI will therefore allow for a more nuanced and less polarizing interpretation of the results of the study.

**RESULTS**

The means and standard deviations of the number of repetitions performed during each set across all conditions are presented in Table 2.

Mean differences with accompanying 95% CIs and effect sizes are reported in Table 3. On average, the number of repetitions completed in the PR condition was statistically greater than in the FR60 and FR120 conditions as 95% CIs did not include zero (Table 3). This difference was greater by 5.7% and 9.2%, respectively. Furthermore, the number of repetitions completed in FR60 was statistically greater than in the FR120 condition by 3.5%.

During the first set, the number of repetitions completed in the PR condition was statistically greater than the number of repetitions performed in both the FR60 and FR120 conditions by 5.2%; however, no observable statistical differences existed between the FR120 and FR60 conditions as 95% CI included zero (Table 3, Figure 1a).

During the second set, the number of repetitions completed in the PR condition was statistically
greater than the number of repetitions performed in the FR60 and FR120 conditions as 95% CIs did not include zero (Table 3). This difference was greater by 4.2% and 8.1%, respectively. Furthermore, the number of repetitions performed in the FR60 condition was statistically greater than in the FR120 condition by 3.9% (Figure 1b).

During the third set, the number of repetitions completed in the PR condition was statistically greater than the number of repetitions performed in the FR60 and FR120 conditions as implied by 95% CIs not including zero (Table 3). This difference was greater by 7.9% and 15.0%, respectively. Finally, the number of repetitions completed in the FR60 condition was statistically greater than the number of repetitions performed in the FR120 condition (Figure 1c) by 7.1%.

Since the number of repetitions differed between conditions on the first set (Table 2), data for the subsequent sets were normalized accordingly (Table 4). When normalized to the performance of the first set, statistically greater number of repetitions was only performed in the FR60 when compared to the FR120 condition during the second set (Table 4). During the third set, the number of repetitions completed in the FR120 condition was statistically lower when compared to the FR60 and PR conditions (Table 4).

### Table 2. Means ± standard deviations for repetitions in each set of each condition.

<table>
<thead>
<tr>
<th>Set 1</th>
<th>Set 2</th>
<th>Set 2/Set 1</th>
<th>Set 3</th>
<th>Set 3/Set 1</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>PR</td>
<td>10.24 ± 0.44</td>
<td>9.72 ± 0.54</td>
<td>0.95 ± 0.05</td>
<td>9.48 ± 0.51</td>
<td>0.93 ± 0.06</td>
</tr>
<tr>
<td>FR60</td>
<td>9.72 ± 0.46</td>
<td>9.32 ± 0.70</td>
<td>0.96 ± 0.06</td>
<td>8.76 ± 0.72</td>
<td>0.90 ± 0.06</td>
</tr>
<tr>
<td>FR120</td>
<td>9.72 ± 0.46</td>
<td>8.96 ± 0.73</td>
<td>0.92 ± 0.06</td>
<td>8.16 ± 0.62</td>
<td>0.84 ± 0.06</td>
</tr>
</tbody>
</table>

PR = passive rest, FR60 = foam rolling for 60 seconds, FR120 = foam rolling for 120 seconds, Set 2/Set 1 = repetitions in set 2 normalized to repetitions in set 1; Set 3/Set 1 = repetitions in set 3 normalized to repetitions in set 1; Average = the number of repetitions across all sets for each condition.

### Table 3. Mean differences between conditions, 95% confidence intervals and effect sizes (Cohen’s d) across all sets.

<table>
<thead>
<tr>
<th></th>
<th>Set 1 Mean diff</th>
<th>95% CI</th>
<th>Set 2 Mean diff</th>
<th>95% CI</th>
<th>Set 3 Mean diff</th>
<th>95% CI</th>
<th>Average Mean diff</th>
<th>95% CI</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR60 – PR</td>
<td>−0.52</td>
<td>0.76, −0.28 *</td>
<td>1.2</td>
<td>−0.76</td>
<td>−0.78, −0.02 *</td>
<td>0.6</td>
<td>−0.72</td>
<td>−1.11, −0.33 *</td>
<td>1.2</td>
</tr>
<tr>
<td>FR120 – PR</td>
<td>−0.52</td>
<td>0.79, −0.25 *</td>
<td>1.2</td>
<td>−0.76</td>
<td>−1.14, −0.38 *</td>
<td>1.2</td>
<td>−1.32</td>
<td>−1.65, −0.99 *</td>
<td>2.3</td>
</tr>
<tr>
<td>FR60 – FR120</td>
<td>0.60</td>
<td>0.36</td>
<td>0.05, 0.67 *</td>
<td>0.5</td>
<td>0.60</td>
<td>0.17, 1.03 *</td>
<td>0.9</td>
<td>0.32</td>
<td>0.06, 0.58 *</td>
</tr>
</tbody>
</table>

* illustrates statistically different as CI does not include 0; ‘Mean diff’ = mean difference, ‘Average’ = between-protocol differences in the number of repetitions across all sets, ‘d’ = Cohen’s d.

### Figure 2. Differences in repetitions during the first (A), the second (B) and the third set (C), including 95% confidence intervals.
DISCUSSION

In contrast to the previous literature on static stretching of the antagonist muscle group,6-8 foam rolling the antagonist muscle group had a detrimental, dose-dependent effect on strength endurance in knee extensions performed to momentary muscular failure. Interestingly, not only was there a dose-dependent response, but the response was additive; that is, the magnitude of the differences between the conditions increased with each set, rather than there being a static difference with each set. However, these effects were limited to the condition with the greatest volume (FR120) when data was normalized to the performance of the first set.

While the mechanisms by which foam rolling acutely increases ROM are not fully understood, a number of mechanisms have been proposed. Briefly, these mechanisms can be divided into two categories: mechanical and neurophysiological.9 The former has been purported to be mediated by changes in fascial adhesions, piezoelectricity, cellular responses, myofascial trigger points, and/or thixotropic and viscoelastic properties of tissue, resulting in an increase in tissue compliance, and therefore, ROM.9 At present, these mechanisms are not supported by the literature. For example, Vigotsky et al28 found no changes in rectus femoris length in the modified Thomas test following a foam rolling intervention, which is a proxy measure of passive stiffness. Similar effects have been noted following massage,29,30 and the global effects following foam rolling further support this hypothesis.31 Moreover, in this study, because an increase in tissue compliance would result in a decrease in the knee flexion moment contribution from the hamstrings, one can surmise that the net knee extension moment would increase, allowing the quadriceps to perform less mechanical work over the set and thus complete more repetitions; however, this was not observed.

Neurophysiological mechanisms can be divided into two subcategories, consisting of spinal and supraspinal mediators. The former involves mechanoreceptors within the muscle and fascia, which, when triggered, have inhibitory effects, such as decreasing muscle tone.9 While some studies exist to suggest that there are muscle inhibitory mechanisms with massage,32,33 the findings of Vigotsky et al28 suggest that any decrease in muscle tone following a foam rolling intervention is not enough to allow greater joint angular excursion for a given moment, thus rendering it clinically insignificant. In the case of this present study, presumably a muscle inhibitory response would have allowed subjects to perform a greater number of knee extensions following the intervention, but this was not observed. Supraspinal mediators, such as central pain modulation or descending noxious inhibitory control, have been professed to modulate perception via noxious input, resulting in an increase in stretch tolerance.31,34 It may be that some increases in ROM following foam rolling do, in fact, occur through mechanical mechanisms or spinal reflex arcs, but these are either clinically irrelevant in and of themselves, or are shadowed by supraspinal responses. In the case of manual therapy, especially more noxious variations, a descending inhibitory response is elicited via endogenous opioids and other neuropeptides acting on the periaqueductal grey and rostral ventromedial medulla.34 Opioid activity is uniquely important during fatiguing conditions, such as those in this study, as activation of opioid-modulated path-

| Table 4. Mean differences between conditions normalized to the first set and the accompanying 95% confidence intervals and effect sizes (Cohen’s d). |
|---------------------------------|---------------------------------|----------------|----------------|---------------------------------|----------------|----------------|
|                                | Set 2                            | d  | 95% CI          | Mean diff   | 95% CI          | d  | 95% CI          |
|--------------------------------|---------------------------------|----------------|----------------|---------------------------------|----------------|----------------|
| FR60 – PR                       | 0.009                           | 0.2 | −0.021, 0.040   | −0.026       | −0.057, 0.006       | 0.4 |
| FR120 – PR                      | −0.028                          | 0.5 | −0.062, 0.006   | −0.087       | −0.121, −0.052*     | 1.4 |
| FR60 – FR120                    | 0.037                           | 0.6 | 0.006, 0.068*   | 0.061        | 0.019, 0.103*       | 1.0 |

(*) illustrates statistically different as CI does not include 0; ‘Mean diff’ = mean difference, ‘d’ = Cohen’s d.
ways may attenuate afferent motor feedback from agonist musculature, resulting in greater power output in the beginning of an exercise, which eventually leads to excess peripheral muscle fatigue. This may be the mechanism by which repetitions decreased with larger doses of foam rolling, but this cannot be said conclusively since work rates were not measured. While there have been a number of studies on power output following foam rolling in non-fatiguing conditions, only one exists during fatigue, which examined the effects of foam rolling on Wingate power output, but those findings were unclear and equivocal. More data are needed to confirm the hypothesis that descending modulatory circuits are at play, as they may explain the findings of this present study.

Analgesia induced by manual therapies has been suggested to be at least partially mediated by the autonomic nervous system (ANS); that is, a shift from sympathetic to parasympathetic tone, which has been associated with increases in ROM. The mechanism by which these ANS shifts occur is unclear, but massage has been associated with changes in both stress hormones, such as cortisol, and neuropeptides, endogenous opioids, oxytocin, and endocannabinoids. These hormones and neuropeptides are also responsible for regulating the ANS; specifically, the aforementioned neuropeptides that are associated with a sympathetic shift also play a role in descending modulatory pathways. A sympathetic shift would likely hinder performance, as parasympathetic shifts appear to augment performance. Despite the logical basis for the aforementioned neurophysiological mechanisms, more research is needed to elucidate their presence and role following a foam rolling intervention. Additionally, the present investigation did not involve assessment of pain and biomarkers to elucidate the mechanisms of fatigue. Thus, readers should note that the discussion related to the mechanisms is speculative at this point.

There is a possibility that the effort required to foam roll was fatiguing, as foam rolling is not a passive task. This possibility was not ruled out by ways of questionnaires or any other means. Considering that adverse effects on maximum repetition performance were found in a dose-response manner, and that these adverse effects were limited to the 120-second condition when the data were normalized to the number of repetitions in the first set, an argument could certainly be made that the present results are confounded by the procedure in question. Furthermore, the protocol in the present study did not involve a sham group in order to exclude this possibility. However, a study has used a planking exercise as a control condition for foam rolling of the quadriceps muscle, due to similarity of isometric holds between the aforementioned activities, and found that perceived exertion was higher during the planking condition when compared to foam rolling. In fact, the authors argued that foam rolling may actually lower perceived ratings of fatigue. In the present study, an argument can also be made that comparing foam rolling to passive rest, rather than a sham or some other control condition, increases ecological validity.

There are a number of limitations to note in the interpretation of this study. First, the 60- and 120-second conditions were performed on the same day, albeit randomized. While presumably randomization would have likely minimized methodological concerns, the group means likely decreased as a result. In addition, this partially convolutes the repeated-measures, as there may have been more variation as to whether, and how much, repetitions decreased with foam rolling. Secondly, all participants were female, so caution should be exercised when trying to extrapolate these results to males. Given that females are less fatigable than males during dynamic contractions, females may have more room for fatigue in studies of this nature.

CONCLUSION
The finding that inter-set foam rolling of the antagonist muscle group decreases maximum repetition performance has implications for foam rolling prescription and implementation, in both rehabilitation and athletic populations. For the purposes of performance and likely adaptation, foam rolling should not be applied to the antagonist muscle group between sets of knee extensions. Moreover, more inter-set foam rolling, i.e. 120 seconds and likely longer, appears detrimental to the ability to continually produce force.
REFERENCES


ABSTRACT

Background: Kinesiology Taping (KT) may promote changes in muscle strength and motor performance, topics of great interest in the sports-medicine sciences. These characteristics are purported to be associated with the tension generated by the KT on the skin. However, the most suitable tension for the attainment of these strength and performance effects has not yet been confirmed.

Hypothesis/Purpose: The purpose of the present study was to analyze the effects of different tensions of KT on the isometric contraction of the quadriceps and lower limb function of healthy individuals over a period of seven days.

Study Design: Blind, randomized, clinical trial.

Methods: One hundred and thirty healthy individuals were distributed into the following five groups: control (without KT); KT0 (KT without tension); KT50; KT75 and KT100 (approximately 50%, 75% and 100% tension applied to the tape, respectively). Assessments of isometric quadriceps strength were conducted using a hand held dynamometer. Lower limb function was assessed through Single Hop Test for Distance, with five measurement periods: baseline; immediately after KT application; three days after KT; five days after KT; and 72h after KT removal (follow-up).

Results: There were no statistically significant differences ($p > 0.05$) at any of the studied periods on participants’ quadriceps strength nor in the function of the lower dominant limb, based on comparisons between the control group and the experimental groups.

Conclusion: KT applied with different tensions did not produce modulations, in short or long-term, on quadriceps' strength or lower limb function of healthy individuals. Therefore, this type of KT application, when seeking these objectives, should be reconsidered.

Level of Evidence: 1b

Keywords: Kinesiology taping; athletic performance; muscle strength dynamometer; lower limb function
INTRODUCTION

Kinesiology taping (KT) was first used in 1973 by Kenzo Kase, although its popularity increased significantly after the 2008 Beijing Olympics.\(^1\) Currently, KT is applied in a wide range of clinical and sports-related conditions, with purported benefits including: changes of muscle function, improvements in blood and lymphatic flow, decrease in pain, provision of joint support, and an increase in skin and proprioceptive stimuli.\(^2,3\)

The adhesive tape used in KT applications differs from other types of bandages and techniques since it does not harm the skin, it can be used for up to five days, has elastic and movement properties that are very similar to human skin, and it can be stretched to up to 140% of its original length.\(^3,5\) There are reports in the literature showing modulations in muscle strength and motor performance after KT application, the exact characteristics sought by the athletic community and, the focus of research in both orthopedic and sports medicine fields.\(^4,6-8\) These effects have been described as being related to the continuous tensioning of the skin by the tape, therefore activating the skins' mechanoreceptors and stimulating the central nervous system modulatory mechanisms, thereby increasing muscle excitability.\(^9,10\)

Nevertheless, there are very few studies that have tested different tensions of KT application aiming to examine the effects of these sensory and modulatory stimuli. In addition, many of these studies, which have presented positive results, involved use, assessments and effects over short-term applications of KT, usually with a small number of participants, analyzed using very specific evaluation methods, which may have led to results that were influenced by tests that favored familiarity in their execution. Thus, there is a lack of accurate data concerning the effects of the application of KT, particularly in relation to stimulation of the skin mechanoreceptors and muscle recruitment.\(^10,12\)

Therefore, the purpose of the present research was to analyze the effects of different KT tensions on quadriceps femoris strength and lower limb function of healthy individuals over a period of seven days. The authors aim to providing precise data concerning the effects of the clinical application of KT.

METHODS

This study was approved by The Research Ethics Committee of Universidade Nove de Julho (UNINOVE) - protocol number 456.617.

Participants

Initially, 150 healthy individuals were pre-selected from institutions where the authors work. Men and women who had no complaints or pain at the lumbar spine and lower limb, who did not exercise on a regular basis, who did not have any history of allergies to their bandages and were available to participate in the proposed assessments, were pre-selected. All participants read and signed a consent form and attested their free participation in the study. The following exclusion criteria were applied: a history of surgery or fractures of the lumbar spine, neurological abnormalities, a history of previous knee pain, and lower limb muscle injuries in the 12 months prior to this study.\(^13\) In total, 130 individuals (65 men and 65 women) aged between 20 and 40 years of age, (average ± SD: 29.20 ± 0.77 years of age; height: 1.69 ± 0.01 m; weight: 70.24 ± 0.95 kg) reached the inclusion criteria and were selected to make up the study sample.

Procedures

Following selection, all of the participants were submitted to initial clinical interview. During this assessment, the following personal data were collected: name; age; height; weight; and dominant lower limb (the preferred limb used for kicking a ball).\(^14\) Subsequently, the assessment of the basic muscle strength and dominant lower limb function of all participants was performed. These assessments were conducted by the same examiner, who had no access to the data concerning to which group the individual was attached.

After these assessments the individuals were randomly distributed by means of a draw of sealed envelopes into the following five groups: Control Group – without KT; KT0 – application of KT without tension; KT50 – application of KT with approximately 50% tension; KT75 – application of KT with approximately 75% tension; and KT100 – application of KT with approximately 100% tension. All KT applications were performed on the quadriceps femoris of the dominant lower limb, aiming at stimulating it (see application section next). Thirteen men and 13 women (26 individuals in total) were
allocated to each of the five groups. Although the individuals were aware of the presence or absence of KT, they were unaware of the tension applied. They were asked not to discuss it with the examiner or with other participants.

**KT application**

In the experimental groups, KT was applied in accordance with the technique described by Kase et al with the objective of activating the quadriceps femoris, with initial anchoring at 10 cm below the anterior-superior iliac spine and final anchoring at the patella’s base. The individuals were requested to perform a maximal extension of their knee in order to obtain length measurements and to make KT final adjustments prior to its application (Figure 1).4,6,15-18

In order to determine the tension imposed during the KT application, the examiner measured the distances between the application points (origin and insertion) of all individual’s quadriceps. After that, the “mathematical rule of three” was used in order to determine and individualize the length of the tape. Finally, KT was applied on each individual's quadriceps according to the tension pre-established for the individual's group (Figure 2).

The same type of KT (black color) was used in all experimental groups (Kinesio Tex™ – Albuquerque, NM). All KT applications were performed by the same examiner, a licensed physical therapist with ten years of experience in the musculoskeletal practice environment, who had achieved the full international kinesiology taping credential. Prior to the application of the adhesive tape, all participants' skin was shaved and cleaned with an antiseptic. All applications were conducted with the participant in supine position, keeping the knee flexed and beyond examination table lateral limits, with the hip in a neutral position.

**Assessments**

The assessments of muscle strength and dominant lower limb function of all participants were carried out, using the same order at the following time periods: Baseline – 72 hours before the application of KT; T1, T3 and T5 – immediately after the application of KT, three days later and five days later, respectively; and 72 hours after the tape had been removed (Follow-Up). The tape was removed immediately after the completion of the T5 assessment. Thus, the participants wore KT for five consecutive days.3 The participants were instructed to continue their normal daily routines while wearing the adhesive tape. Individuals in the control group were assessed at the same time points as those in the experimental groups and received the same instructions.

Prior to beginning the present study, a pilot study was performed to assess the reproducibility and viability of assessing quadriceps strength using a handheld dynamometer. In this pilot study, five healthy individuals who did not exercise on a regular basis (10 lower limbs: five dominant and five non-dominant) were analyzed in a seven days interval. These individuals were tested using the same methods as described herein and the results obtained demon-
strated an excellent reproducibility for hand held dynamometry of the quadriceps femoris, with an intraclass coefficient of correlation (ICC) of 0.96.

Quadriceps femoris strength (maximal isometric voluntary contractions) was assessed using a manual dynamometer (Lafayette Instrument Company, Lafayette, IN). Participants were positioned on an extensor chair with their hips at 90° flexion and 0° rotation, and the knee flexed at 60°. A three-point belt was used to stabilize the torso and hips of the participants during the test. In assessments, the participants were asked to keep their arms folded in front of their torso. The dynamometer was positioned on the anterior region of the tibia, 2.5 cm above the lateral malleolus. A nylon belt was positioned perpendicularly to the application of force in order to stabilize the dynamometer and resist the force generated by the participants' quadriceps (Figure 3). Participants received standard verbal instructions to exert maximal force during the measurements. A submaximal voluntary contraction was first performed, so that they could familiarize themselves with the test, and was then followed by two measurements of maximal voluntary contraction (five seconds each), with intervals of 30 seconds between each attempt.

After a five-minute interval, the participants’ dominant lower limb function was assessed using the Single Hop Test for Distance. The participants were positioned in single limb support at a starting point, with their arms crossed behind the torso, and encouraged to jump as far as possible from the start point, while still able to land on the lower limb being assessed and remain stable for at least two seconds. Each individual had two attempts and the data were then analyzed. Prior to the collection of these data, all participants performed as many jumps as they felt were necessary to familiarize themselves with the test. The individuals were barefoot during the performance of the test and the distance was always measured from hallux to hallux (Figure 4).

Data analysis
Muscle strength assessments were normalized by body mass using the following formula: (muscle strength [kg] / body mass [kg]) x 100. The average value from the two attempts at the muscle strength assessments and the Single Hop Test for Distance were used in the analysis.

The Shapiro-Wilk test was used to confirm the normality of the data. The mean effects of the intervention and the differences in muscle strength and lower limb function – at the five assessment time points – between the groups were calculated using one-way ANOVA and the Bonferroni post-hoc adjustment. The statistical significance level was set at 5% (p < 0.05). The statistical analysis was conducted using version 19 of the Statistical Package for the Social Sciences (SPSS).

RESULTS
The groups in the present study were homogenous, since no statistically significant differences (p > 0.05) were found in terms of their demographic characteristics and the strength and function values (Table 1). During the study, 18 individuals' did not complete the assessment protocol and their data were lost to follow up, six from the Control Group (3 men and 3 women), six from the KT0 group (5 men and 1 woman) and six from the KT50 group (5 men and 1 woman), due to their failure to appear at one of the assessments. Thus, the data for 112 individuals were used in the final analysis (Figure 5).

Table 2 presents the data obtained for the muscle strength tests and lower limb function of individuals analyzed in all study groups.
Comparisons ($p > 0.05$) were observed in the comparisons between the data for Single Hop Test for Distance in the control group and in the other experimental groups (KT0, KT50, KT75 and KT100) at any of the assessment time points (Table 4).

**DISCUSSION**

The purpose of this blind, randomized, clinical trial was to determine the effects of different tensions of KT application on quadriceps strength and lower limb function of healthy individuals over a period of seven days. In the present study, the different tensions of KT application did not promote changes in the participants' quadriceps strength, given that no statistically significant differences ($p > 0.05$) were found in the comparisons between the data obtained in the control group and each of the other experimental groups (KT0, KT50, KT75 and KT100) at any of the assessment time points (Table 3).

**Lower limb function**

The lower limb function of the participants was also not affected by KT, as no statistically significant differences ($p > 0.05$) were observed in the comparisons between the data for Single Hop Test for Distance in the control group and in the other experimental groups (KT0, KT50, KT75 and KT100) at any of the assessment time points (Table 4).

**Table 1.** Sample demographic characteristics and descriptive data for muscle strength, and lower limb function. Reported as number (%) or mean (SD)

<table>
<thead>
<tr>
<th></th>
<th>Control N=20</th>
<th>KT0 N=20</th>
<th>KT50 N=20</th>
<th>KT75 N=26</th>
<th>KT100 N=26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>10 (50%)</td>
<td>08 (40%)</td>
<td>08 (40%)</td>
<td>13 (50%)</td>
<td>13 (50%)</td>
</tr>
<tr>
<td>Female</td>
<td>10 (50%)</td>
<td>12 (60%)</td>
<td>12 (60%)</td>
<td>13 (50%)</td>
<td>13 (50%)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>28.3 ± 3.1</td>
<td>29.2 ± 1.8</td>
<td>28.7 ± 2.1</td>
<td>29.5 ± 1.4</td>
<td>30.3 ± 2.6</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.70 ± 0.10</td>
<td>1.68 ± 0.12</td>
<td>1.68 ± 0.08</td>
<td>1.69 ± 1.13</td>
<td>1.70 ± 0.06</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>71.5 ± 16.9</td>
<td>68.9 ± 15.9</td>
<td>66.9 ± 12.1</td>
<td>70.4 ± 15.7</td>
<td>70.5 ± 15.4</td>
</tr>
<tr>
<td>Hop Test (m)</td>
<td>1.37 ± 0.28</td>
<td>1.20 ± 0.28</td>
<td>1.34 ± 0.32</td>
<td>1.37 ± 0.28</td>
<td>1.27 ± 0.25</td>
</tr>
<tr>
<td>Quad Strength (kg/f)</td>
<td>47.8 ± 12.2</td>
<td>45.9 ± 13.2</td>
<td>48.3 ± 15.2</td>
<td>45.4 ± 10.5</td>
<td>54.4 ± 9.2</td>
</tr>
</tbody>
</table>

Quad Strength – quadriceps strength; m – meters; kg – kilograms; kg/f – kilograms/force; SD – standard deviation
Figure 5. Flow-chart of the participants’ distribution and the final data analyzed.

Table 2. Muscle strength and lower limb function at all time-points analyzed, reported as means (SD)

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Groups</th>
<th>Baseline</th>
<th>T1</th>
<th>T3</th>
<th>T5</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>47.8 (12.2)</td>
<td>50.6 (13.0)</td>
<td>49.5 (11.3)</td>
<td>49.5 (12.3)</td>
<td>46.3 (11.1)</td>
</tr>
<tr>
<td></td>
<td>KT0</td>
<td>45.9 (13.2)</td>
<td>45.4 (12.0)</td>
<td>47.0 (12.8)</td>
<td>47.3 (11.9)</td>
<td>46.3 (12.8)</td>
</tr>
<tr>
<td>Quad Strength</td>
<td>KT50</td>
<td>48.3 (15.2)</td>
<td>47.8 (16.6)</td>
<td>46.7 (15.4)</td>
<td>47.9 (17.3)</td>
<td>48.5 (12.9)</td>
</tr>
<tr>
<td></td>
<td>KT75</td>
<td>45.5 (10.5)</td>
<td>45.4 (12.5)</td>
<td>45.1 (13.3)</td>
<td>49.3 (10.8)</td>
<td>46.9 (11.1)</td>
</tr>
<tr>
<td></td>
<td>KT100</td>
<td>54.4 (9.2)</td>
<td>50.9 (9.2)</td>
<td>49.9 (9.0)</td>
<td>53.1 (9.9)</td>
<td>52.9 (10.3)</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>136.8 (28.5)</td>
<td>137.4 (30.9)</td>
<td>136.1 (32.7)</td>
<td>136.3 (31.6)</td>
<td>138.6 (31.7)</td>
</tr>
<tr>
<td></td>
<td>KT0</td>
<td>120.2 (28.6)</td>
<td>121.4 (26.8)</td>
<td>122.1 (28.7)</td>
<td>122.3 (26.7)</td>
<td>136.7 (31.9)</td>
</tr>
<tr>
<td>Hop Test - X</td>
<td>KT50</td>
<td>134.1 (32.3)</td>
<td>138.7 (33.7)</td>
<td>137.0 (31.0)</td>
<td>138.5 (32.6)</td>
<td>141.5 (28.0)</td>
</tr>
<tr>
<td></td>
<td>KT75</td>
<td>136.7 (28.4)</td>
<td>143.3 (29.0)</td>
<td>141.9 (31.2)</td>
<td>141.7 (28.9)</td>
<td>134.3 (25.8)</td>
</tr>
<tr>
<td></td>
<td>KT100</td>
<td>126.6 (25.8)</td>
<td>131.7 (25.3)</td>
<td>133.4 (26.2)</td>
<td>135.9 (26.8)</td>
<td>134.3 (25.8)</td>
</tr>
</tbody>
</table>

Quad Strength – quadriceps strength; Hop Test – single hop test for distance; T1 – immediately after KT application; T3 – three days after KT; T5 – five days after KT; Follow-up – 72h after KT removal; † – mean; SD – standard deviation

Table 3. Data – mean (SD) from statistical comparisons between time points – for muscle strength

<table>
<thead>
<tr>
<th>Quad Strength</th>
<th>G1</th>
<th>G2</th>
<th>G1 - G2</th>
<th>Baseline</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>Follow-Up</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KT0</td>
<td>0.61</td>
<td>0.12</td>
<td>-9.51-5.69</td>
<td>0.20</td>
<td>-0.68</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KT50</td>
<td>0.89</td>
<td>-0.63</td>
<td>-7.10-8.09</td>
<td>0.49</td>
<td>-1.39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KT75</td>
<td>0.52</td>
<td>1.81</td>
<td>-9.43-4.86</td>
<td>0.17</td>
<td>0.09</td>
<td>-12.64</td>
<td>2.31</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KT100</td>
<td>0.07</td>
<td>0.49</td>
<td>-6.00-13.69</td>
<td>0.92</td>
<td>-1.28</td>
<td>-7.10</td>
<td>7.85</td>
<td>0.90</td>
<td>0.12</td>
<td>-6.87</td>
</tr>
</tbody>
</table>

Quad Strength – quadriceps strength; G1 – control group; G2 – experimental group; CI – confidence interval

The International Journal of Sports Physical Therapy | Volume 12, Number 1 | February 2017 | Page 90
musculoskeletal injury prevention based upon the results of their studies. However, the positive results obtained in these studies were achieved by means of study designs that favored the familiarization of the participants with the outcome measures, which may have had a direct effect on the muscle strength and performance results. Further, unlike the present investigation, these studies assessed amateur and professional athletes who complained of pain (patellofemoral pain syndrome and shoulder impingement syndrome) immediately after the application of KT, which prevents the inference of long-term results. Pain can affect muscle recruitment and modify the biomechanics of functional and sports-related movements. Thus, KT may have enabled altered muscle recruitment and performance of these athletes, given that they required interventions that would facilitate the recruitment of motor units, reduce pain and the consequent restoration of the strength, biomechanics and function of muscles. Several different theories have been proposed to explain how KT increases neuromuscular recruitment: the facilitation of neuromuscular stimuli, the activation of skin receptors by the tactile stimulus of the tape, an increase in blood flow, and the consequent muscle activity generated by the increase in the interstitial space created by the taping procedure. However, none of these explanations seemed to facilitate changes in the factors examined in the current research, even when greater tension of KT was applied. It is possible that the normalized neuromuscular recruitment of the healthy individuals assessed in the present study (without pain or neuromuscular deficits), as well as the absence of adhesive tape on the knee, could have contributed to the lack of effect in tactile stimuli and the alteration in motor unit recruitment, thus not offering support.

<table>
<thead>
<tr>
<th>Hop Test</th>
<th>G1</th>
<th>G2</th>
<th>Baseline</th>
<th>T1</th>
<th>T3</th>
<th>T5</th>
<th>Follow-Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1 - G2</td>
<td>Control</td>
<td>KT0</td>
<td>0.06</td>
<td>-1.89</td>
<td>-34.01</td>
<td>-0.76</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>KT50</td>
<td>0.75</td>
<td>-0.31</td>
<td>-10.16</td>
<td>14.61</td>
<td>0.89</td>
<td>-0.13</td>
</tr>
<tr>
<td></td>
<td>KT75</td>
<td>0.98</td>
<td>-0.01</td>
<td>-16.50</td>
<td>16.21</td>
<td>0.49</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>KT100</td>
<td>0.21</td>
<td>-1.24</td>
<td>-26.61</td>
<td>6.09</td>
<td>0.50</td>
<td>-0.66</td>
</tr>
</tbody>
</table>

Pain can affect muscle recruitment and modify the biomechanics of functional and sports-related movements. Thus, KT may have enabled altered muscle recruitment and performance of these athletes, given that they required interventions that would facilitate the recruitment of motor units, reduce pain and the consequent restoration of the strength, biomechanics and function of muscles. Several different theories have been proposed to explain how KT increases neuromuscular recruitment: the facilitation of neuromuscular stimuli, the activation of skin receptors by the tactile stimulus of the tape, an increase in blood flow, and the consequent muscle activity generated by the increase in the interstitial space created by the taping procedure. However, none of these explanations seemed to facilitate changes in the factors examined in the current research, even when greater tension of KT was applied. It is possible that the normalized neuromuscular recruitment of the healthy individuals assessed in the present study (without pain or neuromuscular deficits), as well as the absence of adhesive tape on the knee, could have contributed to the lack of effect in tactile stimuli and the alteration in motor unit recruitment, thus not offering support.
for the participants’ knees nor altering the function of their lower limbs.

Although no changes in muscle strength or lower limb function were found in the results of the present study, further studies with alternative applications of KT, as well as different populations and clinical situations, are necessary. The present study has several limitations, as it only assessed healthy individuals who did not participate in regular physical exercise. Therefore, these results cannot be extrapolated to injured populations. It well-known that athletes and people with injuries exhibit different biomechanical and muscle recruitment patterns than non-athletes and healthy people. In addition, the individuals assessed herein were not blinded in relation to their test conditions (the presence or absence of KT) and the tensions applied to the adhesive tape were not measured with a specific and validated instrument. Although the assessment methods used herein were valid and reproducible, other methods could be used to test muscle strength and lower limb function.

CONCLUSION

Different tensions of KT did not promote short nor long-term changes in isometric quadriceps strength or lower limb function of healthy individuals. Therefore, this type of KT application with for these clinical objectives needs to be reconsidered.

REFERENCES


ABSTRACT

**Background**: The Functional Movement Screen (FMS™) is a battery of tests designed to assess movement competency; the overhead deep squat test, specifically, has been shown to be an accurate predictor of overall FMS™ scores. Self-massage (SM) is a ubiquitous warm-up utilized to increase joint range of motion and, therefore, may be effective for improving performance of the overhead deep squat test.

**Purpose**: To examine how different doses (30, 60, 90, and 120 seconds) of SM of different areas of the body (plantar fascia, latissimus dorsi, and lateral thigh) affects the score obtained on an overhead deep squat test.

**Methods**: Twenty recreationally active females were recruited to be tested on four occasions: sessions one and two consisted of baseline testing, session three consisted of SM applied to the lateral thigh, and session four consisted of SM applied to the lateral torso and plantar fascia.

**Results**: In all SM conditions, at least 90 seconds was required for a change in deep squat score from baseline; therefore, it is concluded that SM the lateral torso, plantar fascia, and lateral thigh for 90 seconds or more are effective interventions for acutely improving overhead deep squat scores.

**Conclusion**: Self-massage appears to be an effective modality for inducing acute improvements in the performance of the FMS™ overhead deep squat in all conditions tested.

**Level of evidence**: 2b

**Keywords**: Flexibility, foam rolling, self-manual therapy, self-myofascial release, tennis ball
INTRODUCTION

The squat is a fundamental movement pattern that is required for numerous activities of daily living, such as sitting, lifting, and most sporting activities. Furthermore, it is a staple exercise in strength and conditioning programs that has been shown to increase performance, as well as being used in clinical rehabilitation programs. A prerequisite for more intense — that is, loaded — squat activities is the correct and consistent performance of a bodyweight squat.

The Functional Movement Screen (FMS™) is a pre-participation screening system comprised of seven “fundamental movement patterns” that require both stability and mobility, such as the overhead deep squat. Each movement pattern is given a score from 0 to 3, with 0 being given in the presence of pain; 1 if the individual is unable to perform the movement; 2 if the individual is able to perform the movement, but needs to compensate in some way; and 3 if the individual is able to perform the movement without any compensations.

The overhead deep squat component of the FMS™ was designed to assess bilateral symmetry (or lack thereof) and functional mobility of the hips, knees, and ankles. By adding the dowel held overhead, it also assesses bilateral, symmetrical mobility of the shoulders and thoracic spine, in addition to stability and motor control of the core musculature. Poor performance of this test can be the result of several factors including, but not limited to, poor glenohumeral and thoracic spine mobility, limited mobility in the lower extremity — e.g., poor closed kinetic chain dorsiflexion or poor hip flexion — and limited stability and/or motor control of the core musculature. Some evidence suggests that the overhead deep squat test can predict the overall FMS™ score and thus may provide a time-efficient assessment of individuals who may require further screening.

One of the potential deficits in the performance of the squat is limited mobility. More specifically, because the overhead deep squat involves large angular excursions of the ankles (dorsiflexion), knees (flexion), hips (flexion), and shoulders (flexion), competent performance of the overhead deep squat is predicated on the mobility of the aforementioned joints to flex and extend through large angular excursions. Restrictions to these movements may be attributable to extensors around these joints, in addition to ligaments, connective tissue, and, in some cases, structural variability, which provide resistive moments or endpoints; as such, warmups that increase the extensibility of these soft-tissues may be efficacious for improving the performance of the overhead deep squat. It is important to note, however, that such interventions may only be effective for limitations in mobility, but not stability.

Acutely, improvements in mobility can be achieved by self-massage (SM); i.e., using a foam roller, a roller massager, or tennis ball. Current literature on the dose-response of the acute effects of SM on changes in range-of-motion (ROM) remains equivocal. Sullivan et al. did not find statistically significant differences between different volumes of SM, but noted a trend for greater increases with greater volumes. Couture et al. did not find any difference in ROM changes between different volumes. However, in contrast to previous studies, Couture et al. also did not observe changes in ROM in comparison to baseline. This discrepancy may have been a function of the tool used, intensity (pressure) of SM, method used for ROM assessment, or pace.

At present, there are two primary, competing hypotheses as to the mechanisms by which self-massage improves ROM. The first is a mechanical perspective, which states that the act of self-massage deforms the tissues to which it is applied, which in turn will allow for greater extensibility of those tissues. The second is a neurophysiological perspective, which states that the sensory input provided by self-massage, such as noxious stimuli, elicits a central neurophysiological response, which either modulates perception, allowing for a greater ROM, or, alternatively, that the sensory input may decrease efferent drive and neural tone. If the central neurophysiological mechanism is indeed at least partially a driver of changes in joint ROM, then changes in ROM will occur at joints foreign to the ones being targeted, which has recently been shown to occur. Implicated by these findings is that mobility limitations during the overhead deep squat can be improved, no matter the structure to which self-massage is applied.
Therefore, the purpose of this study was to investigate the acute effects of different volumes of self-massage applied to the lateral thigh (Experiment 1) and lateral torso and plantar surface of the foot (Experiment 2) on the performance of the overhead deep squat test of FMS™. The lateral thigh was chosen because the underlying areas, i.e., iliotibial band and tensor fascia latae, have been suggested to be one of the common hindrances in the performance of the squat; the plantar surface of the foot and lateral torso were chosen because the latissimus dorsi may limit shoulder flexion, while, from a fascial perspective, the plantar surface of the foot may be related to ankle dorsiflexion ability. However, from a central, neurophysiological perspective, the area to which self-massage is applied should not matter. Therefore, limited extensibility of these areas may be associated with decreased hip flexion and/or extension, shoulder flexion, and dorsiflexion, respectively, and thus, increasing the extensibility of these areas may help individuals achieve greater scores on the overhead deep squat test. If shown to be effective, SM could be incorporated into corrective exercise programs that are designed to improve fundamental movement competency.

**METHODS**

**Subjects**

A convenience sample of twenty recreationally active, resistance-trained females were recruited and participated in both experiments (Table 1). No *a priori* sample size calculation was conducted due to the ordinal nature of FMS™ scores, so a convenience sample of 20 females was recruited. Anthropometric data included body mass (Techline BAL – 150 digital scale, São Paulo, Brazil) and height (Stadiometer ES 2030 Sanny, São Paulo, Brazil). Subjects were included if they had been involved in resistance training program for at least one year prior to the experiment, for an average of 40-50 minutes per session, 3-4 sessions per week, using loads with 8-12 repetitions maximum, and rest intervals between one and three minutes between sets. That way, familiarity with the squatting movement pattern was ensured in order to minimize the effect of learning. Participants were excluded if they had any experience with SM or a musculoskeletal or neuromuscular injury that could have affected their ability to perform the overhead squat; furthermore, participants were excluded if they scored 0 or 3 on the overhead deep squat test. Prior to the study, participants were provided a verbal explanation of the procedures and signed informed consent and Physical Activity Readiness Questionnaire. All procedures were in accordance with Declaration of Helsinki and the study was approved by the Institutional Review Board of University Hospital Clementino Fraga Filho of the Federal University of Rio de Janeiro.

**Procedures**

**Self-massage**

SM was performed using The Grid Foam Roller (Trigger Point Technologies, 5321 Industrial Oaks Blvd., Austin, Texas 78735, USA) and a tennis ball (Head Master, Belo Horizonte, Minas Gerais, Brazil). In Experiment 1, foam rolling was performed in a decubitus lateral position with the foam roller placed under the lateral side of the thigh. The leg being treated was extended, while the other was crossed over the treated leg in a flexed position. Participants were instructed to roll the lateral part of their thigh up and down on the foam roller, between the greater trochanter and lateral epicondyle of the knee, in dynamic motions, while trying to exert as much pressure on the foam roller as possible.

| Table 1. Subject characteristics. Data expressed as means ± SD. |
|---------------|-----------------|-----------------|
|               | Experiment 1*   | Experiment 2*   |
| N            | 20              | 20              |
| Age (years)  | 26.2 ± 6.4      | 26.3 ± 6.3      |
| BM (kg)      | 63.6 ± 10.2     | 63.4 ± 9.9      |
| Height (cm)  | 164.0 ± 6.9     | 164.0 ± 6.9     |
| BMI          | 23.4 ± 2.0      | 23.5 ± 2.1      |
| RTE (months) | 17.7 ± 3.7      | 20.0 ± 3.5      |

BM = body mass; BMI = body mass index, RTE = resistance training experience. *all subjects were females.
In Experiment 2, the lateral side of the torso and plantar surface of the foot were treated. For the former, foam rolling was performed in a decubitus lateral position. Participants were instructed to roll their lateral trunk up and down on the foam roller, between the proximal third of the arm and inferior part of the ribcage, while trying to exert as much pressure on the foam roller as possible. SM on the plantar surface of the foot was performed with a tennis ball in a standing position. These methods differ slightly from Grieve et al.12, in that Grieve et al.12 had participants perform SM while seated rather than standing, but standing likely results in greater pressure and, presumably, a greater effect. Participants were instructed to roll the tennis ball on the sole of the foot between the midfoot and proximal phalanges, while trying to exert as much pressure on the ball as possible. In both experiments, the order of treatment between the left and right limbs was randomized.

**FMS™ Overhead Deep Squat**

A full description of the overhead deep squat test (Figure 1) has been provided previously.18 Briefly, the individual begins standing with his/her feet approximately shoulder width apart with the dowel pressed overhead while keeping the elbows extended. The individual then descends as far into a squat as they can while maintaining an upright torso, heels on the floor, and the dowel pressed overhead. The descended position is then maintained for a count of one second before the individual is allowed to return to the starting position. If the score of ‘3’ has not been achieved (Figure 1, E and F), the individual proceeds to perform the same test with a 2x6 block under his or her heels. If a competent movement pattern is demonstrated, the individual receives a score of ‘2’ (Figure 1, C and D). Screening was always performed by the same experienced rater in both experiments. Experienced raters are expected to achieve acceptable reliability, particularly for overhead deep squat test.19 In order to ensure that the rater in this present experiment was adequate, test-retest reliability and minimum detectable change scores were calculated. Standardized test instructions were provided.18 Participants were allowed three trials and the best trial was recorded.

![Figure 1. FMS™ for overhead deep squat test. A and B = score 1; C and D = score 2; E and F = score 3.](image)

**Experimental approach to the problem**

A randomized (aleatory entry in latin square format) within-subject design was used for treatment (i.e., lateral thigh, lateral torso and plantar surface), as well as the experimental protocols. Two experiments were conducted, separated by roughly two to three months. For each experiment, the same participants visited the laboratory on four occasions at similar times during the day to avoid diurnal variations, with a minimum of ninety-six hours between visits. All procedures were performed barefoot and no additional warm-up was performed beforehand.

In Experiment 1 (Figure 2), participants visit the laboratory four times with 96-hours between visits. Anthropometric data was collected during the first visit. On the second and third visits, the participants underwent overhead deep squat testing (baseline 1)
and retesting (baseline 2), respectively. The experimental visit followed and consisted of four different, single-set SM with foam rolling protocols treating both lateral thighs unilaterally in a randomized order: P30 – thirty seconds of foam rolling per side, P60 – sixty seconds of foam rolling per side, P90 – ninety seconds of foam rolling per side, P120 – 120 seconds of foam rolling per side. A fifteen-minute interval was employed between each protocol, based on the findings that acute increases in ROM following SM are persistent for 10 minutes, but not longer. After each protocol, participants were scored on their performance of the overhead deep squat test.

In Experiment 2 (Figure 3), anthropometric data was collected during the first visit followed by assessment of the overhead deep squat performance on the second visit (baseline). Only a single day of testing for the overhead deep squat was performed for the second experiment because the data from the first experiment showed similar effects of different SM protocols when compared to baseline 1 and baseline 2 (see Results). On the third and fourth visits, participants performed SM of lateral torso and plantar surface of the foot, respectively, as per randomization. During each of these two visits, four different, single-set SM protocols (P30, P60, P90 and P120) were employed in a randomized order with a sixty-minute rest interval between each protocol: P30 – thirty seconds of self-massage per side, P60 – sixty seconds of self-massage per side, P90 – ninety seconds of self-massage per side, P120 – 120 seconds of self-massage per side. After each protocol, participants were scored on their performance of the overhead deep squat test.

**Statistical analyses**

Reliability was established using the baseline measures from the first two days of the first experiment and calculating test-retest intraclass correlation coefficients (ICC). From the ICCs, a minimum detectable change (MDC) at the 95% level was calculated. A Friedman nonparametric test was used to determine the effects of different experimental conditions on the dependent variable. If the null hypothesis was not accepted, pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. All analyses were performed using SPSS (version 21, SPSS Inc., Chicago, IL, USA). Statistical significance was set at an alpha level of 0.05.
RESULTS
Subject details are provided in Table 1. Using the baseline measures on the first two days, a test-retest ICC of 0.481 was found, which corresponds to a MDC of 1.00.

Experiment 1 – Lateral Thigh
Participants achieved a statistically greater score on the overhead deep squat test with P90 and P120 as compared to both the baseline 1 (p = 0.004 and p < 0.001, respectively) and baseline 2 (p = 0.020 and p = 0.001, respectively) values (Table 2, Figure 4). No other statistically significant differences were observed.

Experiment 2 – Lateral Torso and Plantar Surface of the Foot
For both conditions – that is, the plantar surface of the foot and lateral torso – participants achieved statistically greater scores on the overhead deep squat

<table>
<thead>
<tr>
<th>Condition</th>
<th>Volume</th>
<th>Median</th>
<th>Interquartile Range</th>
<th>Min</th>
<th>Max</th>
</tr>
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<tr>
<td>Baseline 1</td>
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<td>2 3</td>
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<td>Δ from Baseline 1</td>
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<td>0.75–1</td>
<td>0 2</td>
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</table>

SM – self-massage of the lateral thigh; P30 – thirty seconds of foam rolling for each side; P60 – sixty seconds of foam rolling for each side; P90 – ninety seconds of foam rolling for each side; P120 – 120 seconds of foam rolling for each side.
*Statistically different from baseline 1;
†Statistically different from baseline 2.

Figure 4. Box and whisker plots of the effects of foam rolling the lateral thigh on FMS™ squat score. * denotes a statistical difference from both Baseline 1 and Baseline 2.
test with P90 (p = 0.040 and p = 0.029, respectively) and P120 (p = 0.001 and p < 0.001, respectively) as compared to the baseline value (Table 3, Figure 5). Furthermore, participants achieved statistically greater scores with P120 as compared to P30 (p = 0.019 and p = 0.032, respectively). A greater score was also achieved when the lateral torso was treated for 120 seconds as compared to when the plantar surface of the foot was treated for 30 seconds (p = 0.011). There were no other statistically significant differences between conditions.

All statistical changes observed exceeded the calculated MDC.

**DISCUSSION**

The main findings of the present study were: 1) higher volumes (> 90 seconds) appear to be superior to lower volumes (< 90 seconds) for acutely improving performance of the FMS™ overhead deep squat test; 2) 90 seconds appears to be the necessary threshold to achieve these beneficial changes; 3) treatment of lateral side of the torso and plantar surface of the foot seem to be equally effective in inducing acute improvements in overhead deep squat test if done for sufficient time; i.e., 90 seconds.

Previously, research has not shown there to be a statistical difference between different volumes of SM for increasing ROM, but has noted a ‘trend’ for greater doses potentially inducing greater changes in ROM.\(^\text{10,11}\) The present study extends this observation by showing that greater volumes seem to be superior for inducing movement performance, which may be a result of acute changes in ROM. Moreover, the present study showed that 90 seconds appears to be the volume-threshold necessary to induce these changes, as 30- and 60-seconds were not found to result in a statistically different performance of the overhead deep squat test as compared to baseline. Interestingly, Bradbury-Squires et al.\(^\text{10}\) also found improvements in ‘movement efficiency’ following SM, as assessed by a decrease in electromyography amplitude during a lunge. The current findings could be considered in agreement with Bradbury-Squires et al.\(^\text{10}\) in the context that the FMS™ test battery has been suggested as an assessment tool for movement competency.\(^\text{18}\) In contrast, not only did Couture et al.\(^\text{13}\) show no

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**Table 3.** Differences between conditions and protocols for Experiment 2. Data expressed as medians with interquartile ranges.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Volume</th>
<th>Median</th>
<th>Interquartile Range</th>
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<th>Max</th>
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<tr>
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<tr>
<td></td>
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<td>3</td>
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<td></td>
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<tr>
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<td>0.75–1</td>
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</table>

PF – plantar surface of the foot; LTO – lateral torso; P30 – thirty seconds of self-massage for each side; P60 – sixty seconds of self-massage for each side; P90 – ninety seconds of self-massage for each side; P120 – 120 seconds of self-massage for each side.

*Statistically different from baseline; †Statistically different from P30; ‡Statistically different from PF P30.

**Figure 5.** Box and whisker plots of the effects of foam rolling the lateral torso (A) and plantar surface of the foot (B) on FMS™ squat score. * denotes a statistical difference from Baseline.
statistical difference between SM performed for two sets of 10 seconds and four sets of 30 seconds, but there were also no statistical differences in ROM as compared to baseline. This discrepancy could possibly be a function of the tool and intensity (pressure) used as well as methodology of ROM assessment. The latter was tightly controlled, as knee extension ROM was measured by restricting any contribution from other joints. Conversely, other studies have assessed ROM wherein contribution from other joints cannot be excluded. Similarly, in the present study, a complex, multi-joint movement was used, and it is unclear as to whether or not the same results would have been observed had the experimental procedure included a single-joint ROM assessment. With regard to the type of tool used, both Sullivan et al. and Bradbury-Squires et al. used a roller massager, while Couture et al. used a commercially-available foam roller made out of polystyrene foam. In contrast, in the present study, a uniformly cylindrical foam roller composed of a hard and hollow inner core enclosed with a layer of ethylene vinyl acetate foam was used. This type of foam roller has been shown to produce more pressure on area to which it is applied as opposed to those made of polystyrene foam. Sullivan et al. and Bradbury-Squires et al. also used a specifically-designed apparatus to control for pressure applied to the underlying tissue, and in doing so, increased internal validity of the results. On the other hand, both Couture et al. and the present study did not use a special device, but provided participants with similar instructions as to how pressure should be applied. While pressure relative to body weight was not measured in this present study, as opposed to Couture et al., it is possible that, as a function of different body parts being treated, the participants in the current study were able to induce greater pressure on the underlying tissue. However, it should to be noted that, to date, the effect of intensity (pressure) has not been explored in a tightly controlled setting and thus its effects remain unclear and require further exploration. However, preliminary evidence suggests that variations in pressure may exert different effects on active and passive ROM.

At present, the mechanisms by which SM induces acute changes in ROM have not been fully elucidated, but many have been proposed, including both mechanical and neurophysiological mechanisms. The former has been associated with changes in fascial adhesions, piezoelectricity, cellular responses, myofascial trigger points, and/or thixotropic and viscoelastic properties of the tissue, resulting in increased tissue compliance. However, Vigotsky et al. did not find any changes in rectus femoris length in the modified Thomas test, a proxy measure of passive stiffness, following SM intervention. Granted, participants were also taken through a rigorous dynamic warm-up which could have maximized the potential acute extensibility gains prior to testing. In addition, similar effects have also been observed following massage. Furthermore, the available evidence suggests that SM exerts global effects. The latter is also supported by the findings of this present study, as similar improvements in the overhead deep squat test were noted in all conditions tested. Taken together, findings from the aforementioned studies suggest that the mechanical contribution to changes in ROM following SM intervention needs to be reconsidered.

With regard to neurophysiological mechanisms, both spinal and supraspinal mediators have been considered. The former has been associated with mechanoreceptors within muscle and fascia and are suggested to have inhibitory effects when triggered, such as decreasing muscle tone. However, the findings of Vigotsky et al. suggest that any decrease in muscle tone following SM is insufficient to allow for greater ROM, thus rendering these mechanisms clinically insignificant. It may be that some increases in ROM following SM are a result of mechanical mechanisms or modulation of a spinal reflex arc, but these are likely clinically insignificant by themselves, or are predominated by supraspinal mediators. The latter, such as central pain modulation or descending noxious inhibitory control, have been asserted to mediate perception via noxious input and thus increase stretch tolerance.

Analgesic effects and relaxation following manual therapies have been suggested to be mediated by autonomic nervous system activity (ANS); i.e., a shift from sympathetic to parasympathetic tone, which has been associated with increases in ROM. The exact mechanism of this ANS shift is unclear; however, massage has been associated with changes in both stress hormones – for example, cortisol and neuropeptides – for example, endogenous
opioids, oxytocin, and endocannabinoids. Both of these appear to be responsible for regulating the ANS, and specifically, neuropeptides may play a role in descending modulatory pathways. Similarly, proxies of ANS activity have been found to change following SM. Given that SM has been shown to induce a noxious stimuli and that the participants were instructed to exert as much pressure as possible on the area under treatment, it is probable that changes observed in the present experiments were elicited as a result of a descending inhibitory response. It is equally probable that the observed changes were due to an ANS shift to parasympathetic tone. Considering that this present study found that there was a minimum volume-threshold to induce beneficial changes, it would seem prudent to hypothesize that a certain amount of time is needed for the response to take place. Despite the logical basis for the aforementioned mechanisms, it has to be noted that they are based solely on explanations available from the existing literature, and the present study was not designed to assess these mechanisms, and more research is required to elucidate their existence and role in SM, specifically, rather than extrapolating from the massage and manual therapy literature.

There are a number of limitations to note when interpreting the result of the present study. Firstly, no pre-intervention screen was performed on the day of testing and thus the comparisons were performed between days. Therefore, between-day variability in test scores could have confounded the results. Secondly, different SM conditions were performed on the same day interspersed by a 15-minute and 60-minute interval of passive rest during Experiments 1 and 2, respectively. While presumably, randomization would have likely minimized methodological concerns, it is possible that there was a learning effect to the performance of the test. Indeed, previous research has shown that the ‘control’ group can exhibit movement screen changes after 12 weeks without being subjected to the intervention program designed to improve the outcome scores. However, given that the participants were resistance trained and thus familiar with the squat pattern, the learning effect was likely smaller. In Experiment 1, a 15-minute rest-interval had been chosen based on the findings that acute increases in ROM following SM are persistent for 10 minutes, but not longer. However, a recent study suggested that changes can last up to 20 minutes, but this evidence was not available until after the experiment had been completed. For the second experiment, it was decided to extend the rest-interval to 60-minutes as to decrease the risk of carryover from previous trials. Nevertheless, no statistical differences were observed between protocols that would indicate a 15-minute interval to be insufficient and a confounding factor for repeated measures. Thirdly, while the overhead deep squat test has been shown to predict the overall FMS™ score, it is limited as to its ability to assess overall asymmetry. Moreover, the fact that the trials were not investigator-blinded should be taken into account, as FMS™ scores are a subjective, qualitative outcome that may be subject to bias; therefore, by knowing what and how much each subject foam rolled before scoring her, there may have been inherent bias. Lastly, the pace of rolling was not controlled for, thereby reducing internal validity of the results due to the possibility of pace-dependent outcomes. Nonetheless, not controlling for pace enhances ecological validity of the findings, as it is a better representation of the scenario in practice.

CONCLUSION
In conclusion, SM appears to be an effective modality for acute improvements in the FMS™ overhead deep squat performance, in all conditions tested; i.e., SM to the lateral thigh, plantar surface of the foot, and lateral side of the trunk. Furthermore, treatment lasting 90 seconds may be needed for beneficial changes to occur, with a slight possibility that longer durations may provide additional benefits. Whether the same modality is beneficial for chronic – that is, long-term – improvements in the overhead deep squat test or the full FMS™ test battery is a matter for future research.

REFERENCES


ABSTRACT

Background: Inhibition of the quadriceps muscle and reduced knee-extension strength is common shortly following total knee arthroplasty (weeks to months), due to reduced voluntary activation of the quadriceps muscle. In healthy subjects, strength training with heavy loads is known to increase agonist muscle activity, especially if the exercise is conducted using rapid muscle contractions.

Purpose: The purpose of this study was to examine if patients with total knee arthroplasty could perform rapid knee-extensions using a 10 RM load four to eight weeks after surgery, and the degree to which rapid knee-extensions were associated with greater voluntary quadriceps muscle activity during an experimental strength training session, compared to that elicited using slow knee-extensions.

Study Design: A randomized cross-over study.

Methods: Twenty-four patients (age 66.5) 4-8 weeks post total knee arthroplasty randomly performed one set of five rapid, and one set of five slow knee-extensions with the operated leg, using a load of their 10 repetition maximum, while surface electromyography recordings were obtained from the vastus medialis and lateralis of the quadriceps muscle.

Results: Data from 23 of the 24 included patients were analyzed. Muscle activity was significantly higher during rapid knee-extensions (120.2% [10th-90th percentile: 98.3-149.1]) compared to slow knee-extensions (106.0% [88.8-140.8]) for the vastus lateralis (p<0.01), but not for the vastus medialis (120.8% [90.4-134.0]) and (121.8% [93.0-133.0]) (p=0.17), respectively. Slow and rapid knee-extensions were performed at a median angular velocity of 19.7 degrees/sec (13.7-24.4) and 51.4 degrees/sec (28.9-63.1), respectively

Conclusion: Four to eight weeks after their total knee arthroplasty, the patients in the present study were able to conduct rapid knee-extensions according to the experimental protocol with an approximately doubled angular velocity compared to slow knee-extensions. This was associated with increased muscle activity in the vastus lateralis when compared to slow knee-extensions, but not in the vastus medialis. Whether this significant, although relatively small, difference in vastus lateralis muscle activity has any clinical relevance needs further study.

Level of Evidence: 3

Keywords: Exercise evaluation, knee-extension velocity, quadriceps muscle, rehabilitation, total knee arthroplasty

The funding bodies have not influenced the research process, i.e. protocol, design, data collection, off line analysis, composition of manuscript or considerations on publication.

*These authors contributed equally (shared first authorship).

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BACKGROUND

Total knee arthroplasty (TKA) is a recommended intervention for end-stage knee joint osteoarthritis (OA),1 and in many cases it successfully relieves pain and discomfort.2,3 Although current perioperative care is dominated by fast track or enhanced recovery programs, which have successfully reduced length of hospital stays,4,5 a substantial reduction in knee-extension strength and rate of torque development is still a major pathophysiological problem weeks to months following surgery.6,7 Adding to this problem is the fact that knee-extension strength is reduced already before surgery 2,8 but is exacerbated further post-surgery,2,9–11 with an average reduction of 83% at hospital discharge compared to pre-surgery values.12 The loss of knee-extension strength is not always resolved over time, as a large body of evidence indicates persistent knee-extension strength weakness months 2,10,13–15 and years 7,14,16 after surgery, compared to the non-affected contralateral limb or limbs of age-matched healthy peers.

The acute loss of knee-extension strength following TKA is caused primarily by reduced voluntary activation of the quadriceps muscle, known as arthrogenic muscle inhibition (AMI).9,17-18 The cause of AMI is multifactorial, but some of the key mechanisms are thought to be inflammation, swelling, and receptor damage following surgery.17 Because of this, afferent signaling from the knee joint is altered post-surgery, affecting the central nervous system (CNS) by changing the excitability of multiple spinal and supraspinal pathways, which inhibits the quadriceps muscle and reduces knee-extension strength.17,18 In patients with TKA, this results in limited force production for the execution of tasks of everyday living,19,20 e.g. reduced gait speed, walking distance and stair climbing ability 2,13,21 as well as increased risk of falls.22

The latest systematic review and consensus recommendation on rehabilitation following TKA does not find evidence for a specific type of exercise program, but progressive strength training of the lower limbs is one of the exercise modalities recommended.23,24 When healthy subjects perform strength training using heavier loads, it is generally associated with pronounced neural adaptations, such as increased voluntary activation of the trained muscle 25,26 especially if the exercise is executed using rapid contractions.27,28 In patients following total hip arthroplasty, progressive explosive resistance training has been associated with increased maximal strength and rate of force development in the quadriceps muscle after 12 weeks of progressive resistance training.29 Similarly, recent preliminary results showed significantly greater improvements in walking distance and knee-extension strength after eight weeks of high velocity knee-extension exercise (concentric phase <1 second, eccentric phase 3 seconds) compared to slow velocity knee-extension exercise (concentric and eccentric phases each 3 seconds) performed four to six weeks after surgery in patients with TKA.30 In healthy individuals, greater activity in the quadriceps muscle has also been shown as an acute effect to a single set of rapid knee-extensions compared to slow knee-extensions.31,32 Accordingly, if rapid knee-extensions can be performed during strength training shortly following TKA, this may be a simple way to reduce AMI after surgery with the intention of better and faster recovery. Previous studies investigating rapid versus slow contractions in patients shortly following TKA report how they used verbal directions and metronomes to help guide the movement velocity, however they did not measure the degree to which the angular velocity was actually different between the rapid and slow contractions.30,33

The purpose of this study was to examine if patients with total knee arthroplasty could perform rapid knee-extensions using a 10 RM load four to eight weeks after surgery, and the degree to which rapid knee-extensions were associated with greater voluntary quadriceps muscle activity during an experimental strength training session, compared to that elicited using slow knee-extensions. The authors hypothesized that the rapid knee-extensions would increase quadriceps muscle activity more than the slow knee-extensions.

METHODS

Study design

The protocol consisted of a familiarization session where the 10 RM load for knee-extension (the maximum number of repetitions per set that can be performed at a given resistance with proper lifting technique) 34 was determined, and a subsequent experimental session at least three days later where
surface electromyography (EMG) recordings of the quadriceps muscle were made during slow and rapid knee-extensions. For the experimental session, a randomized cross-over design was used, with a balanced randomization (1:1, slow and rapid knee-extensions, respectively). That is, 12 patients started with the slow contractions and completed the rapid afterwards, and the other 12 patients started with the rapid contractions and completed the slow afterwards. Further, the data analyst was blinded with respect to contraction type.

The present study was embedded in a study evaluating knee-extension muscle activity across different exercises after TKA (unpublished, ClinicalTrials.gov identifier: NCT01708980). All outcomes for this study were compared to a group of sedentary individuals with no prior TKA surgery.

**Figure 1. Flow chart of participating patients and study design.**
embedded study were pre-defined and the analyses were made blinded.

The reporting of the study follows CONSORT 2010 Explanation and Elaboration: updated guidelines for reporting parallel group randomized trials \(^{35}\) and Standards for Reporting EMG Data suggested by Merletti. \(^{35}\) The protocol for this trial was approved by The Committee on Biomedical Research Ethics for the Capital Region of Denmark (H-1-2011-027).

Participants

Twenty-four patients were recruited during their outpatient rehabilitation by consecutive sampling from four different rehabilitation centers in the Copenhagen Area (Vanløse, Vesterbro/Kgs. Enghave/Valby, Brøndby and Hvidovre). The inclusion criteria were: patients having received TKA surgery four to eight weeks prior to testing, and were 18-80 years of age. The exclusion criteria were: less than 70 degrees of active range of motion flexion in the operated knee, if they had alcohol or substance abuse or if they had any other musculoskeletal or neurological disorder requiring specialized rehabilitation. Prior to the study, all patients were informed about the study, both verbally and in writing as defined in The Declaration of Helsinki. All patients gave their written informed consent to participation in the study.

Intervention

At the familiarization session, all individual preparations and adjustments were made, and at the experimental session a strength training session was simulated, at which the experiments were conducted.

Familiarization session: At the familiarization session, the knee-extension strength training machine (TechnoGym, Silverline, Rehabilitation Device, Bracknell, United Kingdom) was individually adjusted to each patient for the testing of both maximal voluntary isometric contraction (MVC) in knee-extension at a knee joint angle of 60 degrees and dynamic knee-extensions, during which the patients should be able to employ a minimum range of 70 degrees (10 to 80 degrees of knee-flexion). The adjustments placed each patient in 90 degrees bilateral hip-flexion and with the resistance pad of the machine placed on the front of the lower part of the shin bone, approximately 5 cm above the lateral malleolus (Figure 2).

Each patient then performed a three minute warm up on a stepping machine at a self-selected, but sub-maximal intensity. The warm up was followed by sets of slow dynamic knee-extensions to determine the load in kilograms corresponding to 10 RM, and was supervised by an experienced physical therapist. This was typically accomplished in one to three attempts, according to the physical therapist’s best estimate.

To standardize knee-extension velocity, the patients were guided by an audio file. Instructions on how to perform the knee-extensions in a smooth manner in the required range of joint motion without pauses or resting the weight stacks in between knee-extensions were given. Before ending the familiarization session, patients practised both slow and rapid knee-extensions, and were then randomized to the order of knee-extensions for the subsequent experimental session.

Experimental session: Subsequently to a warm up as for the familiarization session, the patients performed three knee-extension MVC’s, separated by two-minute pauses, for the operated knee with the knee joint positioned at 60 degrees flexion. Instructions were given to extend the knee as strongly as possible against the fixed resistance pad of the knee-extension machine for approximately five seconds, thereby gradually building up force to a maximum. To facilitate patients in achieving their maximum
force, standardized and vigorous verbal encouragement was provided. The highest EMG value obtained from the three MVC’s where used as reference for the subsequent EMG amplitude normalization.

The patients then performed a single set of five rapid and a single set of five slow dynamic knee-extensions with the operated leg using a load of 10 RM according to the randomization order. The five repetitions at 10 RM were used to avoid fatigue during the knee-extensions. The pre-recorded audio files assisted the patients in managing the velocity-specific timing during both slow and rapid knee-extensions. Slow knee-extensions were performed in a 10-second loop audio file, with three, two and three seconds for the concentric, isometric and eccentric phases, respectively, and a two-second pause in resting knee-flexion between the repetitions, aiming for an angular velocity of 20 degrees/sec. Rapid knee-extensions were performed in an eight-second cycle, consisting of approximately one second (or less if possible for the patient – aiming for an angular velocity ≥ 60 degrees/sec) to perform the concentric contraction phase on the command “LIFT”, two seconds for the isometric hold in extension, followed by three seconds of eccentric contraction and two seconds of pause in knee-flexion. The concentric contractions, performed on the command “LIFT”, were executed with an intention to attain maximal acceleration and velocity; thereby knee-extension velocity during the rapid knee-extensions could potentially be, three times faster than the slow knee-extensions. Consequently, the achieved angular velocity was dependent on each patient’s ability to perform knee-extensions rapidly.

Muscle activity during the knee-extensions was recorded using an EMG system from Delsys (Bagnoli EMG™ System, Delsys, Natick, Massachusetts). At the start of the experimental session, standard skin and electrode preparation, consisting of careful shaving, abrasion and cleaning of the skin, as well as application of gel and medical-grade adhesive to the electrodes, was carried out. Non-disposable rectangular single-differential surface electrodes (DE 2.1, Delsys, Natick, Massachusetts), with a length and an interpole-distance of 1 cm, were placed on the skin overlying the vastus medialis (four finger-breathths proximal to the superior-medial angle of the patella) and lateralis (over the lateral aspect of the thigh, one handbreadth above the patella), of the quadriceps muscle, as described by Perotto and associates. A reference electrode was placed over the patella bone. To avoid movement artefacts, all wires were taped carefully to the skin.

The EMG signals were sampled at 1000 Hz (16-bit A/D converter, 6036E, National Instruments, Hørsholm, Denmark), amplified at the electrode level via built-in preamplifiers, and transmitted through insulated wires to a main amplifier unit (Bagnoli-16, Delsys, Natick, Massachusetts) that filtered the signals using a bandwidth of 20 to 450 Hz, with a common-mode rejection ratio of 92dB. Prior to data collection, EMG signal quality was assessed visually during light contractions of the quadriceps muscle. An electrical goniometer (Goniometer Biosignal Sensors, Delsys, Natick, Massachusetts) was mounted with adhesive tape on the lateral side of the knee to quantify the knee joint range of motion (Figure 3).

**Outcomes**

Primary outcome: During the offline EMG analysis (EMGworks 3.7 Analysis, Delsys, Natick, Massachusetts), the EMG amplitudes recorded during the slow and rapid concentric contractions (knee-extension) were normalized to the peak EMG amplitude (EMGmax) determined from the MVCs, and expressed as percentage of this value (%EMGmax). For both slow and rapid contractions, muscle activity was calculated as a mean of the peak amplitudes for each of the five knee-extensions. A smoothing root mean square (RMS) filter was initially applied to the raw data. For the MVCs, the RMS values were calculated using a 1-second window length and a 0.999-second window overlap. The MVC with the greatest amplitude was used as the EMGmax data point for each muscle. For the rapid and slow knee-extensions, the concentric phase was initially located using the goniometer recordings (Figure 3). The RMS values were then calculated for the concentric phases using a 0.200-second window length and 0.199-second window overlap.

Secondary outcomes: The secondary outcomes were knee-extension velocity at slow and rapid knee extensions, and pain in the operated knee at rest, during and after knee-extensions. Knee-extension...
velocity during slow and rapid knee-extensions was measured with the electrical goniometer mounted on the lateral side of the knee (Figure 3). This measurement was used to validate the experimental protocol, that is, that the rapid contractions were in fact more rapid than the slow contractions. Pain was assessed using a 100-mm visual analogue scale (VAS) with endpoints of 0 representing “no pain” and 100 representing “worst pain imaginable”. Patients were asked to rate their pain in the operated knee at rest in real time and during the following activities by recall: Ten RM load determination (familiarization session), MVC and, rapid and slow contractions (experimental session). Pain at rest was measured immediately before and approximately one minute after every type of activity. Pain during activity was measured within seconds after completion of the knee-extensions by recall.

Randomization and blinding
Concealed envelopes were used to randomly allocate all patients to the order of knee-extension velocity. It was not possible to blind either patients or the investigators to the velocity of the test, but the data analyst was blinded. Furthermore, the patients were blinded with regard to the study hypothesis.

Statistical analyses
A power analysis was initially performed using a significance level of 5% (two-tailed t-test), a power of 80%, a mean muscle activity of 85 %EMGmax, and a common standard deviation of 18 %EMGmax.38
which showed that 23 subjects were needed to show a 15% difference in quadriceps muscle activity between knee-extensions types (15% more muscle activity during rapid compared to slow knee-extensions). We considered the 15% difference in muscle activity the minimal clinical important difference. To account for potential dropout or missing data, 24 patients were included.

The statistical analyses were performed using STATA (version STATA13.1). By the use of histograms, scatterplots, Shapiro Wilk tests and Q-Q-plots of the residuals, it was observed that data were skewed and non-normally distributed. Consequently, it was decided to use non-parametric statistics and to present data as medians with corresponding 10th-90th percentile ranges.

Between knee-extension-velocity differences in muscle activity and activity-related knee pain differences during both rapid and slow knee-extensions, as well as resting knee pain differences before and after both rapid and slow knee-extensions, were assessed using Wilcoxon sign rank tests.

RESULTS

Patients
A total of 158 potentially eligible patients with TKA referred to the four rehabilitation centers were assessed for eligibility, and 24 patients were included (days after surgery, mean (SD) 38.3 [9.4]) (Figure 1). Data from one patient was subsequently discarded during the offline EMG analysis due to poor signal quality, thus, data from 23 patients were analysed. The decision to discard data from this patient was made prior to the data analysis. Two of the 23 patients only completed three rapid knee-extensions and one patient only completed four rapid knee-extensions. A fourth patient only completed four repetitions of the slow knee-extensions. These four patients that did not complete the intended number of repetitions were analysed using the available data. Patient characteristics of the 23 patients are presented in Table 1.

Outcomes

Primary outcome: Muscle activity was significantly higher during rapid knee-extensions (120.2 %EMGmax [98.3-149.1]) (values expressed as median and 10th-90th percentile ranges) compared to slow knee-extensions (106.0 %EMGmax [88.8-140.8]) for the vastus lateralis (p<0.01). Muscle activity was not significantly higher during rapid knee-extensions (120.8 %EMGmax [90.4-134.0]) compared to slow knee-extensions (121.8 %EMGmax [93.0-133.0] for the vastus medialis (p=0.17) (Table 2).

Secondary outcomes: Slow knee-extensions were performed at standardized velocities at a median angular velocity of 19.7 degrees/sec (13.7-24.4) and

<table>
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<tr>
<th>Table 1. Baseline characteristics for patients</th>
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<td>Variable</td>
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<tr>
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<td>Median (10th-90th)</td>
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<td>Body mass (kg)</td>
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<td>VAS (0-100 mm)</td>
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Baseline data on patients randomized into 2 groups defined by order of contraction type. Gender distribution is reported as absolute numbers in each group and the relative number in percentage. All other variables are presented as median (10th-90th percentile). VAS = Visual Analogue Scale.
rapid knee-extensions at 51.4 degrees/sec (28.9-63.1), which were significantly different (p<0.01).

Activity-related knee pain during the rapid knee-extensions (VAS = 0 mm [0-51]) was not significantly higher (p = 0.36), compared to that during the slow knee-extensions (VAS = 0 mm [0-39]). Resting knee pain after rapid knee-extensions (VAS = 0 mm [0-5]) was significantly higher (p = 0.0046) compared to resting knee pain after slow knee-extensions (VAS = 0 mm [0-2]). For both the 10 RM load determination and the MVC’s there was no significant difference between resting pain levels before or following the two activities (p>0.05). The activity-related pain was significantly higher for both the 10 RM load determination (VAS = 16 mm [0-48]) and the MVC’s (VAS = 0 mm [0-42]) compared to resting pain levels, VAS = 0 mm (0-14) and 0 mm (0-9), respectively (p <0.05) (Table 2).

No adverse events were experienced by the patients.

**DISCUSSION**

In general, patients, four to eight weeks post TKA surgery, were able to more than double their knee-extension velocity during the rapid knee-extensions compared to slow. In doing so, the primary hypothesis was partly confirmed, as rapid knee-extensions, compared to slow knee-extensions, increased muscle activity significantly in the vastus lateralis muscle, but not in the vastus medialis muscle. Although the difference was significant in vastus lateralis it was relatively small and whether this has any clinical relevance needs further study. Secondly, the patients with TKA did not experience a higher increase in knee pain during the rapid knee-extensions compared to slow knee-extensions.

Results from two recent studies add to the equivocal interpretation of the findings in the present study.\(^30\),\(^33\) Doerfler and colleagues found that an eight-week high-velocity exercise program commenced four to six weeks after TKA increased knee-extension strength more than a slow velocity exercise program.\(^30\) These results, at least in part, are consistent with the results of the present study suggesting a (clinically relevant) effect of exercise comprising high knee-extension velocity. To the contrary, Kelly and colleagues did not find a difference between groups performing high velocity exercise compared

| Table 2. Primary and secondary outcomes. The primary outcome is normalized EMG amplitudes (%EMGmax) and the secondary outcomes are angular velocity (degrees/sec) and pain measurement before, during and after testing procedures. All data are reported as median (10th-90th percentile) |
|-----------------|-----------------|-----------------|-----------------|
| **Primary outcome** | Slow knee-extensions | Rapid knee-extensions |
| Vastus medialis muscle activity, %EMGmax | 121.8 (87.8-141.0) | 120.8 (87.4-155.1) |
| Vastus lateralis muscle activity, %EMGmax | 106.0 (88.8-140.8) | 120.2 (98.3-149.1)* |
| **Secondary outcomes** | Slow knee-extensions | Rapid knee-extensions |
| Angular velocity, deg/sec | 19.7 (13.7-24.4) | 51.4 (28.9-63.1)* |
| Resting pain pre knee-extensions, VAS (0-100 mm) | 0 (0-2) | 0 (0-2) |
| Resting pain post knee-extensions, VAS (0-100 mm) | 0 (0-2) | 0 (0-5)* |
| Activity pain during knee-extensions, VAS (0-100 mm) | 0 (0-39) | 0 (0-51)* |
| **Secondary outcomes** | 10 RM load determination | MVC |
| Resting pain pre knee-extensions, VAS (0-100 mm) | 0 (0-14) | 0 (0-9) |
| Resting pain post knee-extensions, VAS (0-100 mm) | 0 (0-0) | 0 (0-2) |
| Activity pain during knee-extensions, VAS (0-100 mm) | 16 (0-48) | 0 (0-42) |

*Denotes significant difference between slow and rapid knee-extensions, p<0.05. ¤ Denotes significant difference between activity pain level and resting pain level, p<0.05. VAS = Visual Analogue Scale, RM = Repetition Maximum, MVC = Maximum Voluntary Contraction.
Muscle activity in vastus medialis: The findings in the present study are indistinct as an uneven increase in quadriceps muscle activity was observed between vastus medialis and vastus lateralis. Some explanations can be offered as to why the observations for vastus medialis were non-significant. An open kinetic chain knee-extension exercise was used in the present study to assess and compare the quadriceps muscle activity during slow and rapid knee-extension velocities, respectively. This particular knee-extension exercise was chosen for this study, since it is an isolated knee-extensor exercise that, in healthy individuals, induces a high degree of neural efferent drive to the quadriceps muscle in general, without eliciting higher levels of synergistic or antagonistic muscle activity around the knee.39 Specific activation of the quadriceps muscle is highly relevant, due to the persistent weakness and inhibition especially affecting the quadriceps muscle following TKA. Furthermore, the open chain knee-extension exercise is a single-joint, non-weight bearing exercise, in which the exercise machine stabilizes the body throughout the movement. Consequently, the motor-task was performed without high demands to functional ability and balance, which was viewed as essential, as patients should focus on rapid velocity only. However, other studies in healthy adults have shown that open chain knee-extensions may induce a higher degree of activation of vastus lateralis compared to vastus medialis.43,44 These observations could, at least in part, offer some explanation as to why the vastus medialis was not activated to the same degree during the rapid contractions. Another possible explanation to the observed uneven increase in muscular activity of the explored vastii muscles, between slow and rapid knee-extensions is intra-articular knee swelling which is a common knee related symptom following TKA.31 Experimentally induced knee-swelling is known to inhibit the quadriceps muscle 45,46 and some studies have found the vastus medialis to be inhibited earlier and by lesser amounts of fluid than the vastus lateralis.47,48 Accordingly, although there is no clear consensus in the literature on this topic, the potential presence of knee joint fluid, may have contributed to the uneven increase in muscle activity between vastus medialis and vastus lateralis, during rapid knee-extensions. That is, because the vastus medialis may have been

Interpretation
Feasibility of rapid knee-extensions as training modality: For the patients in this study, the increase in activity-related knee pain during rapid knee-extensions was not significantly higher than during slow knee-extensions (Table 2). However, a significant, albeit not clinically relevant (<10% difference),40 increase was registered in pain after rapid knee-extensions compared to slow knee-extensions. Thus, in spite of this statistical difference in pain after rapid and slow knee-extensions, this training modality appears feasible for patients four to eight weeks post TKA.

Muscle activity in vastus lateralis: The observed median increase in muscle activity in vastus lateralis of 8.5 % EMGmax during the rapid knee-extensions is indicative of additional motor unit recruitment and/or increased motor unit discharge rate, caused by increased CNS activation in order to increase knee-extension velocity.41 In the literature, there is no clear consensus on the precise relationship between different velocities and coexisting EMG amplitudes, as these are also influenced by other factors such as external load and joint angle.38,42 Croce et al, investigated the effect of submaximal contraction intensity and velocity on EMG amplitude in the quadriceps muscle during knee-extensions, and observed the lowest EMG amplitudes at 50 degrees/sec when comparing to higher velocities.42 Thus, it is possible that the patients in the present study were unable to perform maximal velocity knee-extensions sufficiently fast to promote EMG amplitudes that were markedly higher than those elicited at slow velocity. Consequently, it is possible that a more pronounced difference in muscle activity (i.e. EMG amplitudes) between rapid and slow knee-extensions could have been attained, if patients had been able to perform knee-extensions more rapidly than observed. Hence, the accomplished maximal knee-extension velocity of 51.4 degrees/sec in this study may partly explain why the increase of 8.5% as observed in vastus lateralis did not reach the predetermined 15% (as well as may explain the non-significant observations for vastus medialis).
inhibited more, the greater voluntary drive associated with the rapid contractions was of a magnitude that elicited an increase in vastus lateralis activation only, or to a greater extent. However, the potential presence of knee joint fluid was not measured.

Clinical implications: Arthrogenic muscle inhibition is a major barrier for the success of rehabilitation of patients with TKA. Especially the quadriceps muscle is subject to a significant loss of function, which is associated with decreased maximal knee-extension strength, quadriceps activation and functional capacity in patients 12 months post TKA. The recent study by Doerfler et al suggested some positive preliminary effects of high velocity exercise compared to slow velocity exercise in terms of improved walking distance and knee-extensor muscle strength in patients with TKA after surgery, supporting the use of high velocity exercise.

In many daily activities, where a fast reaction is required, e.g. during prevention of a fall, the ability to contract rapidly (rate of force development [RFD]) is of great importance. The RFD seems to be lower in patients with TKA compared to pre-operative values and age-matched healthy controls. Pertaining to the notions above, explosive resistance training would be a rational option, as this type of resistance training has shown to increase RFD in healthy elderly and in patients with total hip replacement, and elicits greater improvement on RFD results and better effect on functional outcome than conventional resistance training in healthy age-matched peers.

The clinical implication of the above is that intervention and rehabilitation strategies, when seeking to increase central activation and reduce AMI, may benefit from modalities that facilitate RFD, as in the present study. Therefore, it seems plausible that explosive type contractions, as performed in this study, are highly relevant to employ in this group of patients to target the RFD deficit and thereby improve functional capability. But as this study investigated short-term effects only, any long-term effects of high velocity resistance training on RFD need to be investigated further. It also needs to be investigated further whether moving the load more medially during the knee extensions could facilitate greater activation of the vastus medialis.

**LIMITATIONS**

The present randomized cross-over study investigated the short term effects only, i.e. the instantaneous effect of knee-extension velocity on muscle activity. Thus it is not possible to draw conclusions on long term effect of this training modality on knee-extension velocity and muscle activity in either of the investigated muscles. Likewise, the authors do not know if possible physiological gains from knee-extension exercise translate into improved functional performance. Further, the long term effects on pain levels after the test session are unknown.

**CONCLUSIONS**

Four to eight weeks after their TKA, the patients in the present study were able to conduct rapid knee-extensions according to the experimental protocol with an approximately doubled angular velocity compared to slow knee-extensions. Rapid knee-extensions increased the vastus lateralis muscle activity more than slow knee-extensions, but the same response was not seen in the vastus medialis. Knee pain during knee-extensions was not different between slow and rapid knee-extensions while knee pain following the rapid knee-extensions was slightly higher than following the slow knee-extensions. The patients’ ability to voluntarily perform knee-extension more rapidly and thereby achieve higher degrees of angular velocities than observed in this study may not be accomplished without specific training of rapid, explosive type knee-extensions for a longer period of time. Thus, whether the significant, albeit relatively small, difference in vastus lateralis muscle activity has a clinical relevant impact needs to be investigated further.

**REFERENCES**


ABSTRACT

Background/Purpose: Physical performance measures (PPMs) such as The Star Excursion Balance Test (SEBT) and the Y-Balance Test (YBT) are functional movement tests used to assess participants’ dynamic balance, which can be a vital component in physical exams to identify predisposing factors for risk of injury. The YBT is a functional assessment tool for the upper and lower body. It evolved from the SEBT, which has been previously used in research as a lower body functional assessment. It is comprised of fewer movement directions, which help limit fatigue. The YBT kit is a commercialized tool, which may pose barriers for clinicians with limited budgets and/or strict approval process for purchasing capital items in their clinics, especially healthcare providers in the secondary school setting. The cost may also pose a barrier for researchers with limited budgets. A less expensive, easy to make kit, may provide clinicians an opportunity to integrate functional testing into their evaluation or research. The purpose of this pilot study was to describe a cost efficient method to gather participant's upper quarter YBT (UQYBT) measurements and examine the inter- and intra-rater score agreement between this method and the commercial YBT measurements.

Methods: A convenience sample of 20 physically active participants volunteered to participate in a comparison study of the Upper Quarter Y-Balance Test (UQYBT) using the commercialized kit and the Modified Upper Quarter Y-Balance Test kit (mUQYBT) made with three cloth tape measures, athletic tape, a goniometer and three 2x4x8 wood blocks. A Pearson Product Moment correlation and Bland-Altman analyses were used to examine the relationship between intra-rater scores comparing the UQYBT and mUQYBT. Inter-rater scores were analyzed using intraclass correlation coefficients (ICC) (2,1) and Bland-Altman analyses.

Results: All Pearson Product Moment r-values for intra-rater scores were greater than .96 and statistically significant at p<0.05. Coefficients of determination suggest that the mUQYBT scores account for approximately 92% of the UQYBT composite score when analyzing intra-rater comparisons. Bland-Altman plots suggest moderate agreement between the two tests with a potential bias towards higher composite scores in the mUQYBT. Inter-rater ICC scores were all greater than .98, while Bland-Altman plot analyses suggest moderate agreement between the raters.

Conclusion: The mUQYBT produced similar results in both inter- and intra-rater measurements when compared to the commercialized YBT kit and offers a cost-effective alternative for assessing upper quarter PPMs for clinicians with limited budgets.

Level of Evidence: 2b

Keywords: Y-Balance Test, upper quarter functional tests, physical performance measures
INTRODUCTION

Physical performance measures (PPMs) and self-report measures (SRMs), also known as patient reported outcomes (PROs), are utilized to assess function in physically active populations. Physical performance measures objectively assess function while PROs allow subjective participant assessment of function. Therefore, clinicians should implement PPMs as an outcome measure into clinical practice to fully capture functional movement, which allows clinicians to baseline, track and measure progress. Two widely accepted PPM’s that test functional movement include the Star Excursion Balance Test (SEBT) and the Y-Balance Test (YBT).

The Star Excursion Balance Test (SEBT) is designed to assess participants dynamic balance in the lower extremity in eight directions. Clinicians, however, found the SEBT to be time consuming and physically strenuous for participants when implemented in practice; therefore, a modified test was developed. The modified test reduced the number of directions from eight to three (medial, inferolateral, and superolateral). This was the first example of a standardized Y-Balance Test (YBT) utilizing three bilateral practice trials and the best of three testing trials. Accompanying the YBT was a commercialized kit which is offered in either plastic or bamboo sold online through the Functional Movement Systems website (functionalmovement.com). In addition to the lower quarter application, the YBT was applied to the upper quarter known as the Upper Quarter Y-Balance Test (UQYBT). These changes address the time consuming testing procedures and lack of standardized protocol for use during the SEBT.

The UQYBT is a PPM, which allows for the quantitative analysis of a participant's ability to reach with their free hand while simultaneously weight bearing on the contralateral hand. Currently there are a total of three dynamic closed-kinetic chain upper extremity PPMs described in literature: Upper Quarter Y-Balance Test, The One-Arm Hop Test, and The Closed-Kinetic Chain Upper Extremity Stability Test (CKCUEST). The One-Arm Hop Test and the CKCUEST are performed within the participant's base of support thereby lacking in assessment of the participant's limits of stability and not fully requiring scapular and thoracic mobility; therefore, those PPMs do not fully capture the limits of participant's stability. Alternatively the UQYBT requires the combination of scapular mobility/stability, thoracic rotation, and core stability and are challenged as the participant reaches as far as possible in three directions (medial, inferolateral, superolateral). The YBT kit may be costly for some clinicians especially those working in the secondary school setting and/or who have a limited annual budget for capital items. Since the current price according to the Functional Movement Systems website is $319.95 annual budgets might not allow clinicians to purchase a single tool for a single PPM. Authors suggest that evidence-based PPMs should be affordable, reliable, specific to functional activity, and utilized more often in athletic populations to assess baseline musculoskeletal movement patterns bilaterally. An alternative kit is proposed to help reduce costs for individual and multi-site clinics/research which will help eliminate one of the barriers to implementation of a PPM. The primary purpose of this pilot study was to describe a cost efficient method to gather participant's upper quarter YBT (UQYBT) measurements and examine the inter- and intra-rater score agreement between this method and the commercial YBT measurements. This pilot study assessed the UQYBT as a functional test that was part of a larger scale study involving the shoulder complex. The first objective was to determine agreement between scores on the mUQYBT and the UQYBT when executed by the same researcher. The second objective was to determine agreement between scores on the mUQYBT as executed by multiple clinicians.

METHODS

Materials

Researchers utilized a mUQYBT constructed of the following: three cloth measuring tapes affixed to the laboratory floor (wood surface) precisely matching the angles and measurements of the UQYBT device as measured with a goniometer (see Figure 1), athletic tape (used to secure the measuring tapes and mark the starting point for the stationary hand), and three wooden blocks measuring 2x4x8 (in lieu of the plastic blocks). A wood surface (basketball/volleyball court) was utilized in this comparison trial
because it was a consistent surface between the two researchers. Two mUQYBT and two UQYBT were implemented in this study design, one for each tester to help blind data collection. Measurements were recorded using the YBT worksheets to help the testers track and calculate composite scores for each participant. The YBT worksheet provided consistent guidelines for both testers to follow and implement during the study.

Participants
A convenience sample of 20 healthy participants between 23 and 39 years of age (age = 29.2 ± 4.91 years, males = 12, females = 8) were recruited and volunteered to participate in the pilot comparison study between the UQYBT and the mUQYBT. All participants were able to perform a pushup and plank pain-free and were physically active according to the American College of Sports Medicine (ACSM) guidelines; performed a combination of moderate to vigorous intensity of aerobic physical activity for 75 to 150 minutes a week. All participants performed the testing procedures in athletic clothes.

Testers
For the purpose of this study, two testers were utilized. The testers were certified athletic trainers (1 female and 1 male) with “2 and 7 years of clinical experience respectively.” Each of the testers had previously completed the YBT training through the Functional Movement Systems (FMS) website. The two testers were blinded to the measures collected during their trials and to the data collected by the other tester.

Protocol
Participant age, sex, dominant throwing arm, and upper limb length were recorded prior to testing. To maintain consistency, one tester measured all 20 participants' upper limb length in a standing upright position with the right shoulder abducted to 90 degrees, the elbow fully extended, and the participant's hand in a neutral position. Once positioned, the tester measured the participant's upper limb length from C7 to the tip of their longest finger (limb length = 90.75 ± 5.77 cm). The participants (n=20) were randomly split into two groups and assigned to start with either Tester 1 or Tester 2 for convenience purposes.

The UQYBT and the mUQYBT were performed following the guidelines of the YBT. Each participant was provided a demonstration of the procedures and allowed three practice trials, according the UQYBT procedures, in each direction on their right and left upper limb prior to data collection (see figures 2-4). Note, participants performed the testing procedures barefoot to eliminate any stability and balance issues from footwear. Three trials for the UQYBT and three trials for the mUQYBT were recorded for the left and the right upper limb (superolateral, medial, inferolateral) by each tester for a total of six trials. During the mUQYBT, participants received three minute rest periods between testers. This same protocol was applied for participants between testers during the UQYBT. During changeover from the mUQYBT to the UQYBT a rest period of five minutes was provided.

A performance trial was not accepted if the following occurred; 1) The participant failed to maintain unilat-
eral stability (participant fell over or placed their free hand on the ground for support/stability), 2) participant did not maintain contact with the block, 3) participant had improper hand placement on the block(s) (placed hand on top of block instead of fingertips on closest side), 4) participant lifted a foot off the floor.4,12

The average value from each of the three directions were summed together and divided by three times the upper limb length and then multiplied by 100 to get the total composite score from each participant on both testing devices. Both right and left upper quarter measurements from the 20 participants were used to allow for 40 measurements in the statistical analysis. Previous researchers reported no statistical difference between dominant and nondominant sides,12 which supports the use of dominant and nondominant scores as one group.

STATISTICAL METHODS

The purpose of the analysis was to examine the relationships between the data from two raters assessing the same participants using the UQYBT and the mUQYBT. Three statistical analyses were performed. A Pearson Product Moment correlation was conducted for each tester to examine the relationship between a single tester’s scores comparing the UQYBT and mUQYBT. Since Pearson Product Moment examines the strength of linear association of the variables and not necessarily agreement, the single rater scores comparing the UQYBT and the mUQYBT were also analyzed for agreement using a Bland-Altman plot.14-16 Inter-rater scores for each testing method (e.g., UQYBT vs UQYBT) were examined using intraclass correlation coefficients (ICC). The researchers utilized ICC (2,1) in order to make a conservative analysis and include the testers as a source of error for generalizability to a larger population.16 Inter-rater composite scores for each testing method (e.g., mUQYBT vs mUQYBT) were assessed for agreement using a Bland-Altman plot. All statistics were computed using SPSS 21.0 (IBM Corp., Armonk, NY) with the exception of the Bland-Altman plot which were calculated using Analyse-it® (Analyse-it Software, Ltd, Leeds, UK)
RESULTS/OUTCOMES
Intra-rater comparison statistics can be found in Table 1 and Figures 5-8. All data were normally distributed as assessed by the Shapiro-Wilk test. We calculated the Pearson Product Moment to assess the relationship between scores on the UQYBT and the mUQYBT for each tester. There were strong positive correlations between the UQYBT and the mUQYBT composite scores for each tester (Figures 5,6). Coefficients of determination calculated for each tester suggest that the mUQYBT scores account for approximately 92% of the UQYBT composite score (Table 1). Analysis of mean differences using the Bland-Altman plot suggested acceptable agreement of scores, but in this sample the mUQYBT may systematically produce higher composite scores (Figures 7,8).

Inter-rater comparison statistics can be found in Table 2 and Figures 9 & 10. Intraclass correlation coefficients were above .98 for both testing methodologies. The calculated scores exceed the suggested guidelines for quality clinical reliability. Analyses of mean differences using the Bland-Altman plot suggest acceptable agreement of scores between raters on both the UQYBT and the mUQYBT.

DISCUSSION
Previous researchers have concluded the UQYBT is an acceptable assessment of upper extremity closed kinetic chain (UECKC) function by comparing UQYBT test scores to other UECKC assessments. Further, researchers have demonstrated the UQYBT assesses the mobility and stability of

| Table 1. Intra-rater Comparison of the mUQYBT and the UQYBT Composite Scores |
|---------------------------------|-----------------|-----------------|
|                                | Pearson Product | Bland-Altman    |
| Intra-rater                    | Moment (r) | Coefficient of Determination (r²) | Mean difference (95%CI) | Standard Error of Mean Difference | SD difference | 95% LOA Lower (95%CI), upper (95%CI) |
| Comparisons                    | PPM (r) | (%) | | | |
| mUQYBT vs UQYBT (composite score) |                  |                  |                  |                     |             |                                     |
| Rater 1                        | .96* | 92.2% | -1.2 (-2.0, -0.4) | .371 | 2.34 | -5.83 (-7.1, -4.5), 3.36 (2.1, 4.7) |
| Rater 2                        | .95* | 92.0% | -1.6 (-2.4, -0.89) | .371 | 2.34 | -6.24 (-7.5, -4.9), 2.96 (1.7, 4.3) |

mUQYBT= Modified upper quarter Y-balance test, UQYBT= Upper quarter Y-balance test, LOA= limits of agreement

Figure 5. Pearson product moment correlation for composite scores for Rater 1.

Figure 6. Pearson product moment correlation for composite scores for Rater 2.
scapular and thoracic movement outside of the participant's base of support, thereby requiring the participant to utilize proprioception, balance, strength, and increased range of motion (ROM). As such, the current researchers set out to compare whether a modified version of the UQYBT, which may be more easily employable in some clinical settings, correlated with the UQYBT. Specifically, the researchers intended to explore agreement between the mUQYBT and the UQYBT when scored by a single tester as well as comparing scores between two testers on the mUQYBT. The researchers found adequate agreement between scores on the mUQYBT and the UQYBT when scored by a single tester as well as comparing scores between two testers on the mUQYBT. The researchers also discovered an acceptable level of agreement between two testers on the mUQYBT. Therefore, the investigators suggest the mUQYBT can be used as an alternative testing procedure to the UQYBT.

In the current investigation, Pearson product moment coefficients suggest a high level of relationship (tester 1 = .96, tester 2 = .96) between the mUQYBT and the UQYBT. Calculated coefficients of determination demonstrated that scores on each test accounted for a large portion of the score of the other test (tester 1 = 92.2%, tester 2 = 92.0%). Since the mUQYBT was designed to mimic the UQYBT, the highly correlated relationships would be expected. Therefore, examinations of the agreement between scores on the two tests were warranted.

Bland-Altman plot were conducted for agreement on each rater's score between the UQYBT and the mUQYBT. Mean differences, and the associated 95% CI for both raters suggests that the mUQYBT may systematically bias toward a slightly larger composite score. Also, the wider limits of agreement suggest potential slight disagreements between composite scores produced by the testing methodologies. Since all measures include error in addition to the true score, an understanding of minimal detectable change in an outcome score could provide context.

| Table 2. Inter-rater Comparisons of the mUQYBT and the UQYBT Composite Scores |
|-------------------------------------------------|-------------------------------------------------|
|  | ICC | 95% LOA Lower (95% CI), Upper (95% CI) |
| Inter-rater Comparisons (composite scores) | ICC (95%CI) | Mean Difference (95%CI) | Standard Error of Mean Difference | SDdiff | mUQYBT= Modified upper quarter Y-balance test, UQYBT= Upper quarter Y-balance test, LOA= limits of agreement |
| mUQYBT | .99 (.98,1.0) | .62 (.21, 1.03) | .201 | 1.27 | -1.87 (-2.6, -1.2), 3.11 (2.4, 3.8) |
| UQYBT | .98 (.96, 99) | .22 (.49, .93) | .352 | 2.23 | -4.15 (-5.4, -2.9), 4.58 (3.4, 5.8) |
The ability to make a direct comparison to the previously mentioned study. However, the composite score is derived from the sum of excursion measurements normalized by three times the limb length and multiplied by 100, so a very general comparison between measures might provide a starting point for comparison. The current reported between tester ICC (2,1) for the UQYBT composite scores are high, .98, which is similar to previously reported 1.0 for excursion scores using ICC (3,1). Similarly, the current researchers demonstrated comparable between tester ICC (2,1) for the mUQYBT, .99.

The current researchers conducted further between tester analyses exploring score agreement on the mUQYBT and the UQYBT using Bland-Altman plots. While the ICC examines the correlation, or relationship, between measurements, an assessment of agreement between scores using Bland-Altman is important as well. Mean differences and limits of agreements for the composite scores on the Bland-Altman suggest acceptable agreement on face value (Table 2). Further understanding and comparison of the mean differences and limits of agreement would be aided by published minimal detectable change statistics for UQYBT composite scores.

Anecdotally, the participants preferred the mUQYBT over the UQYBT; they felt more stable and less likely to compromise equilibrium since their stationary arm was on the ground with the mUQYBT versus on an elevated block for the UQYBT. The reported sense of stability may account for the slight increase in composite scores on the mUQYBT compared to the UQYBT. Since the mUQYBT produced similar outcomes to the UQYBT, we suggest implementing the mUQYBT as a PPM in clinical settings where the proprietary UQYBT equipment may be cost prohibitive. The mUQYBT can be utilized as a PPM to help assess bilateral musculoskeletal function in overhead athletes.

The overall sample size (n=40) in this comparison pilot study was small and therefore the reader should use his/her own discretion when interpreting the results of this study. Even though the sample size was n=40, the UQYBT produced similar outcomes to a previous study whose sample size was n=96. Another consideration for the small sample size, is that this was a pilot study that accompanied a larger study involving the shoulder complex. Regardless
of sample size or the fact that this is a pilot study part of a larger study, the mUQYBT produced similar results compared to the standard UQYBT.

**CONCLUSION**

The current investigation supports the mUQYBT as a viable alternative for the UQYBT. Utilization of the mUQYBT could prove beneficial as a clinical PPM when and where the UQYBT may be cost prohibitive, such as secondary schools with limited budgets as well as multi-site research. Further research is warranted to confirm the current relational and agreement numbers between the mUQYBT and the UQYBT. Investigators also need to explore the test-retest performance of the mUQYBT. Investigators can also explore the modified kit for agreement on the lower quarter Y-balance test as well. Once the properties of the test kits are confirmed, further testing can be initiated to explore the role of the mUQYBT in clinical decision-making.

**REFERENCES**

ABSTRACT

Background: The Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) has been proposed as an option to assess upper limb function and stability; however, there are few studies that support the use of this test in adolescents.

Purpose: The purpose of the present study was to investigate the intersession reliability and agreement of three CKCUEST scores in adolescents and establish clinimetric values for this test.

Study Design: Test-retest reliability

Methods: Twenty-five healthy adolescents of both sexes were evaluated. The subjects performed two CKCUEST with an interval of one week between the tests. An intraclass correlation coefficient (ICC\(^{3,3}\)) two-way mixed model with a 95% interval of confidence was utilized to determine intersession reliability. A Bland-Altman graph was plotted to analyze the agreement between assessments. The presence of systematic error was evaluated by a one-sample t test. The difference between the evaluation and reevaluation was observed using a paired-sample t test. The level of significance was set at 0.05. Standard error of measurements and minimum detectable changes were calculated.

Results: The intersession reliability of the average touches score, normalized score, and power score were 0.68, 0.68 and 0.87, the standard error of measurement were 2.17, 1.35 and 6.49, and the minimal detectable change was 6.01, 3.74 and 17.98, respectively. The presence of systematic error (p < 0.014), the significant difference between the measurements (p < 0.05), and the analysis of the Bland-Altman graph infer that CKCUEST is a discordant test with moderate to excellent reliability when used with adolescents.

Conclusion: The CKCUEST is a measurement with moderate to excellent reliability for adolescents.

Keywords: Reproducibility of results; adolescent; upper extremity

Level of Evidence: 2b
INTRODUCTION

Evaluation tests of the upper limb are widely used in clinical and sports practices to provide important information about functional performance. Specifically, dynamic tests, whether in an open kinetic chain (pull-up, throwing test, and shot putting) or closed kinetic chain (one-arm hop test, upper quarter Y-Balance-Test and the Closed Kinetic Chain Upper Extremity Stability Test) enable not only the identification of possible deficits in strength and muscular power but also to evaluate proprioception and motor control. These evaluation tests of upper limb performance complement the analysis of the individual segments and provide quantitative data on progress and the effectiveness of rehabilitation programs.

The Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) is one option for examining upper limb stability. The test is easy to administer, cost-effective, easily understood, and has been validated by the peak torque of internal/external shoulder rotation (isokinetic dynamometer), and maximum grip strength (hand dynamometer), through Pearson correlation coefficients with the average values of the CKCUEST. This test consists of counting how many times the subject performs alternating touches on the opposite hand in a closed kinetic chain position (push-up) over 15 seconds, with three trials and allows three potential scoring outcome measures: average touches (the average of the three trials), a normalized score, and power score. The normalized score is obtained by dividing the number of touches by subject height. The power score is obtained by multiplying the average number of touches by 68% of subject's body weight (kg) divided by 15.

The use of the CKCUEST as an assessment of upper limb function is increasing both by rehabilitation professionals and by researchers. Authors have determined normative values for the test, and have compared results with results of other tests that aim to evaluate upper limb function. In addition, the CKCUEST has also been used to identify risk factors for shoulder pain, determine the effectiveness of different types of intervention, and to determine their predictive ability for performance of a sport specific task.

Additionally, the literature has provided clinimetric values that reinforce the practical relevance of the CKCUEST, allowing reliable use of data collected both in clinical and sports environment and for research. Some researchers have found excellent levels of interday reliability—assessed by an intraclass correlation coefficient (ICC)—for athletes over the age of 18 (ICC = 0.92), adults with shoulder impingement syndrome (ICC ≥ 0.82), and for healthy adults (ICC = 0.97). Although the above studies provide excellent levels of reliability for the CKCUEST, their results cannot be applied to other populations, especially adolescents, who, for the purpose of this research, are defined as athletes between 15 and 19 years old.

The adolescent population has increased vulnerability to musculoskeletal injury, therefore the use of functional tests can contribute to the assessment of this population. However, the reliability of the CKCUEST in adolescents has not yet been established. The primary purpose of the present study was to examine the reliability CKCUEST on a sample of adolescents, and a secondary purpose was to establish clinimetric values for this test.

METHODS

Sample

For sample size calculation, the following equations described by Shoukri, Asyali, and Donner in the Gpower 3.1.7 program was used considering the following values: α = 0.05; β = 0.10 (90%); power correlation ratio to null hypothesis (PHo) = 0.40; correlation ratio for alternative hypotheses (PHe) = 0.80, and a potential loss of 20%. A minimum required sample of 31 subjects was determined.

Subjects aged between 15 and 19 years old, all of whom were healthy, physically active and had no history of injury to the upper limb, were included in this research. Exclusion criteria included refusal to perform the test and the anthropometric measurements, and/or absence from the second evaluation. Because of the departure of six participants, the total sample was composed of 25 adolescents (14 girls and 11 boys), reflecting a final statistical power of 89.64%. Demographic characteristics of all participants are presented in Table 1.
The study was approved by the Research Ethics Committee of the University of Pernambuco – Brazil.

Procedures
After the signed consent forms were collected, information was gathered regarding the age of the subjects, body weight (kg) and height (m) measurements were performed using a digital scale and a portable stadiometer. The first CKCUEST was then performed. Prior to the study, the evaluators responsible for measuring were properly trained. In order to examine test-retest reliability, avoid possible memory effects and adaptation to the test, the second assessments were performed after an interval of seven days. In addition, the subjects were not informed about the scores obtained during the first evaluation at the time of reassessment in order to minimize the motivational effects.

The CKCUEST was carried out following the guidelines as described by Tucci et al. during this test, the boys assumed the push-up position and the girls assumed the modified push-up position (with knee support), with both hands positioned on two pieces of tape affixed to the ground at a distance of 91.4 cm apart (Figure 1). The subject remained in the push-up position while they alternatively touched the opposite hand, for a period of 15 seconds. Each subject was allowed to perform the test once submaximally in order to familiarize themselves with the task prior to the execution of the three repetitions of the actual test. One evaluator was responsible for counting the number of touches, and the other evaluator timed the test and verbally informed the first evaluator of the beginning and end of the test. Evaluators gave verbal cueing during the test to encourage the maximum effort of the subjects. Three repetitions of the 15-second CKCUEST were performed with an interval of 45 seconds between each test. The average touches score was calculated on the basis of the arithmetic mean number of touches recorded during the three attempts. The normalized score, the score was calculated by dividing the average number of touches by the subject’s height in meters. The power score was obtained by the product of the average number of touches and 68% of body weight in kilograms divided by 15.

Statistical Analysis
The statistical procedures were conducted using two computer software packages: Statistical Package for Social Sciences (SPSS) version 20.0 and GraphPad Prism version 5.03. The distribution of the numerical data concerning the age, body weight, height,
The average score, normalized score, and power score was evaluated using the Shapiro-Wilk test with a significance level of 0.05. In cases where the distribution was symmetrical (scores, body weight, and height) the measures of central tendency and dispersion were presented on average and standard deviation and for cases where the distribution was asymmetrical (age) the data was evaluated in the form of median and interquartile range amplitude.

The comparison between the two scores (first evaluation and re-evaluation) was accomplished using a paired *t* test. The relative reliability analysis was calculated using the intraclass correlation coefficient (ICC) two-way mixed model, with the absolute consent method and presentation of confidence interval 95% (CI 95%). ICC values above 0.75 were considered to represent excellent reliability; values between 0.40 and 0.74 represented moderate reliability; and values less than 0.40 indicated poor reliability. In addition, a Bland-Altman chart was plotted for each score from the CKCUEST to verify the absolute agreement between the first and second assessment, from the scatter plot between the difference of the two assessments and the average of the two evaluations. That way, it was possible—accounting for bias—to determine the error limits of agreement, outliers, and trends. Systematic error was verified using a one-sample *t* test based on the average of the difference between testing and retesting and accepting the significance level of less than 0.05.

The Standard Error of Measurement (SEM) was calculated to estimate the variance of each score and the Minimal Detectable Change (MDC) was also evaluated to determine the threshold value for measurement error. Both were calculated by the respective equations:

$$SEM_{95\%} = SD \cdot \sqrt{(1-ICC_{test-retest})},$$

for which the SD is the standard deviation of the mean of the first evaluation (test).

$$MDC = 1.96 \cdot SEM_{95\%} \cdot \sqrt{2},$$

for which the constant 1.96 represents the z-score associated with the 95% confidence level.

**RESULTS**

The description and comparison of the average touches score, normalized score, and power score in the first and second evaluation, as well as the results of the ICC with their respective 95% confidence intervals, SEM, and MDC for each score of the CKCUEST are presented in Table 2 and Table 3.

<table>
<thead>
<tr>
<th>CKCUEST score (n=25)</th>
<th>Average touches</th>
<th>Normalized score</th>
<th>Power score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test</td>
<td>Retest</td>
<td>Test</td>
</tr>
<tr>
<td></td>
<td>25.6 (3.8)</td>
<td>28.0 (5.4)*</td>
<td>14.8 (2.4)</td>
</tr>
</tbody>
</table>

* p<0.05, when test was compared to retest.

<table>
<thead>
<tr>
<th>CKCUEST score (n=25)</th>
<th>Scores</th>
<th>ICC (CI 95%)</th>
<th>SEM</th>
<th>MDC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average touches</td>
<td>0.68 (0.26 – 0.86)</td>
<td>2.17</td>
<td>6.01</td>
</tr>
<tr>
<td></td>
<td>Normalized score</td>
<td>0.68 (0.27 – 0.86)</td>
<td>1.35</td>
<td>3.74</td>
</tr>
<tr>
<td></td>
<td>Power</td>
<td>0.87 (0.64 – 0.95)</td>
<td>6.49</td>
<td>17.98</td>
</tr>
</tbody>
</table>
The agreement analysis between measurements of the three scores—average touches, normalized, and power—can be observed in Figures 2, 3 and 4, respectively. The chart reveals that the bias for the three scores was within the limits of agreement and close to zero, and that outliers were present. The presence of statistical differences in the one-sample $t$ test for the average score ($p = 0.012$), normalized score ($p = 0.014$) and power score ($p = 0.009$) indicates the presence of systematic error.

**DISCUSSION**

The absence of studies that have determined the reliability of the CKCUEST for assessing upper limb functional performance in an adolescent population motivated this study. Despite the relative coefficients demonstrating moderate to excellent reliability values, the examination of agreement still shows fluctuations, being possibly linked to the form of measurement and individual adaptation to the test. In short, the results of this study demonstrate that the CKCUEST has moderate to excellent reliability for evaluation of upper limb stability in adolescents when performed in just one familiarization session.

Previous authors that have assessed the test-retest reliability of the CKCUEST have demonstrated excellent reliability values when three to seven day intervals were allowed between sessions. Goldbeck & Davies initially developed this test as an alternative for evaluating the function of the upper limb in a closed kinetic chain manner, observing an equivalent ICC of 0.92 for the score when referring to average touches. Tucci et al. assessed the reliability of three groups of adults: physically active, sedentary and healthy, and sedentary with diagnosis of impingement syndrome in the shoulder (SIS). The authors demonstrated ICCs ranging from 0.85 to 0.96 in the average touches score, 0.87 to 0.96 for the normalized score, and 0.82 to 0.96 for the power score. Recently, Lee & Kim assessed the reliability of the CKCUEST in 40 male and female adults and also found excellent reliability values for the average touches score (ICC = 0.97). In addition, the authors evaluated the concurrent validity of the CKCUEST and found a strong positive correlation with the values of maximum grip strength ($r = 0.78–0.79$) and peak torque of the internal and external shoulder rotators ($r = 0.87–0.94$), measured by hand and isokinetic dynamometer, respectively.

However, it should be emphasized that the aforementioned studies used a relative reliability analy-
sis (ICC), which is subject to overestimated values of reliability. Deceptive reliability values can occur because when measuring a variable group of different subjects, it is expected that measures although different, can get too close to the average, thus producing high values of ICC. Thus, the use of methods that assess the variance and data agreement appear as an additional option and have been widely used in studies assessing the reliability of muscle strength measures, such as one-repetition maximum tests. In order to avoid erroneous conclusions about the reliability levels, the current study assessed not only the ICC, but also utilized an analysis of the Bland-Altman plots which allowed the authors to better examine models of variance and agreement between measurements, thus aiming to make conclusions about the results more complete.

The reliability values found in the results of the current study are lower than those found in the previous studies, therefore, it is important to highlight the difference between studied populations. Since there are no other studies that assess the CKCUEST in adolescents, a comparison of the values to other adolescents is not possible. Therefore, it is appropriate to explore the possible reasons for the lower reliability values seen in this group of adolescents compared to prior results obtained with adults. Tucci et al. speculated that the anthropometric characteristics of individuals can influence the results of the tests, especially because the equations used to calculate two of the scores depend on body weight and height variables. In addition, the authors suggest that the standardization of the distance between the hands during the test (91.4 cm) may be a factor that contributes to the result, positively or negatively, depending on the individual anthropometrics.

Anticipating that standardization of the hand measurement could change the test execution, Tucci et al. proposed comparing three variations of hand positioning in the CKCUEST (standard positioning, distance between the acromion processes, and 150% of the acromion-hand distance) and found that biomechanical testing (scapular kinematics, maximum force and time to maximum force) was independent of positioning; however, these findings has not been tested in adolescents - who are in the process of both neuromuscular and anthropometric maturation and development, and therefore the same results may not be observed.

The Bland-Altman graph is a good option to assess the agreement of a test and the present study used a graph to suggest that the CKCUEST in adolescents is a correlated test-retest measure and not very concordant. Confirmation of systematic error may indicate that the volunteer performed the test better or worse on revaluation due to factors such as learning effect or a change in motor behavior or motivation during the test performance. This can be assessed by the presence of outliers mainly in the average touches score and normalized score, the majority of the scores in the plots below zero, representing a negative bias, and by a significant increase in the average of the three scores in the second evaluation.

The differences between the first and second evaluations allows speculation that familiarization can change the results of the CKCUEST. This hypothesis is also supported in studies that evaluate the one-repetition maximum test on strength exercises (1-RM), in which it has been seen that more than one session familiarization session on different days is required for load stabilization. Considering that Lee & Kim found a strong correlation between CKCUEST and muscle strength measurements, it can be speculated that the variation of this test may be similar to the 1-RM tests. Another factor that could influence the results of the revaluation is the motivational issue since the subjects were encouraged to make as many touches as possible. However, the authors of this study believe that this factor was minimized, since the verbal encouragement were offer by the same tester and did not varied between the two days and the subject did not have access to an amount of touches completed in the first evaluation.

The CKCUEST is a multi-joint movement assessment, which induces instability in the subject and performance can depend on muscular strength levels, balance, coordination, and, consequently, the physical ability of the individual. These factors raise the need to investigate whether only a single session would be sufficient to indicate the actual value of the subject's performance, considering that no previous study has investigated the amount of attempts required for the stabilization of CKCUEST values.
The performance requirements of the test itself seemed to present a considerable challenge to the some subjects, requiring processing time for learning and motor control and possibly requiring practice sessions on different days for familiarization.

Regarding the variability of the CKCUEST, a small standard error is present, so it is expected that the average touches scores, normalized scores, and power scores will be slightly different when repeated by the same individual but at different times, an expected error value of 2.17, 1.35, and 6.49 respectively. Only Tucci et al\(^1\) previously evaluated the SEM of the CKCUEST. The SEM in their research for average touches ranged from 1.45 to 2.76 touches between groups, from 0.02 to 0.04 touches/height for the normalized score, and from 8.52 to 28.32 touches x 0.68 kg/m for the power score. Although several different populations were studied by Tucci et al,\(^1\) Weir\(^2\) has suggested that the value of SEM is independent of the population subjected to the test, and instead is a fixed characteristic value of the measure.

Finally, for the minimum detectable change interpretation, it is important to differentiate the values obtained in a CKCUEST that may be related solely to measurement error. Tucci et al\(^3\) indicated that the MDC values for their adult populations ranged from 2 to 4 points for the average touches score, from 0.03 to 0.06 for the normalized score (touches/height), and from 9 to 29 touches x 0.68 kg/m for the power score. The results of the present study indicate that in adolescents the minimum difference that is not attributable to variation of measurement is seen with values above 6 touches on the average touches score, 4 in the normalized score, and 18 in the power score.

Some limitations can be described in this study. Failure to stratify the sample by sex and the use of physically healthy adolescents, makes the study restricted regarding extrapolation for other populations, be they healthy or with any pathological conditions. Thus, it is suggested that further studies be carried out dealing with greater sample sizes and different age groups and populations that have different types of dysfunction in the kinetic chain of the upper limb to allow for further development of normative values for the adolescent population.

Another limitation concerns the execution of a single familiarization session. It has been suggested that multiple tests be conducted on different days in order to assess accurately the number of sessions necessary for stabilization of test scores. It is possible that better standardization of the distance between the hands according to the anthropometry of adolescents and the determination of the number of attempts to stabilize the values could contribute to better implementation and completion of the test. Moreover, the form of to equate standardization of the current scores may not be suitable for adolescents. Considering these limitations, the authors believe that future studies should perform allometric analysis in order to get the best CKCUEST standardization system for adolescents.

CONCLUSION
The CKCUEST is a tool that demonstrates questionable reliability levels for use in assessing stability and functional performance of the upper limb of adolescents when subjects were provided only a single familiarization attempt. The results show moderate to excellent reliability, and relative agreement between the three scores derived from the evaluation.

REFERENCES


ABSTRACT

**Background & Purpose:** Insertional Achilles tendinopathy (IAT) can be a challenging condition to manage conservatively. Eccentric exercise is commonly used in the management of chronic tendinopathy; however, it may not be as helpful for insertional tendon problems as compared to mid-portion dysfunction. While current evidence describing the physical therapy management of IAT is developing, gaps still exist in descriptions of best practice. The purpose of this case report is to describe the management of a patient with persistent IAT utilizing impairment-based joint mobilization, self-mobilization, and exercise.

**Case description:** A 51-year-old male was seen in physical therapy for complaints of posterior heel pain and reduced running capacity. He was seen by multiple physical therapists previously, but reported continued impairment, and functional restriction. Joint-based non-thrust mobilization and self-mobilization exercise were performed to enhance his ability to run and reduce symptoms.

**Outcomes:** The subject was seen for four visits over the course of two months. He made clinically significant improvements on the Foot and Ankle Activity Measure and Victorian Institute of Sport Assessment-Achilles tendon outcomes, was asymptomatic, and participated in numerous marathons. Improvements were maintained at one-year follow-up.

**Discussion:** Mobility deficits can contribute to the development of tendinopathy, and without addressing movement restrictions, symptoms and functional decline related to tendinopathy may persist. Joint-directed manual therapy may be a beneficial intervention in a comprehensive plan of care in allowing patients with chronic tendon changes to optimize function.

**Level of Evidence:** Therapy, Level 4

**Keywords:** Ankle, Achilles tendon, manual therapy, pain

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BACKGROUND AND PURPOSE

Insertional Achilles tendinopathy (IAT) can be a challenging condition to manage in runners, with prevalence estimates ranging between 6.5-18%. The etiology of Achilles tendinopathy is typically multifactorial, including intrinsic risk factors (i.e. diabetes, obesity, hypertension, hyperlipidemia, abnormal ankle dorsiflexion (DF) range of motion (ROM), impaired plantarflexor (PF) strength, and excessive pronation) and extrinsic factors (such as training errors or incorrect footwear). Medications such as statins and fluoroquinolones have been implicated in the development of tendinopathy. IAT often manifests as ossification of the enthesial fibrocartilage. Tendon degeneration may also occur at the tendon-bone interface resulting in micro tears within the tendon. Haglund’s deformity, a boney prominence at the posterosuperior aspect of the calcaneal tuberosity, is often seen in combination with IAT, however a direct link of this bony variant to symptoms is not consistent. Interestingly, IAT has been associated with inflammatory arthropathies, but causative associations have not been described.

The diagnosis of IAT is typically based on clinical examination, including complaints of decreased functional levels, localized posterior heel pain, tenderness and thickening at the Achilles insertion on palpation, and other tissues being excluded as primary pain generators. The benefit of diagnostic imaging is under debate, as up to 59% of asymptomatic tendons may show abnormalities on imaging, yet normal imaging studies do not rule out the tendon as the source of pain. More specifically, magnetic resonance imaging in patients with IAT may demonstrate microtearing within the tendon at the insertion into the calcaneus while ultrasound imaging has shown larger tendon diameter and lower echogeneity in those with IAT. Lower echogeneity within the tendon on the involved extremity may also be associated with greater symptom severity.

Conventional conservative treatment for IAT has included rest, orthotics and footwear modification, extracorporeal shockwave therapy, eccentric training, stretching and soft tissue management. Eccentric calf-muscle strengthening has been generally successful in the management of mid-portion Achilles tendinopathy, yet the effects for patients with IAT are less positive. It could be postulated that IAT does not respond as well due to decreased vascularity and increased mechanical compression between the calcaneus and the Achilles tendon. With regard to medical management, promising results were noted in a pilot study using sclerosing therapy at areas of neovascularization in 8 of 11 subjects, including 8-month follow up. Surgical intervention is usually reserved until after six months of conservative treatment has failed.

Currently, there is limited direct evidence to support the use of joint based manual therapy in this population. In fact, clinical trials assessing effectiveness of conventional treatment for IAT do not include joint based manual therapy in either group. This is interesting, as foot and ankle mobility deficits have been described as a risk factor in the development of Achilles tendinopathy. Additionally, emerging evidence indicates calcaneal osteoarthritic (OA) changes may be present in this population. Considering how OA conditions have responded positively to joint mobilization, it would seem appropriate to utilize joint mobilization in this population as well. There is also evidence to support the use of joint based manual therapy to those with tendon pathology at other regions. Although not described in the IAT population, joint mobilization can improve local joint biomechanics, act neurophysiologically at the local, spinal, and supraspinal levels and may correct imbalances in conditioned pain modulation by facilitating descending pain inhibition.

While evidence is emerging to understand best practice in the conservative management of patients with IAT, gaps in the literature still exist, specifically in regards to the effects of joint mobilization in this population. The purpose of this case report is to describe the management of a patient with persistent IAT utilizing impairment-based joint mobilization, self-mobilization, and exercise.

CASE DESCRIPTION

A 51 year-old male subject was seen in physical therapy for posterior heel pain. He provided verbal consent to publish his data. As this was a single case report utilizing safe clinical services, this work was deemed exempt from formal IRB review. He complained of a local superficial ache, reported as 0/10
at best and 5/10 at worst on the Numeric Pain Rating Scale (NPRS), and occasional stiffness at the Achilles tendon insertion, of insidious onset three years prior. Symptoms began after running his third marathon, which he believed may have been related to running with a new pair of shoes. His pain was aggravated by running more than five miles, and alleviated by stretching his calf, ice massage, and rest. He also reported ankle stiffness after sitting greater than 30 minutes, which would be alleviated after walking 15-20 steps. At the time of assessment he was running three to five miles per day on treadmills and trails, but not engaging in longer runs because of the pain. He was also swimming and performing upper and lower body resistance exercise 3 times each week. Aside from a left ankle sprain 30 years prior, his past medical history was unremarkable.

He reported multiple prior treatments. Six months following onset, he was seen by a PT where interventions included therapeutic ultrasound, electrical stimulation, and customized foot orthotics. He reported no improvement, and did not continue with the orthotics. Twelve months after symptom onset, he had a cortisone injection at the Achilles tendon insertion, which provided minimal, transient relief. Two years following symptom onset, he was seen by another PT. Throughout the plan of care he performed eccentric heel drops to neutral DF, calf stretching, ice massage to the insertion site, gluteal strengthening exercises, dynamic balance exercises in single leg stance, and he was prescribed over the counter inserts for arch support. He noted 75% reduction in symptoms, and continued with his home exercise program (HEP) following discharge, but longer running distances remained limited. His primary goal was to return to running marathons without symptoms.

**CLINICAL IMPRESSION #1**
The subject’s symptom report appeared consistent with chronic Achilles tendinopathy. This was based on the symptom location, nature, behavior, and no other local tissue dysfunction appearing more likely. Tendinopathy often responds well to eccentric tissue loading exercises, however, this intervention strategy had already been attempted, without a level of subject-preferred improvement. Mobility deficits are a risk factor for developing tendinopathy, and if not addressed, could contribute to persistence of symptoms and functional limitations. As such, the therapist believed interventions to improve local joint and/or soft tissue mobility (if impaired) would be necessary.

**EXAMINATION**
The subject was examined and treated by the same therapist (DJ) at each visit, with pertinent findings presented in Table 1. While symptoms were reported to be local to the ankle, proximal segments were screened and biomechanical assessment was performed to determine relevant contributing factors. Lumbar, hip, and knee screening, consisting of active range of motion (AROM) with overpressures in all planes, was negative for symptom reproduction. Hip extension was limited and when assessing joint mobility, a posterior-anterior (PA) glide of the right proximal femur was hypomobile. Bilateral and unilateral squats did not reproduce symptoms, although early heel rise was present, suggesting possible ankle DF mobility restrictions. Hip strength of the extensors and abductors were tested in prone and sidelying, respectively, and were graded as normal bilaterally. No symptoms were noted on the left. As neural pathology may contribute to heel pain, neurodynamic mobility was assessed in supine with the straight leg raise. Modifications were made to bias the neural structures in the lower limb by adding ankle PF with inversion, PF with eversion, and DF, yet the subject’s primary symptoms were unprovoked.

Passive and dynamic testing of the ankle complex followed proximal tissue screening. Pain was reported during the push off phase of a single leg hop, which was evaluated for symptom provocation and analysis of single limb landing patterns. Ankle PF endurance was measured by single-leg heel raise repetitions. Pain limited performance on the right. Ankle DF ROM, measured with a inclinometer in standing, was restricted on the right. However, when the subject’s knee was flexed, right ankle DF ROM increased, indicating a probable impairment of gastrocnemius length. Upon palpation, tenderness and thickening at the insertion of the right Achilles tendon and increased resting tension of the right gastrocnemius, yet no trigger points or referred pain to the posterior calcaneus was noted. The midportion of the Achilles tendon, retrocalcaneal bursa, posterior tibial nerve,
and plantar fascial origin were not tender. Talocrural and subtalar joint (STJ) accessory motion was restricted on the right, while the left was normal.

**Outcome Measures**

A number of objective and self-reported functional outcome measures were used to determine progress. The Victorian Institute for Sport Assessment developed a valid and reliable self-reported functional scale for disability related to Achilles tendon dysfunction (VISA-A). The VISA-A is comprised of 8 questions, scored 0 to 100, with lower scores indicating greater disability. It was shown to have good test-retest (r = 0.93), intrarater (r = 0.90), and interrater reliability (0.90). A recent initial investigation determined the minimal clinically important difference (MCID) to be 6.5 points in this population. The Foot and Ankle Measure (FAAM) is another reliable, responsive, and valid self-reported outcome measure used for a variety of musculoskeletal disorders of the lower extremity. It includes a 21-item activities of daily living (ADLs) and 8-item sports subscale, each question graded 0 (unable to to) to 4 (no difficulty), with higher scores indicating higher levels of function. The MCID for the ADL and Sports subscales were found to be 8 and 9 points, respectively. At discharge, the Global Rating of Change (GROC) scale was administered. The GROC scale is a self-reported 15 point Likert scale with -7 being a ‘a very great deal worse’, 0 being ‘no change’ and +7 being ‘a very great deal better’. A change of 3 or more points was determined to be a clinically important difference. Additional measures of change were the number of heel raise repetitions performed, pain response, and single leg hop as these were functional movements that recreated his symptoms.

### Table 1. Examination Findings

<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
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</thead>
<tbody>
<tr>
<td><strong>Location of Symptoms</strong></td>
<td>Right achilles tendon insertion</td>
</tr>
<tr>
<td><strong>Biomechanical Assessment</strong></td>
<td>Early heel rise present with single and double leg squat; Single leg hop test increased pain (3/10)</td>
</tr>
<tr>
<td><strong>Proximal Joint Screening</strong></td>
<td>Negative for symptom reproduction</td>
</tr>
<tr>
<td><strong>Neurodynamic Mobility</strong></td>
<td>Negative for symptom reproduction</td>
</tr>
<tr>
<td>(straight leg raise)</td>
<td></td>
</tr>
<tr>
<td><strong>Strength / Endurance</strong></td>
<td>5/5 hip abductors and extensors,</td>
</tr>
<tr>
<td></td>
<td>Heel raise repetitions: Right 20 (limited by 5/10 pain), Left 25</td>
</tr>
<tr>
<td><strong>Joint Accessory Motion</strong></td>
<td>Hypomobile PA glide right proximal hip</td>
</tr>
<tr>
<td></td>
<td>Hypomobile AP glide right talocrural joint</td>
</tr>
<tr>
<td></td>
<td>Hypomobile lateral glide right subtalar joint</td>
</tr>
<tr>
<td><strong>Ankle DF ROM</strong></td>
<td>Left: 42°</td>
</tr>
<tr>
<td>(in standing)</td>
<td>Right: 54°</td>
</tr>
<tr>
<td><strong>Palpation</strong></td>
<td>Tenderness (6/10) and thickening of involved achilles tendon at insertion</td>
</tr>
<tr>
<td><strong>Self-Reported Outcome</strong></td>
<td>VISA-A: 57%</td>
</tr>
<tr>
<td>Measures</td>
<td>FACAM: ADL subscale 65.5%, Sport subscale 40.6%</td>
</tr>
</tbody>
</table>

AP: anterior-posterior; DF: dorsiflexion; FAAM: foot and ankle measure; PA: posterior-anterior; ROM: range of motion; VISA-A: Victorian Institute of Sport Assessment – achilles tendon
CLINICAL IMPRESSION #2
Presenting signs and symptoms appeared consistent with IAT. This was supported by the symptom report, tenderness to palpation with thickening noted at the Achilles insertion on the calcaneus, the absence of tenderness at other locations around the foot and ankle, and no symptom reproduction with proximal joint screening. Neurodynamic testing was normal, and the symptoms were made better or worse with activity, in a pattern consistent with musculoskeletal pathology, making systemic disease processes less likely. Clinical findings were supported by diagnostic ultrasound imaging showing hypoechoic signal with loss of the typical fibrillary pattern of the right Achilles tendon at its insertion.

Despite improvement with the subject’s second PT episode of care, the subject had experienced ongoing symptoms. As such, the therapist attempted to provide an intervention not previously offered. Joint-directed impairment-based manual therapy was added to exercise and activity modification, in attempts to decrease pain, improve mobility, and decrease strain on the Achilles tendon insertion site. The specific techniques, clinical rationale, and results of manual therapy techniques can be seen in Table 2, and were performed as described by Maitland et al.29

INTERVENTION
Visit 1 – Evaluation
Following the examination, a grade IV anterior-posterior (AP) non-thrust mobilization of the right talocrural joint (TCJ) was performed secondary to limitations noted during right ankle DF (Figure 1). This intervention was selected to decrease the strain on the PF mechanism, improve ankle hypomobility, and decrease pain. The technique was performed until more joint mobility was noted. Heel raises were re-evaluated for repetitions and pain response. After manual therapy, the subject was able to perform the same number of repetitions, but with 2/10 pain, rather than the 5/10 pain reproduced earlier. For a HEP he was instructed to continue with eccentric exercise 3 sets of 15 repetitions, to neutral dorsiflexion, and 3 sets of 30 second duration calf stretching each to be performed twice daily. Different from previous therapy, the subject was instructed to maintain a more neutral rearfoot position during the stretch, to decrease possible unilateral strain on the Achilles tendon.

<table>
<thead>
<tr>
<th>Table 2. Manual therapy interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visit</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>1 (evaluation)</td>
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<td></td>
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<td>2</td>
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<tr>
<td>3</td>
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<td></td>
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<tr>
<td>Abbreviations: AP: anterior-posterior; DF: dorsiflexion; HEP: home exercise program; PA: posterior-anterior; ROM: range of motion; STJ: subtalar joint; TCJ: talocrural joint</td>
</tr>
<tr>
<td>*Each technique was performed until the treating therapist noted improved joint mobility, a specific timed dosage was not utilized</td>
</tr>
</tbody>
</table>
increased PF activity. The therapist performed a grade IV lateral subtalar glide (Figure 2) until mobility improved, after which the hop test was retested and was asymptomatic. The subject was instructed to continue with eccentric exercise and stretching as before, with five minutes of daily self-mobilization of the STJ (Figure 3) added to maintain the improved mobility between sessions.

Visit 3 – 4 weeks after evaluation
The subject reported continued symptomatic and functional improvement. He was running 7-10 miles daily without symptoms. At 11 miles he had 2/10 pain, but mentioned that cardiorespiratory endurance was more of a limiting factor than pain. Upon examination, both the hop test and heel raises were asymptomatic, and palpation of the Achilles insertion was less tender (2/10). The VISA-A and FAAM were re-administered, with clinically significant improvements noted.

Despite improvements, symptoms remained, prompting the therapist to re-examine other possible contributing factors. Running gait was re-examined using simple video analysis, and while asymptomatic, early

Visit 2 – 2 weeks later
The subject reported improvement after the initial evaluation. He reported running five miles each day, with 3/10 pain at worst, and reported consistency with his HEP. Upon examination, stiffness remained of the talocrural and STJ, but the Achilles was less tender to palpation (4/10), and he was able to perform 22 heel raises with 2/10 pain. A grade IV+ AP TCJ mobilization was performed in an attempt to improve ankle mobility and, decrease undue tendinous strain. Immediately after joint mobilization, he was able to perform 25 repetitions without pain.

With ankle PF endurance improved and less symptomatic, his single leg hop was retested in order to find another comparable sign and associated contributing factors. Insertional Achilles pain was present, but at a reduced intensity compared to initial evaluation. While TCJ mobility was improved, rearfoot hypomobility remained. Although minimal, STJ motion is necessary during the normal gait cycle, to prevent compensatory patterns, such as

Figure 1. Anterior-posterior talocrural joint non-thrust mobilization. With the patient in supine, the therapist grasps the posterior aspect of the distal tibiofibular region with the stabilization hand. A posteriorly force is directed toward the talus. The plantar aspect of the foot can rest on the therapist’s thigh to improve stabilization.

Figure 2. Subtalar joint lateral glide mobilization. With the patient sidelying on the involved side, the therapist stabilizes the distal tibia and fibula with one hand. With the other hand, the therapist grasps the calcaneus, distal to the talus, and provides a mobilization force perpendicular to the ground.
heal off and decreased hip extension was noted on the right. Early heal off can be a sign of ankle DF restrictions however ankle mobility was normal on re-assessment. Considering the hip mobility restriction present at initial evaluation, and impairment in functional extension ROM, the therapist theorized the subject had to over utilize the ankle PFs to propel himself forward, rather than using momentum and passive recoil through allowing the hip to extend. A grade IV++ passive physiologic mobilization was performed for hip extension on the right (Figure 4). Symmetrical running gait was noted afterwards. The subject was instructed to continue with his previous HEP, and add hip flexor stretching in half-kneeling, in order to maintain improved mobility.

Visit 4 – 8 weeks after evaluation
Due to scheduling conflicts, the subject was seen one month after his previous visit. At this time, he reported consistency with his HEP, no pain or stiffness, and was able to run 15 miles without symptoms. Upon examination, talocrural, subtalar, and hip mobility was normal. Hop testing was asymptomatic, and no heel rise was present with squat testing. Considering the subject’s progress, lack of symptoms, and independence with an HEP for long-term self-management, the subject was discharged with instructions to contact the PT should any questions arise.

OUTCOMES
The subject was seen in physical therapy for four visits over the course of two months. Primary outcomes can be seen in Table 3. Notably, the subject reported satisfaction with his symptom state after interventions, reported no functional disability on
multiple outcome measures, and reported feeling a very great deal better, as compared to initial evaluation. Improvements met the MCID for clinical significance, and were maintained at one-year email follow up, during which time he was able to run three full marathons without symptoms.

**DISCUSSION**

This case report details the inclusion of joint mobilization in the rehabilitation of an individual with persistent IAT. Despite a growing body of evidence regarding best practice in this patient population,12-15 the majority of authors do not describe utilization of joint-directed treatments. Although excessive ankle DF may contribute to the development of Achilles tendinopathy,2 ankle mobility restrictions contribute to abnormal tendon strain.2,40 If these mobility deficits are not eliminated, it could be hypothesized that chronic tendon dysfunction, and associated activity and participation restrictions, would persist.

In order to determine the need for joint mobilization in this population, current evidence must be considered. Eccentric tendon loading has been prescribed for treatment of both mid-portion and insertional Achilles tendinopathy.7,11,12,41,42 The research into the mechanisms for the efficacy of eccentric loading of the Achilles tendon remain ongoing. Eccentric exercise programs resulted in decreased tendon thickening,43 an absence of neovascularization in associated painful areas,44 and reduced pathologically increased capillary blood flow without changes of tendon oxygen saturation in subjects with both insertional and mid-portion Achilles tendinopathy.45 It has been reported that eccentric loading through full ROM is less successful for IAT,12,46 with only 32% of patients having good clinical outcomes in one report.16 At the insertion site where osteophytic changes are common, ankle dorsiflexion beyond neutral may create a mechanical impingement between the calcaneus, Achilles tendon and retrocalcaneal bursa.13 As such, modifications have been made to eccentric heel drop exercises, to end in a neutral dorsiflexion for patients with IAT. More positive outcomes have been noted with this adjustment,13 however 33% of patients reported dissatisfaction, indicating further research into best practice is indicated.

There has been a recent focus in the literature regarding the mechanistic effects of manual therapy. These effects include, but are not limited to, biomechanical and neurophysiological alterations. Biomechanically, limited ankle DF during gait has been associated with excessive STJ pronation.

<table>
<thead>
<tr>
<th>Table 3. Outcomes</th>
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<tr>
<td><strong>Outcome Measured</strong></td>
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<tr>
<td>Pain (NPRS)</td>
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<tr>
<td>VISA-A</td>
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<tr>
<td>FAAM Subscales</td>
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<td></td>
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<tr>
<td>GROC</td>
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<tr>
<td>Comparable Signs (right lower extremity)</td>
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ADLs: activities of daily living; FAAM: foot and ankle measure; GROC: global rating of change; NA: not applicable; NPRS: numeric pain rating scale; VISA-A: Victorian institute of sport assessment – achilles tendon
A relationship has also been shown between excessive pronation and the development of Achilles tendinopathy. Hypotheses for this include: (1) an increased tensile load on the medial tendon and (2) a “wringing” effect of the Achilles tendon. AP TCJ mobilizations have been shown to immediately improve DF ROM. An improvement in DF ROM may decrease the amount of compensatory STJ pronation as the lower limb advances over the ankle joint complex during, thereby decreasing the abnormal loading through the Achilles tendon. In this case, AP TCJ mobilizations were performed at the first two visits resulting in both within and between session improvements in pain and strength as tested by heel raises. Theoretically, normalization of talocrural and STJ coupling following AP TCJ mobilizations may explain the pain reduction seen in this patient. However, it may not be the only biomechanical explanation for the patients’ improvements.

Hip extension during terminal stance has been estimated to be 10° in healthy individuals. Similar to the foot-ankle complex, impaired sagittal plane motion at the hip during gait manifests as a compensatory and excessive tri-planar movement proximally. Hip rotational movement during gait has been shown to be temporally coupled to rearfoot pronation-supination during gait. Impaired hip extensor moments have also been seen in recreational runners diagnosed with Achilles tendinopathy. These relationships suggest hip function should be examined and treated as needed in this patient population. It is possible that immediate improvements in hip ROM following hip extension mobilizations at visit 3 may have facilitated normalizing the foot position for push-off.

While the positive effects of joint mobilization could be related to improvement in joint mobility and biomechanical alterations, there may be a neurophysiological explanation. Alterations of peripheral nociceptive biomarkers and enhanced conditioned pain modulation have been previously demonstrated following joint mobilization illustrating peripheral and central effects. Utilizing joint mobilization in this case may have provided a hypoalgesic effect through pain modulation and decreased pain-induced weakness. This is demonstrated by the immediate improvements in pain and performance of heel raise repetitions (a measure of strength) following talocrural and STJ mobilization. Immediate improvements in strength have been seen in numerous regions following joint mobilization and are likely explained by a combination of peripheral and central mechanisms.

As with every case report, limitations exist. Given the study design, no clear determination of the effectiveness of a single intervention is reasonable, and generalization of results is not possible. It could be argued that a number of confounding variables exist, and as such, results should be interpreted with caution, if not skepticism. However, in the absence of higher quality studies, investigations should be made into best practice management options for individuals with challenging health conditions. The authors hope this work will facilitate further investigation into best outcomes of the IAT population.

CONCLUSION

Insertional Achilles tendinopathy (IAT) can be a challenging condition to manage. Mobility deficits have been described as a risk factor for developing IAT, however no studies to date have investigated the utilization of joint-directed manual therapy for the IAT population. In this case a 51 year-old male with persistent IAT responded positively to eccentric exercise and impairment based manual therapy, with improvement maintained at one-year follow-up. Manual therapy may be a positive adjunctive intervention in the management of individuals with chronic tendon dysfunction.

REFERENCES


ABSTRACT

Background and Purpose: While there is limited evidence supporting the use of soft tissue mobilization techniques for Subacromial Pain Syndrome (SAPS), synonymous with subacromial impingement syndrome, previous studies have reported successful outcomes using soft tissue mobilization as a treatment technique. The purpose of this case report is to document the results of Instrument-Assisted Soft Tissue Mobilization (IASTM) for the treatment of SAPS.

Case Description: Diagnosis was reached based on the subject's history, tenderness to palpation, and four out of five positive tests in the diagnostic cluster. Treatment consisted of three visits where the IASTM technique was applied to the pectoral muscles as well as periscapular musculature followed by retesting pain-free shoulder flexion active range of motion (AROM) and Numerical Pain Rating Scale (NPRS) during active shoulder flexion. Scapulothoracic mobilization and stretching were performed after AROM measurement.

Outcomes: The subject reported an NPRS of 0/10 and demonstrated improvements in pain free flexion AROM in each of the three treatment sessions post-IASTM: 85° to 181°, 110° to 171°, and 163° to 174° with some carryover in pain reduction and pain free AROM to the next treatment. Through three treatments, DASH score improved by 17.34%, Penn Shoulder Score improved 29%, worst NPRS decreased from 4/10 to 0/10, and a GROC score of 6.

Discussion: IASTM may have a beneficial acute effect on pain free shoulder flexion. In conjunction with scapulothoracic mobilizations and stretching, IASTM may improve function, decrease pain, and improve patient satisfaction. While this technique will not ameliorate the underlying pathomechanics contributing to SAPS, it may serve as a valuable tool to restore ROM and decrease pain allowing the patient to reap the full benefits of a multi-modal treatment approach.

Level of Evidence: 5

Keywords: instrument assisted soft tissue mobilization, shoulder complex, subacromial impingement syndrome, subacromial pain syndrome

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BACKGROUND AND PURPOSE
Subacromial Pain Syndrome (SAPS), an improved nomenclature for what was previously categorized as Subacromial Impingement Syndrome (SIS), may account for as much as 30% of patients presenting with shoulder complex pain and dysfunction, rendering it the most prevalent of the shoulder diagnoses.  

Dierks et al define SAPS as “all non-traumatic, usually unilateral, shoulder problems that cause pain, localized around the acromion, often worsening during or subsequent to lifting of the arm.” Clinical diagnoses falling under this umbrella term include bursitis, tendinosis calcarea, supraspinatus tendinopathy, partial tear of the rotator cuff, biceps tendinitis, and tendon cuff degeneration. Common examination findings associated with SAPS include abnormalities with scapular kinematics and posterior glenohumeral (GH) joint capsule tightness; both of which may contribute to altered joint kinematics such as decreased upward rotation and posterior tilting of the scapula.

The effects of manual therapy (MT) as an intervention for SAPS have previously been investigated and yielded primarily low to moderate evidence supporting its efficacy as a treatment. In a meta-analysis, Desjardins-Charbonneau et al. reported with low to moderate levels of evidence that MT alone or in conjunction with other modalities may have a clinically important reduction in a patient’s pain. Their review looked almost entirely at the effects of GH joint mobilization as well as thrust and non-thrust mobilization of the cervical and thoracic spine on pain and range of motion in the shoulder complex. There has been limited and indirect research into the effects of soft tissue mobilization (STM) or Instrument Assisted STM (IASTM) as a primary treatment for SAPS, but these interventions have the potential to provide beneficial acute effects on pain, function, and patient satisfaction.

Low levels of evidence support STM as a successful intervention for reducing pain and increasing range of motion (ROM) in the shoulder complex. Al Dajah et al demonstrated success in reducing pain, increasing GH external rotation at 45° abduction, and overhead reach ROM with STM applied to the subscapularis. Laudner et al used IASTM applied to the posterior cuff musculature of healthy college-aged baseball players to significantly increase GH internal rotation and horizontal adduction ROM in one treatment. Tightness of the posterior cuff has been found to alter scapular kinematics and contribute to the cause of SAPS by displacing the scapula laterally. Surenkok et al experimented with the acute effects of scapulothoracic joint mobilizations and found improvements in shoulder ROM and scapular upward rotation. The authors of this study suggest that because the scapulothoracic joint is not a synovial joint but bound by muscle, that this intervention is successful in the dissolution of adhesions, realigning collagen, and increasing fiber glide. It is hypothesized that SAPS presenting with decreased upward scapular rotation without limitations in GH joint mobility, may be the result of soft tissue restrictions.

Under the theory that IASTM has the ability to reduce scar tissue related restrictions, break up adhesions, and improve mobility, the intervention was applied to the pectoral, latissimus dorsi, peri-scapular, and posterior cuff muscles. To further mobilize the soft tissue potentially restricting scapular movement, ST joint mobilizations were performed with the intention to increase ROM and improve function of the tissues stabilizing the ST joint. By extrapolating the findings from previous research studies, it is hypothesized that the proposed intervention will assist in normalizing scapulohumeral mobility and allow for the completion of therapeutic exercises to address the imbalances associated with SAPS. The purpose of this case report is to document the results of IASTM for the treatment of SAPS.

CASE DESCRIPTION: PATIENT HISTORY AND SYSTEMS REVIEW.
A right hand dominant, 20 year-old, male recreational weightlifter and barber by profession was referred to physical therapy by his primary care physician with a diagnosis of bilateral “sprain of the rotator cuff capsule”. The complaint originated about two weeks prior to his initial physical therapy (PT) evaluation with an onset of pain in bilateral shoulders approximately six hours after completing a shoulder workout targeting hypertrophy of the deltoid musculature. The subject reported introducing a new variation of the dumbbell lateral shoulder raise utilizing a range of 0° to about 110° abduction to his
routine. The subject's symptoms in the right shoulder subsided within a few days of the initial irritation, but the left shoulder symptoms increased over the course of the following two weeks. The subject ceased all upper body weightlifting except for training biceps and triceps in a neutral shoulder position as advised by his primary care physician. He had no complaints of pain while carrying out his job related tasks as a barber. The subject denied the use of any medications at the time of the examination and was in good health as verified by his physician during his annual physical one week earlier.

At the time of PT evaluation, the subject denied any numbness, tingling, or burning sensations. He reported perceived weakness in elevating the left shoulder above 90° due to pain. Pain with shoulder elevation was reported as a 4/10 on the Numeric Pain Rating Scale (NPRS) (ICC = .63). Pain in a neutral shoulder position at rest was reported as 0/10 on the NPRS. The subject described any pressing motion, such as performed during the flat or incline bench press, or overhead exercises as the most provocative movements, but he also experienced symptoms with reaching overhead and putting on a shirt. He stated, “I am not able to bring my left hand up to my hair.” The subject's goals were to eliminate pain with weight lifting and overhead activities.

EXAMINATION
Observation of body structure and posture revealed forward shoulder posture, under-developed left periscapular musculature compared to the right, elevated right shoulder compared to left, and an anterior pelvic tilt (Figures 1-2). Cervical spine screening was unremarkable and provided no recreation of symptoms. Examination of the thoracic spine revealed hypomobility and tenderness with passive accessory intervertebral movements of the T1-T7 vertebrae (κ = .13-.82). Palpation of the left supraspinatus tendon insertion at the greater tubercle elicited pain consistent with the subject's symptoms. Inspection of the left upper trapezius displayed increased tone with concurrent scapular elevation. Active Range of Motion (AROM) testing recreated painful symptoms at 85° left shoulder flexion although the subject was able to continue into 172° flexion before initiating lumbar and lower thoracic lordotic compensation. Complete ROM testing results are listed in Table 1.

Observation of scapulohumeral kinematics during shoulder flexion and abduction revealed movement system diagnoses of decreased upward rotation and posterior tilting of the scapula when compared to the

CLINICAL IMPRESSION #1
The subject experienced an insidious onset of shoulder pain after performing repetitions of shoulder abduction with a heavy load above 90°. Differential diagnosis consisted of a deltoid strain, rotator cuff strain, rotator cuff tear, cervical radiculopathy and SAPS. Due to his style of weight training as well as profession of barbering, the likelihood of underlying muscle imbalances, postural faults, and flexibility impairments were probable. These suspected impairments led the authors in the direction of SAPS as the manifestation of the underlying deficits as well as rendering the subject a good candidate for treatments addressing soft tissue abnormalities. The examination included ruling out cervical radiculopathy as a possible cause followed by strength, flexibility, palpation, and special testing of the shoulder complex to further isolate the underlying causes as well as movement-based diagnosis.
asymptomatic side. Passive GH joint mobility testing exposed a restriction of the left posterior capsule and a slight restriction of the left inferior capsule. Passive flexion ROM of the shoulder complex was similar bilaterally and both exhibited a muscular end-feel with overpressure. The subject demonstrated 5/5 and pain free manual muscle tests with gross muscle tests of the all shoulder musculature bilaterally except for experiencing pain during resisted external rotation of the left shoulder. All manual muscle testing was performed in the seated position as described by Kendall.\(^ {15}\)

Out of all special testing performed, as listed in Table 2, the subject tested positive for four out of five tests in the SIS cluster described by Michener et al (SN = .75, LR+ = 2.93).\(^ {16}\) The subject tested positive for pectoral and latissimus tightness bilaterally.\(^ {12}\) The scapular dyskinesis test (κw = .48-.61)\(^ {16}\) was performed with a 2.3 kg weight as described by McClure et al.\(^ {17}\) Frontal plane assessment from the posterior showed no winging or aberrant movements but did reveal a decrease in upward rotation of the left scapula compared to the right.

![Posterior View of Posture](image)

**Figure 2.** Posterior View of Posture

<table>
<thead>
<tr>
<th>Table 1. Range of Motion Testing</th>
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<tr>
<td>Movements</td>
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<tr>
<td>Flexion</td>
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<td></td>
</tr>
<tr>
<td>Abduction</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Apley’s Scratch External Rotation</td>
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<tr>
<td>Apley’s Scratch Internal Rotation</td>
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<tr>
<td>External rotation at 45 degrees abduction</td>
</tr>
<tr>
<td>Internal rotation at 45 degrees abduction</td>
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</table>

\(A=AROM\)

\(P=PROM\)
The subject completed the Disabilities of Arm, Shoulder, and Hand (DASH) questionnaire (ICC = .9)\textsuperscript{18} and the Penn Shoulder Score (PSS)(ICC = .94)\textsuperscript{19} outcome measures on the initial visit in order to track disability, limitations in sports activity, and patient satisfaction. These outcomes were chosen due to their established validity and known Minimal Clinically Important Difference (MCID) values.\textsuperscript{18-19} The subject scored a 19/100 on the DASH, 0/100 on the DASH work module, and a 100/100 on the DASH sports module. For the PSS, the subject scored 20/30 for pain (ICC = .88)\textsuperscript{19}, 1/10 for satisfaction (ICC = .93)\textsuperscript{19}, and 45/60 for function (ICC = .93)\textsuperscript{19} adding to a total score of 66/100 with 100 indicating high function, low pain, and high satisfaction with the function of the shoulder.\textsuperscript{19}

<table>
<thead>
<tr>
<th>Tests</th>
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<tbody>
<tr>
<td>Scapular Dyskinesia test with 3 lbs dumbbell\textsuperscript{17}</td>
<td>(-)</td>
<td>(-) decreased upward rotation</td>
</tr>
<tr>
<td>Hawkins/Kennedy sn=.63\textsuperscript{16} sp=.63\textsuperscript{16}</td>
<td>(-)</td>
<td>(+)</td>
</tr>
<tr>
<td>Neer test sn=.81\textsuperscript{16} sp=.54\textsuperscript{16}</td>
<td>(-)</td>
<td>(+)</td>
</tr>
<tr>
<td>Resisted external rotation Sn=.56\textsuperscript{16} Sp=.87\textsuperscript{16}</td>
<td>(-)</td>
<td>(+)</td>
</tr>
<tr>
<td>Empty can (Jobe) Sn=.50\textsuperscript{16} Sp=.87\textsuperscript{16}</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>Painful Arc Sn=.75\textsuperscript{16} Sp=.67\textsuperscript{16}</td>
<td>(-)</td>
<td>(+)</td>
</tr>
<tr>
<td>Drop arm</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>Speed’s Test sn=.38-.69\textsuperscript{29} sp=.56-.83\textsuperscript{29}</td>
<td>(-)</td>
<td>(-)</td>
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</table>

The subject’s signs, symptoms, and movement system impairments were deemed consistent with SAPS. Several noteworthy findings included: decreased scapular upward rotation during shoulder elevation, tightness of the posterior GH joint capsule, forward shoulder posture, and decreased left periscapular muscle development compared to the right. These findings led to the hypothesis that the subject would benefit from IASTM and scapular mobilizations to address the movement system dysfunction of shoulder complex. Successful outcomes were considered as improved mobility without pain as well as improved PSS, DASH, Global Ratings of Change Scale (GROC), and NPRS scores.

**INTERVENTION AND OUTCOMES**

It has been proposed that IASTM instruments can be used as a diagnostic tool for identifying adhesions and abnormalities in tissues via changes in frequency of vibrations transmitted through the tool to the clinician.\textsuperscript{6,9,10,20} Silbaugh investigated the inter-rater reliability of IASTM for detecting myofascial adhesions and reported a kappa coefficient of .344, suggesting low to moderate reliability.\textsuperscript{20} By utilizing the IASTM instrument over the respective muscle groups, soft tissue adhesions were detected by a change in the fluidity of the stroke of the IASTM instrument. Areas with a higher concentration of adhesions were identified by the sensation of traversing a roughened surface with the instrument, whereas tissue with fewer soft tissue restrictions allowed for a smoother glide of the tool against the subject’s skin.

The subject was treated with IASTM, using the Edge Mobility Tool (The Edge Mobility System, Buffalo, NY), applied to the pectoral muscles and medial brachium with the subject in supine and the GH joint placed in 120° abduction to place adequate tension on the selected tissues in the style of pectoral tightness test (Figure 3).\textsuperscript{12} The IASTM technique was performed for 20 seconds parallel to the muscle fibers followed by 20 seconds perpendicular to the muscle fibers with the instrument held at a 45° angle to the skin.\textsuperscript{6} The Edge Mobility Tool was used beveled side contacting the skin. Pressure was applied lightly at first with a gradual increase due to the subject’s initial sensitivity to the treatment. Pressure was increased with subject tolerance to maximal force due to evidence that heavy pressure elicits greater fibroblast
proliferation than light or moderate pressure. The same IASTM protocol of 20 seconds parallel to the muscle fibers and 20 seconds perpendicular to the muscle fibers was applied to the posterior cuff musculature of the GH joint with the subject in prone and arms in 90° abduction and internal rotation draped over the side of the plinth (Figure 4). While in the same position, the technique was applied to the periscapular musculature including the, trapezius, rhomboids, teres minor, teres major, and latissimus dorsi. (Figure 5)

Post-treatment measures included NPRS and pain free standing flexion AROM measured in degrees. Immediately following the intervention, the subject was instructed to stand and perform three repetitions of shoulder flexion and abduction. The subject reported 0/10 pain on the NPRS scale with both motions and 181° pain free flexion AROM. The subject had no complaints of pain at end range flexion or abduction.

To further encourage proper scapulohumeral rhythm, 10 repetitions of grade III scapular mobilization were performed in all directions: superior,
inferior, upward rotation, downward rotation, and distraction.\textsuperscript{3,7} Following scapular mobilization, 10 repetitions of manual resisted exercise from neutral to full flexion and back to neutral were performed to encourage muscle activation in the newly gained range of motion. Lastly, the subject was then given a cross body posterior capsule stretch (Figure 6)\textsuperscript{17} as well as a corner pectoral stretch (Figure 7)\textsuperscript{17} for three repetitions of 60 seconds\textsuperscript{22} for each exercise with the theory of introducing stretching to further improve tissue extensibility after targeting adhesions with IASTM and mobilizations.\textsuperscript{23} Upon completing these stretches, the subject was sent home with a home exercise plan consisting of these two stretches and instructed to do each stretch once a day for 3 repetitions of 60 seconds with the goal of maintaining the newly gained pain free ROM.

The subject returned to the clinic at three and five days post initial treatment. Upon arrival the subject completed the DASH, PSS, Global Rating of Change (GROC), and was tested for pain free flexion AROM as well as NPRS with shoulder flexion. The subject was then treated with the identical treatment protocol to the initial treatment consisting of IASTM, ST mobilizations, MRE’s, and stretching. Pain free shoulder flexion AROM, as well as NPRS with shoulder flexion was measured after the IASTM treatment. The subject showed carryover improvement in pain free range of motion improving from 85º at initial evaluation to 110º at the beginning of the second treatment, then to 171º upon arrival for the third session. After each IASTM treatment, the subject reported 0/10 NPRS and the perception of improved mobility as well as improvements in measured pain free flexion ROM. The subjects DASH score improved 17.34% as well as improving PSS score by 29 points, surpassing MCID’s of 10.2% and 11.4 points respectively\textsuperscript{18-19} (all outcomes are listed in Table 3). Improvements on the PSS indicate improved function, decreased pain, and improved satisfaction.\textsuperscript{19} After this treatment using manual therapy, the subject was prescribed a therapeutic exercise protocol consisting of progressive resisted exercises and neuromuscular re-education of the scapular stabilizing musculature.\textsuperscript{24-25} The subject was educated on proper lifting mechanics and posture to return to a modified weight-training program designed to not exacerbate symptoms.
DISCUSSION
This case report describes the use of IASTM to augment the effects of scapular mobilization on SAPS. To date, much of the literature looking at manual therapy intervention for SAPS addresses the spine and GH joint itself, but minimal research has been carried out on the effects of soft tissue mobilizing of the surrounding structures. Patients with SAPS typically present with soft tissue restrictions limiting the mobility of the scapula. These restrictions may manifest in movement system dysfunction, or may be secondary to a learned misuse due to pain. Surenkok et al. looked at the acute effects of ST mobilization on shoulder ROM, scapular upward

<table>
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<tr>
<th>Table 3. <strong>Outcome Measurements</strong></th>
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<tbody>
<tr>
<td><strong>Outcome</strong></td>
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<tr>
<td>---------------------</td>
</tr>
<tr>
<td><strong>MCID= 1017</strong></td>
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<tr>
<td><strong>DASH Work Module</strong></td>
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<tr>
<td><strong>DASH Sports Module</strong></td>
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<td><strong>Penn Shoulder Score</strong></td>
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<td><strong>Pain</strong></td>
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<td><strong>Satisfaction</strong></td>
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<td><strong>Function</strong></td>
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<tr>
<td><strong>Pain Free Shoulder Flexion AROM (°)</strong></td>
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<tr>
<td><strong>NPRS with Shoulder Flexion28</strong></td>
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<td><strong>GROC</strong></td>
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†met MCID
IASTM- Instrument Assisted Soft Tissue Mobilization
DASH- Disabilities of the Arm, Shoulder, and Hand questionnaire; Lower score indicates less disability
MCID- Minimal Clinically Important Difference
AROM- Active Range of Motion
NPRS- Numeric Pain Rating Scale
GROC- Global Ratings of Change scale
Penn Shoulder Score: High score indicates improved function
NA: Not Applicable
begins on the spectrum of a validated objective measure of AROM. Improvements in pain free shoulder flexion and NPRS combined with improvements in other subjective outcome measures such as the PSS, DASH, and GROC can help deduce patient perceived improvement in function and ability. While the subject did show an increase in DASH score from the initial evaluation to the second visit, the change does not meet the MCID of 10.2. From the second to third visit, the subject improved by 24.34 points surpassing the MCID.

The subject in this case had signs of mild scapular dyskinesia, which leads the authors to believe the causation of his symptoms was decreased scapular mobility due to soft tissue restrictions and not due to weakness of his scapular upward rotators. In cases where a patient has deficits in scapular stabilization strength and motor control, manual therapy intervention including this protocol of IASTM and ST mobilizations, can possibly be an effective precursor to proven therapeutic exercise/neuromuscular re-education. Once proper mobility has been restored, it is expected that the patient will have an improved ability to perform exercises with proper mechanics. Without proper strength and neuromuscular control, the pure ability of the passive scapular mechanics may not transfer over to active movements. Marzetti et al looked at neurocognitive therapeutic exercise (NCTE) compared to traditional therapeutic exercise as treatment for SAPS. While both groups improved, the NCTE group showed greater improvements in DASH scores with results maintained over a 24-week follow-up period. In cases where soft tissue restrictions persists along with scapular dyskinesia a plan of care using IASTM followed by a NCTE protocol may be beneficial. SAPS typically has multiple impairments causing the end result of subacromial pain. The treatment of this syndrome could potentially benefit from interventions aimed at the underlying soft tissue, structural, and neuromuscular impairments to insure positive patient outcomes on a case-by-case basis. Soft tissue restriction can be a major impairment that can impede proper mechanics and hinder the patient's full potential in rehabilitation. Further investigation of using this IASTM intervention to enhance the effects of exercise is needed.

IASTM alone proved to show immediate effects in pain free shoulder flexion AROM as shown in the pre- to post- intervention measures in Table 3. IASTM may reduce any soft tissue adhesions limiting scapular upward rotation, thus allowing greater shoulder complex range of motion without pain in the subacromial space. Pain free flexion AROM is a valuable measure for SAPS due to accounting for the subject's subjective input of where their pain begins on the spectrum of a validated objective measure of AROM. Improvements in pain free shoulder flexion and NPRS combined with improvements in other subjective outcome measures such as the PSS, DASH, and GROC can help deduce patient perceived improvement in function and ability. While the subject did show an increase in DASH score from the initial evaluation to the second visit, the change does not meet the MCID of 10.2. From the second to third visit, the subject improved by 24.34 points surpassing the MCID.

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A number of limitations exist within this case report. While the subject did exhibit improvements under the aforementioned IASTM protocol, it is not possible to determine that the intervention solely was responsible for the patient's decrease in symptoms using case report methodology. The potential mechanisms of IASTM are discussed in this paper, but the possibility for neurologic, physiologic, and psychological contributory mechanisms were not taken into consideration. Further research into the mechanisms behind IASTM impacting multiple body systems is needed. Also, this case does not establish the long-term impact of IASTM on SAPS. Further research is needed into the extent of the effects IASTM may exhibit on SAPS patients.

CONCLUSION
When combined with ST mobilizations and stretching, IASTM may be effective in acutely improving pain free flexion ROM, decreasing disability, improving function, decreasing pain, and improving patient satisfaction. While IASTM will not ameliorate all underlying pathomechanics contributing to SAPS, it may serve as a valuable tool to restore ROM and acutely decrease pain, thereby allowing the patient to reap the full benefits of a multi-modal treatment approach.

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20. Silbaugh K. Validity of Instrument Assisted Soft Tissue Mobilization for Detecting Myofascial...


ABSTRACT

**Background and Purpose:** Shoulder instability, a common issue among athletes who engage in contact sports, may lead to recurrent subluxations, or partial dislocations of the shoulder. Young athletic patients generally respond poorly to the nonsurgical treatments for shoulder instability that are commonly utilized. The purpose of this case report is to describe the effects of the treatment guided by the Mulligan Concept (MC) coupled with reflex neuromuscular stabilization (RNS) also known as reactive neuromuscular training (RNT), on an adolescent football player with glenohumeral joint (GHJ) instability who sustained a traumatic anterior subluxation.

**Case Description:** The MC shoulder Mobilization with Movement (MWM) and RNS were applied in the treatment of an anterior shoulder subluxation injury sustained by a competitive adolescent football player. The Numeric Pain Rating Scale (NPRS), the Disability in the Physically Active (DPA) scale, the Patient specific Functional Scale (PSFS) and the Shoulder Pain and Disability Index (SPADI), were administered in order to identify patient-reported outcomes.

**Outcomes:** The shoulder MWM and RNS provided immediate relief of all of the patient’s pain and increased ROM after the first treatment. The use of the coupled treatments resulted in a resolution of pain, an increase in range of motion (ROM) and improvement in perceived stability. A minimal clinically important difference (MCID) was reported on the NPRS and minimal detectable changes (MDC) were reported on the NRS and PSFS, after the first treatment. Equally important, MCIDs were reported on the DPA scale and SPADI scale over the course of treatment.

**Discussion:** In this case report, the MC shoulder MWM, coupled with RNS, was an effective treatment for this patient and provided a short time to resolution (6 treatments; 19 days) compared to other descriptions of recovery in the literature. Clinicians treating patients who display anterior shoulder instability can consider this as a viable treatment option. Even though current literature indicates that surgery is an optimal treatment for reducing recurrent subluxations, in young athletes who participate in contact sports, the effects of surgery are substantial. Therefore, the consideration of the presented option for non-operative treatment is important.

**Level of Evidence:** 4-Case Report

**Key words:** Instability, Mobilization with Movement, Muscle Patterns, Nonsurgical Treatment

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BACKGROUND AND PURPOSE

The glenohumeral joint (GHJ) is one of the most mobile joints in the human body, which predisposes it to pathologic instability and contributes to its status as one of the most frequently dislocated/subluxed joints in the body. Instability is a common contributing factor to anterior shoulder subluxations and dislocations in adolescents. Dislocation has been defined as requiring manual reduction of the shoulder joint; while subluxation has been defined as the joint slipping or popping out of its socket, but returning to the appropriate position without manual assistance. The most common shoulder injuries vary, depending on the age group and level of activity; however, anterior instabilities leading to subluxations account for 20% of all shoulder injuries sustained by athletes who engage in contact/collision sports.

Thus, GHJ instability leading to recurrent subluxations is a common problem among collision/contact athletes. Typically, GHJ instability is diagnosed through patient history, observation, palpation, manual muscle testing, and orthopedic tests specific to laxity and instability. The orthopedic testing battery commonly includes a load and shift test (laxity), an apprehension test (instability), and a relocation test (instability). Magnetic Resonance Arthroscopy/Imaging (MRA/MRI), through which diagnostic confirmation is typically made, is considered the gold standard for determining instabilities of the shoulder, because it provides details regarding laxity present in the surrounding soft tissues.

Traditional conservative treatment for GHJ instability consists of strengthening the scapular, glenohumeral, scapulothoracic, and rotator cuff muscles, as well as conducting proprioceptive exercises as part of an eight-week daily rehabilitation program. Traditional treatment exercises are progressive and dependent upon each individual patient's case, but typically, have common components (Table 1). The use of conservative, nonsurgical treatments has resulted in poor outcomes and a high recurrence rate of subluxations/dislocations in adolescent-age patients.

The surgical options for recurrent anterior shoulder subluxation/dislocation, which may or may not result in instability, generally include either an open or an arthroscopic Bankart procedure. Open Bankart repairs yield a 0 – 10% recurrence rate and arthroscopic Bankart procedures yield about a 15% recurrence rate. Despite the low recurrence rates, surgical treatments are not without risks and complications. Open Bankart repairs have a much slower recovery of muscle strength (specifically in regards to forward flexion) than arthroscopic repairs. Open Bankart repairs also require an increased hospitalization time compared to that which is required by arthroscopic treatment. Moreover, there is a 31% post-operative dislocation rate in adolescents who are treated with surgery. These outcomes indicate a need for further research into non-operative treatments and improved post-surgical rehabilitation.

In theory, the Mulligan Concept (MC) intervention and reflex neuromuscular stabilization (RNS) also known as reactive neuromuscular training (RNT) are viable treatments for GHJ instability. The Mulligan Concept focuses on treatments that in theory cor-

| Table 1. Progressive Resistive Exercise |
|---------|---------|---------|
| Phase 1 | Phase 2 | Phase 3 |
| Pain w/restricted ROM | Interventions for pain/PROM & AROM | Isometric → Eccentric → Plyometric/Proprioceptive Exercises | Sport-Specific Drills → Full Contact |
| Pain w/full ROM | Interventions for pain/AROM/Isometric Exercises | Eccentric → Plyometric/Proprioceptive Exercises | Sport-Specific Drills → Full Contact |
| No pain | Isometric / AROM/Proprioceptive Exercises | Eccentric → Plyometric/Proprioceptive Exercises | Sport-Specific Drills → Full Contact |
| PROM = Passive ROM | AROM = Active ROM | → = Progression |
rect positional faults through pain-free mobilizations with movement (MWM). Resolution of the patient’s symptoms during the MWM guides the clinician in acute treatment strategies. The positional fault, described by Brian Mulligan as a mal-alignment due to injury, could theoretically result from an anterior subluxation (macro trauma), repeated collisions (e.g., tackles [micro trauma]), muscle imbalance, or poor arthrokinematics. A positional fault can lead to pain, decreased range of motion (ROM), decrease strength and overall joint dysfunction, which may, in turn, lead to deficits in motor control. It could also be theorized that the origin of pain associated with a shoulder positional fault is the result of compression on the nerve supply to the glenohumeral joint (GHJ) capsule, which is highly innervated with pain receptors.

Reactive neuromuscular training/reflex neuromuscular stabilization is a treatment that is posited to restore proper muscle movement patterns (motor control) so joint stability can be reestablished and functional ability enhanced. Reactive neuromuscular training facilitates motor responses through the unconscious process of integrating and interpreting the peripheral sensations received by the central nervous system (CNS). The descriptive term for this type of treatment is transitioning from RNT to RNS because the treatment is reflexive in nature and does not require progression or long-term treatment, which is inferred by the word “training.” As it relates to the shoulder complex, perception of the joint movement/position is essential for upper limb function and cannot be accomplished without feedback from the mechanoreceptors and central programming from the motor cortex. Stimulating the joint and muscle mechanoreceptors promotes maximal discharge to the appropriate CNS levels. The musculotendinous mechanoreceptors of the GHJ are primarily located within the supraspinatus, infraspinatus and pectoralis minor muscle insertions.

Reflex neuromuscular stabilization is accomplished by applying a light external load to amplify the dysfunctional movement, causing the patient to reactively correct the dysfunctional movement pattern. It is important to note that RNS is often performed at the end of a patient’s treatment session to “groove” (i.e., make reflexive) a healthy motor pattern during fatigue/weariness, as well ensure proper proprioceptive control with increased pain-free ROM, compared to restricted/painful ROM. Quality of movement during fatigue is important, especially in an athletic population where many sport specific repetitions are normally required. No definitive evidence exists to suggest when RNS should be used in a rehabilitation protocol, but clinical reasoning dictates that fatigue be addressed during rehabilitation. The ultimate goal of treatment is to restore normal pain-free ROM with quality movements (i.e. motor control), following a treatment session.

An optimal rehabilitation program for GHJ instability is driven by an assessment and correction of muscle pattern dysfunction as well as faulty postures. Successfully treating a faulty posture without addressing a muscle pattern dysfunction could inhibit return-to-play or leave the patient more susceptible to repeated injury. Both the MC and RNS theoretically address these imperative components. Notably, a patient that is responsive to this coupled treatment may potentially avoid or delay surgery as well as avoid a lengthy traditional rehabilitation protocol. The purpose of this case report is to describe the effects of the treatment guided by the MC coupled with RNS, also known as RNT, on an adolescent football player with GHJ instability who sustained a traumatic anterior subluxation.

CASE DESCRIPTION

The subject was a 17-year-old male, high school football player (running back and linebacker) with a history of diagnosed multidirectional instability (MDI) in both shoulders. He suffered with chronic subluxation of his left shoulder and had completed post-surgical rehabilitation for a posterior labral tear approximately eight months prior to sustaining the injury to his right shoulder. The subject had also completed eight weeks of prescribed progressive resistive exercises with a physical therapist prior to injuring his right shoulder (therapy was for diagnosed MDI). The subject was cleared to fully participate in his sport following this therapy, but he participated during competitions using a dual shoulder support (SB05 Dual Shoulder brace; EVS Sports, Rancho Dominguez, CA). Approximately six weeks after completing rehabilitation, the subject suffered...
a traumatic anterior subluxation while performing a tackle during a football game and was unable to continue to participate in that game after the injury. In addition to agreeing to participate in this case report, the subject and his guardians provided written, informed assent/consent.

**CLINICAL IMPRESSION #1**

During the on-field examination, obvious deformity and life threatening injuries were ruled out. The subject presented with 2/5 grip strength, limited and painful ROM in flexion and extension (not measured on the field), and 9/10 current pain rated on the numerical pain rating scale (NPRS). The remainder of the field exam was within normal limits (e.g., normal dermatome assessment, strong distal pulse) and consistent with a shoulder anterior subluxation. The subject was immobilized in a sling for comfort and was referred for a radiograph. The radiograph was negative for fractures; the treating physician diagnosed the subject with general shoulder pain from an anterior subluxation, for which he prescribed compression, ice, and Motrin. The physician also recommended an MRI to rule out further structural damage. The subject decided to delay further diagnostic imaging until after the season was over (six remaining weeks) and was returned to the care of his athletic trainer (AT) for re-evaluation and treatment until the completion of the season, with a directive of “participation as pain tolerated.”

**EXAMINATION**

During the re-examination by the AT (two days after subluxation), the subject reported that he had rested throughout the weekend and had experienced pain and difficulty performing overhead activities (e.g., washing hair). Observation and palpation of the bony structures and soft tissues in the shoulder were found to be normal, and no other symptoms were reported. During the clinical examination, the subject presented with pain in his shoulder at the end-range of forward flexion (5/10) and pain/limitation in abduction (170°; 6/10; Table 2). All other motions were pain-free and comparable to the opposite side. Grip strength (5/5) was also comparable to the opposite side. The subject’s load and shift test was positive, his apprehension test was positive, and his relocation test was positive (reaffirming the apprehension test). The initial scores on the outcome measures were 5/10 on the NPRS (current pain), 4/10 on the patient specific functional scale (PSFS; overhead catch), 47/64 on the disablement in the physically active (DPA) scale, and 40%/100% on the shoulder pain and disability index (SPADI). The clinical diagnosis was “anterior shoulder instability with painful and limited ROM.”

**CLINICAL IMPRESSION #2**

The Mulligan Concept and RNS were deemed ideal treatment paradigms for this subject, addressing the plausible faulty posture of the glenohumeral joint and the neuromuscular dysfunction that may have contributed to the anterior subluxation. Reactive neuromuscular stabilization is an important concept when restoring ROM, fostering proper motor control through the subject’s gained ROM, theoretically rendering the subject less likely to sustain repeated injury. The subject was discharged from treatment after reporting being symptom-free for 24 hours.

| Table 2. Pre/Post Treatment (Trt.) Outcome Measures |
|---------------------------------|----------|----------|----------|----------|----------|----------|----------|
|                                | Trt. 1   | Trt. 2   | Trt. 3   | Trt. 4   | Trt. 5   | Trt. 6   | Discharge |
| **NPRS (current)**             | Pre      | Post     | Pre      | Post     | Pre      | Post     | Pre/Post  |
|                                 | 5        | 0*‡      | 3        | 0*‡      | 1        | 0        | 0         |
| **PSFS**                       | 4+       | 9‡       | 7        | 9‡       | 8        | 10       | 10        |
| **DPA Scale**                  | 47       | N/A      | N/A      | N/A      | 12*      | N/A      | N/A       |
| **SPADI**                      | 40%      | N/A      | N/A      | N/A      | N/A      | N/A      | N/A       |
| **Abduction**                  | 170°+    | 180°     | 180°     | 180°     | 180°     | 180°     | 180°      |
| **Forward Flexion**            | 180°+    | 180°     | 180°     | 180°     | 180°     | 180°     | 180°      |

NPRS=Numeric Pain Rating Scale; PSFS=Patient Specific Functional Scale, DPA Scale = Disability in the Physically Active Scale; SPADI=Shoulder Pain and Disability Index Abduction/Forward Flexion=measured using active range of motion

*MCID met or exceeded
‡MDC met or exceeded

No Pain

+ = pain
INTERVENTION

Outcome Scales
The outcome scales that were used in this case study included the following: (a) the NPRS (collected at intake, pre/post treatment, and at discharge), which is a valid and reliable pain scale that is used to assess the subject's pain (0 = no pain, 10 = extreme pain).\textsuperscript{19} The minimally clinical important difference (MCID) and the minimal detectable change (MDC) for the NPRS is regularly reported as a decrease of 2 points; \textsuperscript{19} (b) PSFS (collected at intake, pre/post treatment, and at discharge), which is a valid and reliable scale that is used to assess the subject's function (0 = unable to perform, 10 = performs without problem). The minimal detectable change for the PSFS is regularly reported as an increase of 3 points for a single activity score,\textsuperscript{20} an MCID value was not found in the literature; (c) DPA (collected at intake, treatment 4, and at discharge), which is a valid and reliable scale that is used to assess disablement over four dimensions: impairment, functional limitation, disability, and quality of life (0 = no disability, 64 = maximum disability).\textsuperscript{21} The MCID for the DPA scale is reported as a decrease of 9 points for acute conditions,\textsuperscript{21} an MDC was not found in the literature; and (d) the SPADI (collected at intake and at discharge), which is a valid and reliable scale that is used to assess pain and disability due to musculoskeletal pathology (0 = best, 100 = worst).\textsuperscript{22} The MCID for the SPADI scale is reported as a decrease in 13 points and the MDC was reported as a decrease of 18 points.\textsuperscript{23} Goniometric measurement was used to measure ROM at intake pre/post treatment and at discharge. Discharge criteria consisted of full, pain-free ROM; an NPRS average of 1 or less; and a PSFS of 9 or higher.

Treatment Procedure
The subject was treated with a MC shoulder MWM, first: The clinician applied a belt-assisted shoulder abduction MWM, with the clinician standing behind the seated subject. The glide consisted of a posterior, lateral, inferiorly directed force on the humeral head, which was provided through the belt while the subject performed humeral abduction and the clinician applied overpressure at his end ROM\textsuperscript{14} (Figure 1). The belt was wrapped around the clinician’s hips and the subject’s shoulder [mobilization was applied by the clinician, who moved her hips away from subject (Figure 1)], allowing the humeral head to glide in an oblique and slightly inferior direction.\textsuperscript{14} Throughout the MWM, the clinician supported the belt position (on the subject's shoulder; Figure 2) with one hand and applied a stabilizing force to the scapula of the subject with the opposite hand (Figure 1). Following the MC guidelines, the subject reported being completely pain-free throughout the treatment. The belt-assisted shoulder abduction MWM consisted of 3 sets of 10 repetitions.
Reflex neuromuscular stabilization was performed immediately following the MWM treatment. While both the subject (eyes closed) and clinician were in a standing position, the clinician used her fingertips to provide a light, anterior-to-posterior force on the subject’s sternum, with the verbal cue “do not let me move you” (Figure 3) over the course of two sets of 10. As the subject reactively resisted the force from the clinician, he also abducted the shoulder. Based on the RNS principles the force should have been from posterior-to-anterior at the glenohumeral joint (exaggerating or “feeding” the dysfunction), however the subject was apprehensive and reported discomfort with hand placement. The clinician moved hand placement away from the shoulder and direction of discomfort to the sternum, thus resolving apprehension and remaining pain free. (Figure 3). The RNS modification used in this case report may have been successful because of a concurrent core stability motor control dysfunction in the subject.

The subject received six treatments over 19 days and continued to play football competitively throughout the entire rehabilitation process. He would also ice sporadically after practices and consistently after games and reported using Motrin during the first week of treatments. Each treatment took place a minimum of 24 hours after the previous treatment session.

**OUTCOME**

The subject obtained 180 degrees of pain-free shoulder abduction after the first treatment session. The PSFS activity (catching an overhead pass) was tested after the first visit, and the subject reported excellent function no discomfort (rated 9/10). All pain with forward flexion was resolved with treatment of the abduction, using both MWMs and RNS (Table 2). Treatment sessions two and three remained consistent with the first treatment; however, during RNS, the second set was performed using kinesthetic imagery, alone. During the fourth treatment, the MC was applied in the same manner as during the previous treatments, but RNS was applied by pushing on the sternum for the first repetition in the set and kinesthetic imagery was used during the remainder of repetitions. Prior to treatment five the subject reported taking a hard tackle and feeling unsure of whether or not his shoulder had again subluxed; however he did report an increase in pain (Table 2). Treatment was continued without modification at the next session, and the subject’s reported pain diminished post-treatment (Table 2). During the final treatment, the subject reported resolved (0/10) pain with all shoulder movements (Table 2).

Minimal clinically important differences were reported in three patient outcome scales: NPRS, SPADI, and the DPA scale (Table 2). A minimal detectable change were reported in three patient outcome scales: NPRS, PSFS and SPADI (Table 2). The subject was taped in a manner that supported the treatment glide prior to each football game (Figure 4), and he also wore a dual shoulder support brace. He performed in two games (playing defense...
and offense) during treatment and used ice for 10-15 minutes after every game. The subject completed the remainder of the football season (three games, over 28 days) without the need for further therapy. However, after discussion with his personal physician and guardians, the subject decided that, following the conclusion of the season, he would undergo arthroscopic repair of a Bankart lesion that had been found on his MRI. The subject reported the decision to have surgery was based on history of instability, the MRI findings, and physician recommendation. Subject did not report a return of pain post season.

**DISCUSSION**

Prior to treatment, the subject lacked 10 degrees of shoulder abduction, and motion was painful after 90 degrees of forward flexion and abduction. Traditional, non-operative treatment for an anterior subluxation with limited movement would involve eight weeks of strengthening the surrounding muscles of the shoulder complex and forcing ROM through active and passive stretching.\(^5\) The MC shoulder MWM, coupled with RNS, provided immediate relief of all of the subject’s pain and increased ROM after the first treatment, which is a result that has not been documented after traditional progressive resistance exercises for subluxation. Furthermore, the subject was cleared to return to a collision sport within four days of a traumatic subluxation with full ROM and strength in the upper extremity when compared bilaterally. Time-loss from competition/sporting activity was reduced, compared to the time frames presented in the literature for surgery and traditional rehabilitation. After the full course of treatment, the subject was able to continue to participate in his sport throughout the entire season without subsequent injury or the need for further treatment.

In patients who have GHJ instability or a history of anterior shoulder subluxation, MC shoulder MWM and RNS interventions together may be an effective treatment in lieu of, or adjunct to a traditional exercise program. Even though current literature indicates that surgery is an optimal treatment in young athletes who participate in contact sports and recurrent subluxations,\(^4\) the patient must: (a) recover from the effects of anesthesia, (b) experience a delayed return of muscle strength (especially with an open repair), and (c) partake in a lengthy rehabilitation process.\(^8,10,13\) Therefore, the consideration of the discussed non-operative treatment is essential.

The outcomes in this case report provide some evidence that utilizing MWMs, RNS, taping and bracing may assist in returning an athlete to competition following a shoulder subluxation, even when working with a collision/contact athlete. The combined therapy may produce rapid changes in pain, ROM, and shoulder function. Despite the positive outcomes in this case report, further research with a greater number of subjects is needed to determine the treatment effects of the combined use of the MC shoulder MWM and RNS. It is important to determine if the treatment will produce positive results over a larger population or only on a subgroup of patients. More research is needed to determine long-term effects of the intervention as well as its potential for reducing the need for surgical repair in certain patient cases. Given the limited risks of performing MWMs and RNS, clinicians can utilize the outcomes in this case to consider the inclusion of these techniques into their patient care. However, this case study was a single, short-term subject case, without controlled activity, with a subject who elected to have surgery to repair a Bankart lesion and should not be generalized amongst the athletic population.
CONCLUSION
The results of the MC and RNS used in this case report demonstrate positive immediate results that were maintained for four weeks after the conclusion of rehabilitation, in a case of an adolescent with unilateral shoulder instability. Return to sport was achieved with the interventions and the addition of taping and bracing of the patient prior to each football game. The MC coupled with RNS could be considered for the short-term treatment of a patient with anterior shoulder subluxation, assuming the clinician follows the treatment recommendations (e.g., indications, contraindications) of each treatment paradigm.

REFERENCES
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