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The Editorial staff of The International Journal of Sports Physical Therapy (IJSPT) is dedicated to the review, critical appraisal, and publication of high quality scientific and clinical research, systematic reviews, meta-analyses, and case reports. As IJSPT progresses through its' ninth year of providing high quality research evidence as well as relevant clinical commentary and suggestions for the international sports physical therapy community, we offer the following editorial.

We, along with many other prestigious journals are committed to elevating the quality of published research related to disability and rehabilitation and agree to adherence to the following reporting guidelines, which will be required by IJSPT as of January 1, 2015. Many of these guidelines are all ready in place and have been implemented by IJSPT.

This Editorial is a reprint of a previously published Editorial in The Archives of Physical Medicine and Rehabilitation, and is used with permission. (http://dx.doi.org/10.1016/j.apmr.2013.12.010)

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ELEVATING THE QUALITY OF DISABILITY AND REHABILITATION RESEARCH: MANDATORY USE OF THE REPORTING GUIDELINES

Leighton Chan, MD, MPH
Allen W. Heinemann, PhD, Co-Editors-in-Chief
Archives of Physical Medicine and Rehabilitation
Jason Roberts, PhD

ORIGIN EDITORIAL
With the remarkable growth of disability- and rehabilitation-related research in the last decade, it is imperative that we support the highest quality research possible. With cuts in research funding, rehabilitation research is now under a microscope like never before, and it is critical that we put our best foot forward.

To ensure the quality of the disability and rehabilitation research that is published, the 28 rehabilitation journals simultaneously publishing this editorial (see acknowledgments) have agreed to take a more aggressive stance on the use of reporting guidelines.\(^8\) Research reports must contain sufficient information to allow readers to understand how a study was designed and conducted, including variable definitions, instruments and other measures, and analytical techniques.\(^1\) For review articles, systematic or narrative, readers should be informed of the rationale and details behind the literature search strategy. Too often articles fail to include their standard for inclusion and their criteria for evaluating quality of the studies.\(^2\) As noted by Doug Altman, co-originator of the Consolidated Standards of Reporting Trials (CONSORT) statement and head of the Centre for Statistics in Medicine at Oxford University: “Good reporting is not an optional extra: it is an essential component of good research...we all share this obligation and responsibility.”\(^3\)

WHAT ARE REPORTING GUIDELINES?
Reporting guidelines are documents that assist authors in reporting research methods and findings. They are typically presented as checklists or flow diagrams that lay out the core reporting criteria required to give a clear account of a study's methods and results. The intent is not just that authors complete a specific reporting checklist but that they ensure that their articles contain key elements. Reporting guidelines should not be seen as an administrative burden; rather, they are a template by which an author can construct their articles more completely.

Reporting guidelines have been developed for almost every study design. More information on the design, use, and array of reporting guidelines can be found on the website for the Enhancing the Quality and Transparency of Health Research (EQUATOR) network,\(^4\) an important organization that promotes improvements in the accuracy and comprehensiveness of reporting. Examples include the following:

1. CONSORT for randomized controlled trials (www.consort-statement.org);

2. Strengthening the Reporting of Observational studies in Epidemiology (STROBE) for observational studies (http://strobe-statement.org/);

3. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) for systematic reviews and meta-analyses (www.prisma-statement.org/);

4. Standards for the Reporting of Diagnostic accuracy studies (STARD) for studies of diagnostic accuracy (www.stard-statement.org/); and

5. Case Reports (CARE) for case reports (www.care-statement.org/).
There is accumulating evidence that the use of reporting guidelines improves the quality of research. Turner et al5 established that the use of the CONSORT statement improved the completeness of reporting in randomized controlled trials. Diagnostic accuracy studies appeared to show improvement in reporting standards when the STARD guidelines were applied.6 Early evidence also suggests that inclusion of reporting standards during peer review raises manuscript quality.7 The International Committee of Medical Journal Editors now encourages all journals to monitor reporting standards and collect associated reporting guideline checklists in the process.8 Furthermore, the National Library of Medicine also now actively promotes the use of reporting guidelines.9

HOW WILL REPORTING GUIDELINES BE INTEGRATED INTO MANUSCRIPT FLOW?
By January 1, 2015, all of the journals publishing this editorial will have worked through implementation and the mandatory use of guidelines and checklists will be firmly in place. Because each journal has its unique system for managing submissions, there may be several ways that these reporting requirements will be integrated into the manuscript flow. Some journals will make adherence to reporting criteria and associated checklists mandatory for all submissions. Other journals may require them only when the article is closer to acceptance for publication. In any case, the onus will be on the author not only to ensure the inclusion of the appropriate reporting criteria but also to document evidence of inclusion through the use of the reporting guideline checklists. Authors should consult the Instructions for Authors of participating journals for more information.

We hope that simultaneous implementation of this new reporting requirement will send a strong message to all disability and rehabilitation researchers of the need to adhere to the highest standards when performing and disseminating research. Although we expect that there will be growing pains with this process, we hope that within a short period, researchers will begin to use these guidelines during the design phases of their research, thereby improving their methods. The potential benefits to authors are obvious: articles are improved through superior reporting of a study’s design and methods, and the usefulness of the article to readers is enhanced. Reporting guidelines also allow for greater transparency in reporting how studies were conducted and can help, hopefully, during the peer review process to expose misleading or selective reporting. Reporting guidelines are an important tool to assist authors in the structural development of a manuscript, eventually allowing an article to realize its full potential.

ACKNOWLEDGMENTS
As this issue went to press, the following Editors agreed to participate in the initiative to mandate reporting guidelines and publish this Position Statement in their respective journals. As a collective group, we encourage others to adopt these guidelines and welcome them to share this editorial with their readerships.

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REFERENCES


ABSTRACT

**Purpose/Background:** Injury screening methods that use three-dimensional (3D) motion analysis accurately predict the risk of injuries, yet are expensive. There is great need for valid, cost-effective techniques that can be used in large-scale assessments. Utilizing two-dimensional (2D) measures of lateral trunk motion may identify athletes at risk for lower extremity injury. The purpose of this research was to determine the strength of the relationships between 2D and 3D calculations of lateral trunk angle for female athletes performing a single-leg cross drop landing.

**Methods:** Twenty-one high-school female volleyball players performed a single-leg cross drop landing onto a force plate. The 3D angular trunk motion was calculated, and four different 2D measures of lateral trunk angle were calculated for both left and right landing leg. A one-way multivariate analysis of variance was used to compare 2D measures to the 3D measurements, and Pearson correlations were used to determine the strength of these relationships.

**Results:** The angle formed by the medial shoulder joint center, medial ASIS, and vertical line (LTA4) was similar to the 3D measures of lateral trunk angle during landing (r-values ≥ 0.62; p-values ≤ 0.003; mean differences, -1.0° to 1.2°).

**Conclusions:** Given the recent focus on the role of the trunk in lower extremity injury, using the 2D LTA4 assessment may expand existing assessments into a composite model that can more accurately assess female athletes at risk for injury than models that do not include trunk analysis.

**Clinical Relevance:** Existing models that enable clinicians to effectively identify female athletes at risk for lower extremity injury may be enhanced by including accurate assessments of lateral trunk motion.

**Keywords:** Female, kinematics, risk assessment, trunk displacement
BACKGROUND
Injury screening methods that use three-dimensional (3D) motion analysis accurately predict the risk of debilitating lower extremity injuries in athletes, such as anterior cruciate ligament (ACL) rupture. However, 3D screening techniques are expensive and labor-intensive, and requiring large, dedicated laboratories with costly measurement tools, which limits widespread application. This drives the need for valid, cost-effective techniques that can be used to perform large-scale assessments so targeted interventions can reach a greater population of athletes who are at risk for injury. Relevant tools that use two-dimensional (2D) analyses have been developed to detect risky lower extremity biomechanics. Recently, a clinic-based landing assessment tool using 2D measures of frontal plane knee angle as part of a composite model was developed to identify athletes at risk of having a high knee abduction load upon landing and predicted female athletes who had high knee abduction moments with 84% sensitivity and 67% specificity.

Recently, lower extremity injury risk models that incorporate assessment of lateral trunk motion during dynamic movements have received increased interest and development. During dynamic movements, lateral trunk motion can shift the ground reaction force vector laterally from the stance limb, increasing the potential for a high knee abduction moment, a risk factor for ACL injury. The mechanical link between trunk position and increased knee abduction moment has previously been supported; Hewett et al found using 2D videographic analysis that lateral trunk motion was higher in female athletes during an ACL injury than male athletes and trended toward being higher than female controls, and Dingenen et al reported that combined 2D measures of lateral trunk motion and knee abduction angle were significantly correlated with peak knee abduction moment assessed using a 3D motion system. In order to reduce lower extremity injury risk, identification of those who demonstrate deficits in trunk control during high-risk maneuvers may be important in accurately determining knee injury mechanics. Unfortunately, it is not known what 2D techniques are optimal to capture dynamic lateral trunk motion that may be associated with injury risk. Therefore, the purpose of this study was to explore four different 2D measures of lateral trunk motion with respect to the gold-standard 3D measures in female athletes performing a single-leg cross drop landing in order to determine the strength of the relationships between 2D and 3D measures of trunk movement upon landing.

DESCRIPTION
Participants
A team of 21 high-school female volleyball players (mean age 15.3 SD 1.0 years; height 169 SD 4.8 cm; weight 62.8 SD 8.2 kg) volunteered for participation in this study. Participants were excluded if they had sustained a lower extremity injury that precluded them from athletic activity. Approval by the Institutional Review Board of the Cincinnati Children's Hospital Medical Center for the study protocol was received and informed consent was obtained from each participant prior to testing.

DATA COLLECTION
Three-dimensional trunk angular motion was collected on each participant performing three single leg cross drop (SCD) landings on each side onto an embedded force plate (AMTI, BP600900, Watertown, MA) from a height of 31 cm. The SCD was developed in order to reproduce the effect of lateral trunk movement by perturbing the trunk in a controlled laboratory setting. One investigator prepared each participant with 43 retroreflective markers with a minimum of three markers per segment in a modified Helen-Hayes arrangement. Participants wore a small backpack with three non-collinearly placed markers to track trunk motion. Motion data was collected at 240 Hz using a 10-camera motion capture system (Eagle, Motion Analysis Corp., Santa Rosa, CA). Marker trajectories were filtered using a low-pass fourth order Butterworth filter at a cutoff frequency of 12 Hz and trunk angular motion was calculated using Visual3D (C-Motion, Inc., Germantown, MD). Two-dimensional data was calculated in Visual3D by isolating the frontal plane position data of either three landmarks or two landmarks and a vertical line of reference and determining the angle formed by these landmarks. Figure 2 illustrates the process by which each of the four measures of 2D lateral trunk angle (LTA1-LTA4) was...
Figure 1. Front and back views of the modified Helen-Hayes marker arrangement used in this study. Markers were attached with a minimum of three markers per segment.

Figure 2. Flowchart describing how the four measures of lateral trunk angle (LTA 1-4) were calculated with examples of each measure.
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determined. Lateral was defined as toward the landing leg; for example, the right ASIS is lateral when landing on the right leg, and medial was defined as away from the landing leg.

EXPERIMENTAL TASK
The SCD was performed by balancing on one foot, crossing the landing foot in front of the balancing foot, hopping forward and medially off of the box, and landing in the middle of the force plate and holding for a minimum of two seconds (Figure 3). Trials were repeated if participants stepped off the box instead of hopping, turned their body in the direction of the hop, or were unable to hold the landing.

STATISTICAL TESTING
A one-way MANOVA with Tukey method pairwise post-hoc testing was used to compare lateral trunk angle measurements during the landing phase, designated as 500 ms after initial contact with the force plate. Independent variables were method of trunk angle calculation (3D, LTA1, LTA2, LTA3, LTA4) and landing leg (left, right). Dependent variables were lateral trunk angle at initial contact, maximum medial angle, which was determined when the subject’s trunk reached its most medial position, maximum lateral angle, which was determined when the subject’s trunk reached its most lateral position, and range of motion (ROM), which was determined as the absolute range between initial contact and maximum lateral angle. The level of significance was set at $\alpha=0.05$, and analyses were performed separately for the left and right sides. Pearson correlations were performed, in order to determine the strength of the relationships between 2D and 3D outcome measures.

RESULTS
A main effect was found for the calculation method ($p < 0.001$). Mean 3D measurements for lateral trunk angle were $2.8^\circ$ (SD 4.2$^\circ$) at initial contact, $9.4^\circ$ (SD 5.3$^\circ$) at maximum lateral trunk angle, -1.1$^\circ$ (SD 5.0$^\circ$) at maximum medial trunk angle, and $10.2^\circ$ (SD 3.6$^\circ$) lateral trunk angle ROM. Post-hoc analysis revealed that LTA4 was the only 2D method that was similar to the 3D measurements for each dependent variable ($p \geq 0.894$). LTA2 was similar to the 3D measurements at maximum lateral trunk angle ($p = 0.086$), maximum medial trunk angle ($p = 0.284$), and trunk angle ROM ($p = 0.969$). LTA1 only demonstrated similar values to the 3D measurements at maximum medial trunk angle ($p = 0.999$), while LTA3 was only similar to the 3D measurements in trunk angle ROM ($p = 0.887$). Mean differences (with 95% confidence intervals) for lateral trunk angles calculated by each LTA model with respect to 3D measurements are displayed in Table 1.

Figure 3. Illustration of the single-leg cross drop landing for the right side.
Table 1. Mean differences (with 95% confidence interval) between corresponding 3D and 2D measurements of lateral trunk angle for each of all four LTA techniques

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Independent Variable</th>
<th>Mean Difference</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
<th>p-value</th>
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<td>Initial Contact</td>
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<td></td>
<td>LTA2</td>
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<td>-7.2</td>
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<tr>
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<td>LTA3</td>
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<td>-11.4</td>
<td>-5.7</td>
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<tr>
<td></td>
<td>LTA4</td>
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<td>-2.7</td>
<td>3.0</td>
<td>1.000</td>
</tr>
<tr>
<td>Max Lateral Angle</td>
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<td>-15.3</td>
<td>-19.4</td>
<td>-11.3</td>
<td>.000</td>
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<tr>
<td></td>
<td>LTA2</td>
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<td>-7.8</td>
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<tr>
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<td>LTA3</td>
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<td>-11.8</td>
<td>-3.7</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>LTA4</td>
<td>0.1</td>
<td>-3.9</td>
<td>4.2</td>
<td>1.000</td>
</tr>
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<td>Max Medial Angle</td>
<td>LTA1</td>
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<td>-4.7</td>
<td>3.8</td>
<td>.999</td>
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<td></td>
<td>LTA2</td>
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<td>-7.2</td>
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<tr>
<td></td>
<td>LTA3</td>
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<td></td>
<td>LTA4</td>
<td>1.2</td>
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<td>Trunk Angle ROM</td>
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<td>2.4</td>
<td>.969</td>
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<tr>
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<td>-4.2</td>
<td>2.1</td>
<td>.887</td>
</tr>
<tr>
<td></td>
<td>LTA4</td>
<td>-1.0</td>
<td>-4.2</td>
<td>2.1</td>
<td>.894</td>
</tr>
</tbody>
</table>

LTA = Lateral Trunk Angle
Note: p-value < 0.05 indicates dependent variable mean is significantly different from 3D measurement mean.

A main effect was also found between sides (p < 0.001). Mean 3D measurements for lateral trunk angle during a left side landing (Figure 4) were 1.9° (SD 4.2°) at initial contact, 9.4° (SD 5.8°) at maximum lateral trunk angle, -1.2° (SD 4.2°) at maximum medial trunk angle, and 10.6° (SD 3.7°) lateral trunk angle ROM. Post-hoc analysis revealed that leg side demonstrated statistical differences in lateral trunk angle.

Figure 4. Landmark designations for determination of 2-Dimensional measurements of lateral trunk angle during a cross drop onto the left leg for (1) LTA1, (2) LTA2, (3) LTA3, and (4) LTA4. Red line/shaded area is mean ± SD time-series 3D trunk angle, and blue line/shaded area is 2D trunk angle.
angle only at initial contact (p = 0.024), where lateral trunk angle values for a right leg landing (Figure 5) were 3.6° (SD 4.1°). Similarly, lateral trunk angle at initial contact was also greater for right leg landings than left leg landing in LTA1-4. There was no main effect for method-by-side interaction (p = 0.352). Correlations between independent variables fell within an acceptable range to be used in a MANOVA analysis (0.319 ≤ r ≤ 0.884). Similarly, Pearson correlations revealed significant relationships (p ≤ 0.003) with moderate-to-excellent coefficients of 0.62-0.89 between 3D and LTA4 outcome measures (Table 2).

**DISCUSSION**

Determination of valid 2D techniques is imperative for clinicians who intend to reach a larger population with targeted interventions in order to attempt to prevent injury. This study assessed the validity of multiple 2D techniques used to measure lateral trunk angle during an SCD landing. Of the four techniques used in this study, LTA4, which was calculated using the medial shoulder joint center, the medial ASIS, and a vertical line of reference, most closely exemplified 3D measures of lateral trunk angle. LTA4 can serve as a proxy for clinicians who

---

**Figure 5.** Landmark designations for determination of 2-Dimensional measurements of lateral trunk angle during a cross drop onto the right leg for (1) LTA1, (2) LTA2, (3) LTA3, and (4) LTA4. Red line/shaded area is mean ± SD time-series 3D trunk angle, and blue line/shaded area is 2D trunk angle.

**Table 2.** Pearson Correlation Coefficients and p-values between 3D and LTA4 Outcome Variables

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>r-values</th>
<th>p-values</th>
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<td>.002</td>
</tr>
<tr>
<td>Right</td>
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<td>.011</td>
</tr>
<tr>
<td>Max Lateral Angle</td>
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<tr>
<td>Left</td>
<td>0.89</td>
<td>.000</td>
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<td>Right</td>
<td>0.83</td>
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<tr>
<td>Max Medial Angle</td>
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<td>0.62</td>
<td>.003</td>
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<tr>
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<tr>
<td>Trunk Angle ROM</td>
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<tr>
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<td>.000</td>
</tr>
<tr>
<td>Right</td>
<td>0.87</td>
<td>.000</td>
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</table>

Note: p-value < 0.05 indicates dependent variable mean is significantly different from 3D measurement mean.
do not have access to a 3D motion system to digitize 2D lateral trunk motion.

Post-hoc analysis indicated that the 2D method of calculation that most closely represented 3D measurements of lateral trunk angle was LTA4, showing no statistical differences for any of the four dependent variables considered by this study. Also, for separate dependent variables, LTA1, LTA2, and LTA4 each expressed a smaller mean difference from 3D measurements than the other 2D methods. This finding indicates that, at some point during landing, each of these models was the optimal choice for reproducing frontal plane 3D trunk kinematics. However, though each 2D model was comparable to 3D motion values at some point and demonstrated individual advantages at various body orientations, LTA4 presented the most robust model for matching 3D lateral trunk angle measurements throughout the landing phase. The reason LTA4 was the most accurate calculation of 2D lateral trunk angle or LTA1-3 were less accurate may be because of the location of the vertical line of reference used in each calculation; the vertical line used in LTA4 lay medially to the trunk, whereas the vertical line overlaid the trunk itself in LTA2 and LTA3 or was not present at all (LTA1). Thus, LTA4 represents a deviation away from a medial point of reference, which may have served as the point at which frontal plane trunk angle is neutral, whereas the others do not. It is possible that the lack of statistical difference between 3D and LTA4 outcome measures was attenuated by extreme miscalculations of trunk angle cancelling each other out (for example, if one subject scored high 3D trunk displacement but low 2D displacement, and another subject scored low 3D displacement and high 2D displacement, there would be no discernible difference in the average); however, strong correlation coefficients between the outcome variables indicate that this is likely not the case.

The use of valid 2D techniques has high potential for clinicians who aim to assess injury risk and prescribe interventions to athletes but do not have access to a 3D motion analysis system. LTA4 serves as a proxy for clinicians who have access to 2D video and can record athletes performing the SCD maneuver, which can then be used to digitize the medial shoulder joint center and ASIS in order to determine lateral trunk motion. Two-dimensional video has been shown to be reliable when comparing video measures of knee-to-ankle separation ratio and frontal plane knee projection angle with 3D measures, with an intraclass correlation coefficient of 0.92. Moreover, 2D video has been used to deliver augmented feedback for athletes to correct frontal plane knee angle while performing a tuck jump task, as well as to improve knee flexion angle and decrease vertical ground reaction force upon landing a jump. The results of the current study have clinical implications in assessing lower extremity injury risk, especially for the knee. Given the recent focus on the role of the trunk in lower extremity injuries, the described LTA4 method of measuring trunk angle could potentially be used in a composite model of lower extremity injury risk. A regression model that incorporated lateral trunk displacement after a sudden force release to predict female athletes who went on to suffer ACL injuries with 83% sensitivity and 76% specificity. During maturation, rapid increases in the height of the center of mass in female athletes make muscular control of the trunk difficult. Deficiency in neuromuscular control of the trunk contributes to increased external knee moments by compromising lower limb stability during dynamic movements. This deficiency is evident in greater displacement of the trunk in the frontal plane during unilateral movements such as cutting or single-leg landings. Figure 6 shows the relationship between subjects' lateral trunk ROM as determined by LTA4 and peak knee abduction angle during landing. Such is an example of an application of this method that could be used to develop a composite model for injury risk prediction; however, further studies are warranted to determine the validity of this approach. That LTA1-4 expressed the same relationships in side-to-side differences as 3D measurements indicates that 2D techniques may have the potential to accurately assess side-to-side asymmetries, which have been documented as a potential risk factor for lower extremity injuries, including ACL injury. Accordingly, in clinical situations where 3D models are not feasible to obtain, 2D models such as LT4 may still serve a clinical function as they may identify changes in performance, presence of asymmetries, and relative injury risk without difficulty of implementation.
CONCLUSION

While there is a pressing need to develop cost-effective and accurate risk assessment tools for widespread clinical use, the current results provide a promising approach to the application of 2D techniques to support this need. Focusing solely on joint motion and moment may not only lead to a misinterpretation of the injury mechanism but may also prohibit the application of optimal intervention to reduce risk. Determination of lateral trunk displacement during athletic maneuvers such as the SCD has been purported to be an important indicator of injury risk. The method proposed by the study could be used to enhance or refine existing clinical and 2D models to give the clinician a more comprehensive picture of an athlete’s risk for lower extremity injury.

REFERENCES


ABSTRACT

**Purpose/Background:** Trunk exercises, such as trunk stabilization exercises (SE) and conventional trunk exercises (CE), are performed to improve static or dynamic balance. Recently, trunk exercises have also been often used as part of warm-up programs. A few studies have demonstrated the immediate effects of SE and CE on static balance. However, immediate effects on dynamic balance are not yet known. Therefore, the purpose of this study was to compare the immediate effect of SE with that of CE on the Star Excursion Balance Test (SEBT).

**Methods:** Eleven adolescent male soccer players (17.9 ± 0.3 years, 168.5 ± 5.4 cm, and 60.1 ± 5.1 kg) participated in this study. A crossover design was used, and each participant completed three kinds of testing sessions: SE, CE, and non-exercise (NE). Experiments took place for three weeks with three testing sessions, and a 1-week interval was provided between different conditions. Each testing session consisted of three steps: pretest, intervention, and posttest. To assess dynamic balance, the SEBT score in the anterior, posteromedial, and posterolateral directions was measured before and 5 minutes after each intervention program. The data of reach distance were normalized with the leg length to exclude the influence of the leg length on the analysis.

**Results:** The SEBT composite score was significantly improved after the SE (p < 0.05) but did not change after the CE and NE (p > 0.05). Furthermore, in the SE condition, SEBT scores of the posterolateral and posteromedial directions were significantly improved at the posttest, compared with those at the pretest (p < 0.05).

**Conclusions:** This study demonstrated the immediate improvements in the posteromedial and posterolateral directions of the SEBT only after the SE. This result suggests that the SE used in this study is effective in immediately improving dynamic balance.

**Levels of Evidence:** 3b

**Keywords:** Core training, dynamic balance, sit-up, stabilization exercise

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INTRODUCTION

The trunk, which is located at the middle of the kinetic chain, is an essential region for coordination during sports performance and for preventing injuries. In the current study, the trunk was defined as the region of the low back and pelvis, and trunk stability was considered as the ability to control the position and motion of the trunk during dynamic loading and movement conditions.1 Trunk stability is important for the connection of movements between the lower and upper body, as well as the control of body balance and movements.2,3 In order to obtain optimal trunk stability, coordination, co-activation, and neural control of trunk muscles are needed.4 Trunk muscles are classified into local and global muscles depending on their anatomical orientation and function.5 Local muscles, which have more direct or indirect attachments to the lumbar vertebrae, are associated with the segmental stability of the lumbar spine. On the other hand, global muscles attach to the hips and pelvis, and are related to torque production and the transfer of load between the thoracic cage and the pelvis.5

Trunk exercises are often performed to improve sports performance and strength, prevent injuries, and rehabilitate patients with low back pain or dysfunction. One type of trunk exercises, described as conventional exercises (CE), include repeated flexion and extension of the trunk, such as sit-ups or back extensions, and are performed to strengthen the trunk muscles.6 Another type of trunk exercises described as trunk stabilization exercises (SE) keep the lumbar spine in a neutral position and adjust functional postures with minimal accompanying trunk movements, such as the back bridge and side bridge. The main aim of the SE is to restore and improve the coordination and co-contraction of global and local muscles.7 Previous studies have demonstrated that SE improve trunk stability,8,9 and athletic performance,8,10 and prevent low back pain.9,11,12 Recently, several researchers have demonstrated that SE improve static and dynamic balance.1,13-15

SE’s are also used as part of warm-up programs, such as the “FIFA 11+” injury prevention program. Previous authors have demonstrated that poor trunk stability and strength are associated with a higher risk of lower extremity injuries.16,17 Warm-up programs including the SE have been demonstrated to reduce the incidence of lower extremity injuries.18-21 Bizzini et al22 have demonstrated that physiological responses, performance, and static and dynamic balance were improved immediately after the FIFA 11+ program. Thus, these factors would be expected to be linked to reducing the incidence of the injuries. However, it is not known how much the SE contribute to improving physiological responses, performance, and static and dynamic balance and preventing injuries because there have been very few studies that investigated the immediate effects of the SE alone. To the authors’ knowledge, only two reports about the immediate effects of trunk exercises on static balance have been published.23,24 Kaji et al23 reported that the SE program immediately improved static balance. Imai et al.24 compared the immediate effect of the SE on static balance with that of the CE. They found that static balance improved immediately with SE but did not improve with the CE. This result indicates that the effect of training on static balance varies depending on the types of trunk exercises and that the immediate improvement of static balance is a specific effect of the SE. Imai et al11 and Kahle et al13 previously reported that dynamic balance was improved by a 12-week and 6-week SE program, respectively. However, the immediate effect of SE or CE on dynamic balance is not yet known because of the lack of evidence related to the immediate effect of trunk exercises.

Therefore, the purpose of this study was to compare the immediate effect of SE on dynamic balance with that of CE. Dynamic balance is often assessed by using the Star Excursion Balance Test (SEBT), which is a series of single-limb squats in which the subject uses the non-stance limb to maximally reach a touch point along designated lines on the ground.25 This test is simple and inexpensive, and has demonstrated good test-retest reliability.26-29 Moreover, the SEBT is useful not only as an assessment of dynamic balance but also a predictive measurement of the risk of lower extremity injuries.30,31 However, there are no reports about the immediate effect of SE or CE on the SEBT. The authors hypothesized that only the SE program would improve the SEBT immediately.
METHODS

Participants
Eleven adolescent male soccer players participated in this study. Their mean ± SD age, height, and body mass were 17.9 ± 0.3 years, 168.5 ± 5.4 cm, and 60.1 ± 5.1 kg, respectively. All participants were members of the same high school soccer club and had been attending soccer practice or games six times per week at the time of the investigation. Players who reported low back pain or a history of lower extremity injuries that required treatment or that might have inhibited performance within the last 12 months were excluded. All players and their parents provided written informed consent before participation. This study was reviewed and approved by the Ethical Committee at the University of Tsukuba, and carried out in accordance with the Declaration of Helsinki.

Procedures
In this study, a crossover design was used and each participant participated in testing with three conditions, which were SE, CE, and non-exercise control (NE), in order to compare the influence of two types of trunk exercises on performance on the SEBT. The research project took place over a period of three weeks with three testing sessions. A 1-week interval was provided between the different conditions to rule out the influence of the previous exercises performed.

Each testing session consisted of three steps: pre-test, intervention, and post-test. The measurements of the SEBT were performed before and five minutes after the training period. The SE and CE programs took five minutes and were directed and supervised by the researcher. In the NE condition, participants sat and rested on a chair for 5 minutes.

The order in which participants performed the exercises of the three conditions was decided by the researcher to minimize the “learning effects”, a term used here to suggest the degree of the participants’ familiarity with the three kinds of exercises, which is most likely determined by the order of the exercises. Consequently, four participants performed exercises in the order SE, CE, and NE; four participants in the order CE, NE, and SE; and three participants in the order NE, SE, and CE.

The Star Excursion Balance Test
The participants performed the SEBT in the anterior, posteromedial, and posterolateral directions. They received verbal instruction and visual demonstration of the SEBT from the same examiner before performing the test.

The participants stood on the leg they used for kicking a ball, with the most distal part of the great toe placed on the center of the grid. While maintaining a single-leg stance, they used the opposite leg to reach, as far as possible toward the end of the line along a grid in the anterior, posteromedial, and posterolateral directions. Then, they touched the ground lightly with the most distal part of the reaching foot before returning to the starting position. Their hands were held at the iliac crest during the test. All tests were performed barefoot to rule out the influences of shoes. After six practice trials were completed, the participants rested for two minutes and then performed three test trials in each direction. The order of the reaching directions was randomized at each test session. The test was discarded and then repeated in the same manner if a participant failed to maintain the unilateral stance, lifted or moved the standing foot from the grid, or failed to return the reaching foot to the starting position.

The longest reach distance in each direction was used for the analysis. For an accurate analysis, the data of reach distance was normalized with the leg length to exclude the influence of leg length. The leg length was measured with a tape measure from the anterior superior iliac spine to the center of the ipsilateral medial malleolus. The composite score was calculated according to the formula \( \frac{(\text{sum of all three directions})}{(\text{leg length} \times 3)} \times 100 \).
the quadruped exercise, participants assumed a quadruped position. They were then asked to hold a neutral pelvis position and to breathe normally. Then, they raised their right arm and left leg simultaneously and held them straight up for five seconds. Next, they raised their left arm and right leg simultaneously and held them straight up for five seconds. Then, they rested for 10 seconds. This routine was repeated five times.

Conventional exercise program
For the CE program, participants performed sit-ups, sit-ups with trunk rotation, and back extensions (Figure 2). For the sit-ups, participants laid supine in the standard sit-up position, knees bent at 90°, and hands folded across the chest with each hand placed on the opposite shoulder. They were asked to bend and raise the upper body until their elbows reached their thigh and then to return to the starting position. This routine was performed 30 times. For the sit-ups with trunk rotation, participants were asked to raise, bend, and rotate the upper body to the left or right until the elbow touched the opposite thigh from the starting position of the sit-up. This was performed 30 times, alternating on the right and left sides.

Figure 1. Trunk stabilization exercise program for this study: (a) the front plank, (b) the quadruped exercise, and (c) the back bridge.

Figure 2. Conventional exercise program for this study: (a) the sit-up, (b) the sit-up with trunk rotation, and (c) the back extension.
back extension, the participants lifted their upper body and legs off the floor simultaneously from a prone position on the floor. After a comfortable elevation, they lowered their upper body and legs to return to the starting prone position. These movements were repeated 50 times.

**Statistical analysis**

Statistical analyses were performed by using the software SPSS for Mac ver. 19 (SPSS Inc. Chicago, IL, USA). The test-retest reliability for the SEBT was calculated by using a two-way random effect model intraclass correlation coefficients (ICCs). The normality and equal variance assumptions were checked by using the Kolmogorov-Smirnov test and Levene test, respectively. The baseline data of the SEBT between groups were compared by using a one-way ANOVA. A two-way (group × time) repeated-measures ANOVA with a mixed-model design was used to assess the changes over time and the between-group difference. When a statistically significant interaction effect was found, a Bonferroni post hoc test was done. Statistical significance was inferred at p < 0.05. Effect sizes (ESs) were calculated by using Cohen’s d to compare the results of the pre-test and the post-test. ESs were interpreted as small (0.21–0.50), medium (0.51–0.80), or large (>0.81).

**RESULTS**

The test-retest reliability analysis demonstrated ICCs of 0.965, 0.888, and 0.948 for the anterior, posterolateral, and posteromedial directions, respectively.

There were no significant differences between groups at the baseline data of each direction (p > 0.05). For the SEBT composite score, significant condition-by-time interactions existed (F = 5.441, p = 0.010). A Bonferroni post hoc test detected that the SEBT composite score was increased significantly only after the SE (p < 0.001, ES = 0.53). A moderate ES (0.53) was associated with this relation. The composite score did not change after the CE (p = 0.097, ES = 0.15) and NE (p = 0.570, ES = 0.06) (Table 1).

In the analysis of each direction, there were significant condition-by-time interactions in the posterolateral direction (F = 5.764, p = 0.008) and posteromedial direction (F = 7.745, p = 0.002). However, no interaction effect in the anterior direction was noted (F = 0.116, p = 0.891). In the SE condition, the Bonferroni post hoc test revealed that the SEBT score of the posterolateral direction (p = 0.002, ES = 0.44) and posteromedial direction (p < 0.001, ES = 0.74) was significantly greater at the posttest than at the pretest (Table 2). Small to moderate ESs were associated with these relations.

**DISCUSSION**

This study compared the immediate effects of different types of trunk exercises on the performance on the SEBT. One interesting finding was that the SEBT composite score significantly improved only after the SE but not after the CE and NE. Thus, the results indicate that the SE has the immediate effects concerning improvement of dynamic balance. Although previous studies have demonstrated that 12 weeks and 6 weeks of the SE improved dynamic balance,

| Table 1. The results of normalized composite score of the Star Excursion Balance Test |
|---------------------------------|-----------------|-----------------|-----------------|----------|
| Composite†                     | Pre             | Post            | % change        | ES       |
| SE                             | 94.0 ± 4.8      | 96.8 ± 5.7‡     | 0.000           | 2.9      | 0.53  |
| CE                             | 94.7 ± 6.1      | 95.6 ± 6.5      | 0.097           | 1.0      | 0.15  |
| NE                             | 95.1 ± 5.1      | 95.4 ± 5.1      | 0.570           | 0.3      | 0.06  |

*Mean ± SD %
†Significant group-by-time interaction (p < 0.05)
‡Significant difference between the pre and post (p < 0.05)
CE, Conventional trunk exercises; ES, Effect size; NE, non-exercise control; SE, Trunk stabilization exercises.
Concerning the reach direction, results show that the reach distance improved in the posteromedial and posterolateral directions and that in the anterior direction did not change. For the posterior directions, the hip flexion range of motion of the stance leg is important. Eccentric muscle contraction of the hamstrings and low back muscles, such as the erector spinae and multifidus, is needed. Thus, the function of the local muscles as monitors and the control of the trunk motion by the global muscles are both important. During the SE program prescribed here, the trunk position was maintained and adjusted by working the local and global muscles. Therefore, participants might have improved the control of the trunk position during the posterior directions of the SEBT after the SE. The SE involving arm and leg lifts used in this study have previously been shown to involve high external oblique activity, which is likely to assist in control of trunk rotation. Thus, the improvement in the control of the trunk rotation may help the control of the lower extremity during the posteromedial direction of the SEBT.

In contrast, the anterior direction was not changed significantly. This supported the findings of the previous study that investigated the effect over 8 weeks of training. Hock et al reported that the range of motion of the dorsiflexion influenced the anterior direction to a greater degree than posterior directions. Therefore, it is possible that the anterior direction is more sensitive to changes affected by the distal contributions.

Although the SE program was effective in improving the SEBT, no change was found after the CE program. The SE differs from the CE in terms of the stresses applied on particular body segments. Some basic principles of physical training must be followed to obtain the optimal effects of physical training. The specific adaptation to imposed demands (SAID) is one such basic principle. The SAID principle states that the human body will adapt specifically in response to the demands and stresses placed on it. The SE program consists of closed kinetic chain positions that place unilateral stresses on the hip extensors, and the task of movement is to maintain and control these positions. This stress resembles the stress of the SEBT in the posteromedial and posterolateral directions. On the other hand, the CE applies stress to the lumbar spine flexors and extensors in a dynamic bilateral manner. Therefore, the SE may be more suitable than the CE in terms of SAID as a training program to improve dynamic balance.

<table>
<thead>
<tr>
<th>Direction</th>
<th>Pre*</th>
<th>Post*</th>
<th>Bonferroni</th>
<th>% change</th>
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<tr>
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<tr>
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<td>102.8 ± 7.3</td>
<td>106.2 ± 8.1</td>
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<td>105.3 ± 5.8</td>
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<td>NE</td>
<td>106.6 ± 4.9</td>
<td>108.0 ± 4.4</td>
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*Mean ± SD %
†Significant group-by-time interaction (p < 0.05)
‡Significant difference between the pre and post (p < 0.05)
CE, Conventional trunk exercises; ES, Effect size; NE, non-exercise control; SE, Trunk stabilization exercises.
Limitations
Several limitations of this study should be considered. First, the sample size was small and the participants were all adolescent male soccer players. Thus, further confirmation of these results must be done in larger and more diverse populations, including female athletes and older individuals. Second, this study investigated the effect on the SEBT of the SE and CE programs comprising three exercises. Various trunk exercises and methods have been utilized to enhance trunk control and the strength of trunk muscles. The results of this study apply only to the SE program used here. Third, this study could not show how long the immediate effect on the SEBT lasts. This problem will need to be investigated in the future to clarify the efficacy of a warm-up program. Moreover, future studies that investigate whether the SE reduce the risk of injuries are needed. Previous studies have demonstrated that the FIFA 11+ program improved the SEBT immediately and that soccer players who adhered to the FIFA 11+ program showed improvement in the SEBT and a reduced injury risk. Thus, the SE program that has been demonstrated to cause immediate improvement of the SEBT may have the benefit of resulting in injury prevention.

Practical application
This study demonstrated that the SE improves dynamic balance. The previous study has shown that the SE program used in this study improves static balance. These results suggest that the SE is effective for immediately improving static and dynamic balance. For warm-up exercises, coaches and trainers use many kinds of exercises to improve performance and prevent injuries in athletes. The SE program used in this study is simple and easy to incorporate into a warm-up routine. Moreover, because an immediate effect on SEBT was demonstrated, the SE may enhance athletes’ dynamic balance, which is required for almost all athletic activities. Therefore, the authors’ would recommend that coaches consider changing their warm-up program to include at least the selected SE exercises, with the hope of enhancing the athlete’s dynamic balance.

CONCLUSION
This study demonstrated that the posteromedial and posterolateral directions of the SEBT were improved immediately after the SE, but not after the CE. Results of this study suggest that the SE program used in this study is effective in immediately improving dynamic balance.

REFERENCES


ABSTRACT

Purpose/Background: Visuomotor ability is an important parameter for neurologic function and effective sport performance. Adding a balance challenge during a structured eye-hand coordination task, such as hitting lights on a light board (Dynavision™), has not been previously reported. Using Division I football players, the aim of this study was to determine normative data on a dual-task performance regimen combining a visuomotor light board task with a balance task. The intent is to use such normative data and baseline data as part of a concussion management program.

Methods: Division I college football team members, n = 105, were consented. Subjects first performed Dynavision™ D2™ Visuomotor Training Device (D2™) eye-hand coordination tasks, the A* and the RT; they then performed the same tasks with an added balance challenge, standing on a BOSU® ball.

Results: Ninety-four athletes completed the full testing procedure on the D2™ system. The mean score of the A* test was 93 ± 11.0 hits per minute; and the mean on the A* test with the added BOSU® balance challenge was 83.7 ± 9.2 hits per minute. The mean RT time was 0.33 ± 0.036 seconds. Mean reaction time increased to 0.38 ± 0.063 while the subject stood on the BOSU® ball. Performance on the D2™ A* and RT were both statistically significantly different in the dual task condition (p<0.05).

Conclusions: Results show an approximate 10% decline in D2™ performance when healthy individuals stand on a BOSU® ball. From the data presented here, the authors determined that there is a 10% decrement in performance when one's balance is challenged on the BOSU® ball. A fall in performance of substantially greater than 10% may indicate abnormal vestibulocerebellar regulatory processing of balance and motion. Further research, using these normative data is needed to determine more specific parameters for definitions of impairment and return-to-play and if there is utility for such studies as part of a concussion management program.

Level of Evidence: III

Key Words: Balance, postural control, vestibular, Dynavision™, concussion
INTRODUCTION
A concussion is a mild traumatic brain injury (mTBI) that results from head trauma due to direct or indirect forces applied to the head and neck. The American Medical Society for Sports Medicine defines a concussion as a temporary disturbance in neurologic function due to trauma. This injury provokes a series of pathophysiological changes. A wide variety of clinical symptoms can occur ranging from no symptoms; when a patient denies any problems, to overt clinical signs and symptoms, which can include headache, confusion, balance and vision disturbances, and others. Loss of consciousness is another sign that people commonly associate with concussion, but has been shown to be associated with less than 5% of athletic concussions.

Each year, it is suspected that at least 3.8 million persons in the United States sustain a mild traumatic brain injury; at least 150,000 of these are sports-related concussions. American football is the leading cause of organized sport-related concussion at both the high school and collegiate level. Recent epidemiological studies of concussion in collegiate football demonstrate rates between 0.376 and 0.617 per 1000 athlete exposures.

Symptomatic presentation of concussions varies greatly from individual to individual based on history, co-morbid factors and severity of neurophysiologic disturbance. Clinical presentation may include (in varying degrees): headache, dizziness, possible loss of consciousness, nausea, vomiting, neurocognitive deficits, or no symptoms at all. Visuomotor and balance changes are also common sequelae following concussion. These symptoms develop secondary to disturbances within the complex neurophysiologic systems involved in vision and balance.

One’s ability to balance is derived largely from the combined functions of the cerebellum and vestibulospinal tract as well as the organs of the inner ear. These systems are responsible for upright postural control and visual tracking. Precise, voluntary motor control of the upper and lower extremities is provided by the lateral and ventral corticospinal tracts, which originate in the cerebral cortex. These complex and extensive neural structures receive proprioceptive and somatosensory input from nerves throughout the body and are highly susceptible to injury in the event of head trauma. A disturbance in function anywhere along the neural chain can lead to deficits in vestibular, visual, motor, or cognitive function.

The vestibular system is constantly barraged by incoming sensory information and typically functions involuntarily, with the control of balance occurring largely in an unconscious manner. Following brain injury, as the brain is attempting to heal, the vestibular system begins to require more conscious control in order to perform coordinated actions and maintain balance during even simple, normal movements. The increase in conscious control of balance subsequently slows the performance of other central nervous system tasks.

According to the National Collegiate Athletic Association (NCAA) and the National Athletic Trainers Association (NATA), current best practice for concussion management includes an evaluation of symptoms, a neurocognitive analysis, and a balance assessment. Many functional assessment systems for neurocognitive and balance performance exist and are used for evaluation pre- and post-concussion. Common neurocognitive tests include; the Standardized Assessment of Concussion (SAC), the Sport Concussion Assessment Tool (SCAT) (3rd Edition), and the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT®). Balance assessments in the sports arena are often conducted using the Balance Error Scoring System (BESS) or the Sensory Organization Test (SOT). Though balance and cognition are often assessed separately in the instance of concussion, it is well understood that these systems are intimately linked via the central nervous system.

The dual-task paradigm is a well-established neuropsychological procedure that examines changes in performance when one simple singular task is combined with another. Depending upon the nature of the task and the cerebral processing required, performance during the dual-task may or may not decline when compared with performance during the singular task.

Several researchers have attempted to study this dual task phenomenon by combining balance testing with a cognitive performance task. In 2011, Resch and colleagues assessed various balance conditions...
in healthy subjects, using the NeuroCom® Smart Balance Master®, with and without the simultaneous performance of a cognitive task. In four of the six balance conditions, the researchers noted that postural sway actually declined with the addition of the auditory cognitive stimulation. Additionally, it was determined that time to response during the cognitive task increased with the addition of the balance challenge. From this, one can ascertain that the brain processes cognitive function secondary to postural and balance demands. This is likely, because balance ability comes, in part, from cerebellar pathways; when one is engaged in a balance activity with a constitutive task, the cerebellum must divide its processing power. A study by Hunter and Hoffman demonstrates results similar to Resch et al. A force platform was utilized to assess postural sway while subjects performed visual and auditory cognitive tasks both with and without eye movement. The researchers noted that the subjects (healthy, young persons) had decreased postural sway with the performance of a cognitive task without eye movement. Additional data from the study indicated that adding visual tracking demands significantly increased the postural sway in healthy young adults.

The purpose of the current study is to establish normative data on visual motor testing, using the Dynavision™ D2™ Visuomotor Training Device (D2™) (Dynavision™ International, West Chester, Ohio), with and without a simultaneous balance assessment in Division I collegiate football players. The authors aim to add to the current literature with practical, sport-specific simulations of balance challenges concurrent with visual target training. A future goal for this research is to eventually use these newly established normative values to assist in developing methods for assessing and managing concussion in athletes.

**METHODS**

**Participants:** Subjects were recruited from a Division I college football team, which consisted of 105 players. All subjects were healthy college-aged males, ranging in age from 18 to 23 years. An athlete was considered for inclusion in the study if he was an official member on the varsity football team roster for the 2013 football season. Athletes were excluded from the study only if they had an injury or illness that prevented safe participation in data collection (i.e. current extremity injury, active concussion symptoms). Athletes were not excluded based on history of prior concussion or concussion-like symptoms, nor were they excluded for a history of extremity injury. Prior to the study, subjects were cleared for safe participation by the head football athletic trainer and the team physician. Basic demographic information for these athletes can be found in Table 1.

<table>
<thead>
<tr>
<th>Table 1. Demographic Information</th>
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<tr>
<td></td>
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<tr>
<td>Age (years)</td>
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<tr>
<td>Weight (pounds)</td>
</tr>
<tr>
<td>Experience*</td>
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</table>

*Experience = years of experience in Division I football

**Procedures:** This study was evaluated and approved by the Institutional Review Board (IRB) for the University of Cincinnati. Subjects read and signed an informed consent statement approved by the IRB. All rights of the subjects were protected.

Two standard protocols employed for testing on the D2™ were utilized, the A-star (A*) test and the Reaction Test (RT). During each of these tests, the athlete's reaction time and visuomotor skills were assessed by pressing an assortment of illuminated buttons as they became visible. The A* test is a one minute test of random illumination of buttons at any location on the light board. The athlete must depress the lit buttons as quickly as possible while button illumination continues (irrespective of successful button depression). Figure 1 shows an individual performing the A* on the Dynavision D2™ system. The RT is a series of tests in three planes, which assesses visual and motor reaction time of the right and left hands individually as well as overall reaction time. The subject depresses the lit button until the next button becomes illuminated; they must then depress this button as quickly as possible before returning to the original button. Each test produces quantifiable data on the number of correct hits and time from illumination to depression of each button. The D2™ has been found to be a reliable instrument for reaction time assessment in recreationally active young adults (ICC = 0.632 to 0.835).

For each participant the authors collected baseline A* and RT data captured from all preseason camps.
the participant attended. In each case, baseline A* and RT data was collected prior to unstable surface testing. Some participants had multiple years of baseline data, as returning players may have attended prior preseason camps. Baseline data collection was performed with the D2™ system with the participant standing on stable ground. For experienced members of the team, baseline data may have been gathered from a previous pre-season camp. New team members received baseline testing at the 2013 preseason camp. Although each participant performed baseline testing prior to testing on the unstable surface, some stable ground data was also collected following this balance challenge condition. ‘Best test’ data represents the highest score achieved by the end of the 2013 preseason camp. This may have taken place before or after the unstable surface testing.

Participants performed the A* and RT while standing on an unstable surface at the 2013 preseason football camp. A BOSU® Pro Balance Trainer (referred to by the authors as a ‘BOSU™’) (BOSU®; Ashland, Ohio) was placed on the floor within arm’s reach of the D2™ system. The BOSU® was turned onto its semi-spherical surface so that its flat surface was facing up; the participants stood on the flat surface of the BOSU® (Figure 2). The height of the D2™ system was adjusted to reproduce the environment that was used for baseline testing. During this session, one trial of A* and RT was performed and recorded with the individual standing on the BOSU®. Players had the opportunity to perform practice runs on this set up prior to data collection. Only one BOSU® run was used for data collection purposes.

**Data Collection and Storage:** Four separate D2™ light boards, each with its own corresponding laptop with D2™ software, were utilized in data collection for the current study. The Dynavision D2™ is an FDA cleared medical device manufactured under Good Manufacturing Practices (GMP) and International Organization for Standardization (ISO) conditions, ensuring sound construction and electronic accuracy. A D2™ reliability study showed moderate to strong reliability in visual reaction time and fair reliability in assessing motor reaction time.23 Time to reaction and number of positive hits within each 60-second trial were collected during testing and stored on a laptop computer utilized solely for D2™ software and data storage. Data were collected from each trial of the A* and RT; the data were coded and stored.
separately in a file unique to each athlete. Each athlete's file stores a date and time-stamped history of each D2™ program completed.

**Data Analysis**: Data from the athletes’ D2™ performance on both the A* and RT was automatically gathered and stored using software provided by the D2™ system. Data included reaction time and number of correct visuomotor responses in one minute. T-tests were used to compare D2™ data to D2™ plus-BOSU® data for the A* and the RT. Level of significance was set at $p \leq 0.05$.

**RESULTS**

**A* Test**: Of the 105 athletes consented for the study, 97 athletes completed the A* on both stable ground and on the BOSU®. Eight of the consented athletes were unable to complete testing due to injury or dismissal from preseason camp prior to the start of data collection. In the first condition, where D2™ was performed on stable ground, the mean score for each athlete's best A* test was 93.5 ± 11.0 hits per minute (hpm). Subsequent A* testing performed with the athlete on the BOSU® revealed a mean score of 83.7 ± 9.2 hpm. This drop in mean score (an average of 9.8 ± 8.3 fewer hpm) was statistically significantly different, $p \leq 0.00001$, between conditions. (Table 2)

**Reaction Test**: The D2™ Reaction Test is able to record both visual (time from illumination of a button to release of the already depressed button) and motor (time from release of the depressed button to depression of the recently illuminated button) reaction time. Ninety-four male athletes completed this portion of the data collection. Following A* testing, three athletes were unable to complete the RT data collection as they were withdrawn for other team commitments. The program utilizes these two measurements to determine overall visuomotor reaction time. For all players, the mean overall reaction time (best test) was 0.33 ± 0.036 seconds while standing on stable ground. Mean reaction time increased to 0.38 ± 0.063 when standing on the BOSU® ball. The increase in mean reaction time of 0.05 seconds was statistically significantly different, $p \leq 0.00001$, between conditions. These results illustrated a statistically significant slowing of overall reaction time with balance on an unstable surface.

All athletes improved their D2™ scores from their first attempt to their final and had a decline in score while doing the BOSU® challenge regardless of their level of experience. However, the magnitude of the decline in scores during the BOSU® challenge was significantly less in upper-classmen (athletes with two or more years of playing experience with the university) compared to younger players. No statistical differences were seen between offensive and defensive athletes in A* scores, while stable ground differences are noted between the groups in the RT test. No differences are noted in A* or RT performance between skilled and non-skilled players in any testing condition (Table 3).

While these data were obtained using healthy individuals with no currently diagnosed concussion or concussion-like symptoms, an athlete’s prior history of concussion was taken into consideration. An

<table>
<thead>
<tr>
<th>Table 2. A* and RT Time Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Best performance time compared to test conducted with athlete on the BOSU®</strong></td>
</tr>
<tr>
<td>Test</td>
</tr>
<tr>
<td>A* (hpm) (n=97)</td>
</tr>
<tr>
<td>Reaction Test Time (sec) (n=94)</td>
</tr>
<tr>
<td><strong>Best time overall compared to test conducted with athlete on the BOSU®</strong></td>
</tr>
<tr>
<td>Test</td>
</tr>
<tr>
<td>A* (hpm) (n=97)</td>
</tr>
<tr>
<td>Reaction Test Time (sec) (n=94)</td>
</tr>
</tbody>
</table>

*Closest time on System= the Dynavision D2™ trial conducted on flat ground that occurred closest in time/date to the trial conducted on the BOSU™, may have occurred before or after the dual task trial.
<table>
<thead>
<tr>
<th>Table 3.</th>
<th>$A^*$ and RT Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Years of Play</strong></td>
<td> </td>
</tr>
<tr>
<td></td>
<td>Athlete played college football &gt; 2 years at time of testing (n=29)</td>
</tr>
<tr>
<td>Closest Time on System*</td>
<td>94.1 ± 10.11</td>
</tr>
<tr>
<td>Best Time on System</td>
<td>97.3 ± 12.18</td>
</tr>
<tr>
<td>Test Conducted on BOSU*</td>
<td>86.4 ± 9.97</td>
</tr>
</tbody>
</table>

| **RT Time (sec) (n=94)** | &nbsp; | &nbsp; | &nbsp; |
| | Athlete played college football > 2 years at time of testing (n=29) | Athlete played college football < 2 years at time of testing (n=65) | p value |
| Closest Time on System* | 0.34 ± 0.032 | 0.35 ± 0.043 | 0.19 |
| Best Time on System | 0.33 ± 0.031 | 0.34 ± 0.038 | 0.26 |
| Test Conducted on BOSU* | 0.38 ± 0.083 | 0.38 ± 0.052 | 0.48 |

**Offensive versus Defensive**

<table>
<thead>
<tr>
<th>A* (hits per minute) (n=97)</th>
<th>Defensive Player (n=42)</th>
<th>Offensive Player (n=55)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closest Time on System*</td>
<td>88.8 ± 10.06</td>
<td>88.2 ± 9.85</td>
<td>0.38</td>
</tr>
<tr>
<td>Best Time on System</td>
<td>94.5 ± 13.28</td>
<td>93.4 ± 8.97</td>
<td>0.31</td>
</tr>
<tr>
<td>Test Conducted on BOSU*</td>
<td>84.8 ± 9.81</td>
<td>82.4 ± 9.07</td>
<td>0.11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RT Time (sec) (n=94)</th>
<th>Defensive Player (n=42)</th>
<th>Offensive Player (n=52)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closest Time on System*</td>
<td>0.34 ± 0.034</td>
<td>0.35 ± 0.043</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Best Time on System</td>
<td>0.33 ± 0.033</td>
<td>0.34 ± 0.038</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Test Conducted on BOSU*</td>
<td>0.37 ± 0.054</td>
<td>0.38 ± 0.070</td>
<td>0.25</td>
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</table>

**Skilled versus Non-skilled Positions**

<table>
<thead>
<tr>
<th>A* (hits per minute) (n=97)</th>
<th>Skilled Position (n=45)</th>
<th>Non-skilled Position (n=52)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closest Time on System*</td>
<td>88.9 ± 8.72</td>
<td>88.0 ± 10.54</td>
<td>0.32</td>
</tr>
<tr>
<td>Best Time on System</td>
<td>93.8 ± 8.51</td>
<td>93.6 ± 12.75</td>
<td>0.45</td>
</tr>
<tr>
<td>Test Conducted on BOSU*</td>
<td>85.2 ± 8.45</td>
<td>82.5 ± 9.95</td>
<td>0.09</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>RT Time (sec) (n=94)</th>
<th>Skilled Position (n=44)</th>
<th>Non-skilled Position (n=50)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closest Time on System*</td>
<td>0.34 ± 0.040</td>
<td>0.35 ± 0.040</td>
<td>0.11</td>
</tr>
<tr>
<td>Best Time on System</td>
<td>0.33 ± 0.040</td>
<td>0.34 ± 0.035</td>
<td>0.41</td>
</tr>
<tr>
<td>Test Conducted on BOSU*</td>
<td>0.37 ± 0.054</td>
<td>0.38 ± 0.070</td>
<td>0.12</td>
</tr>
</tbody>
</table>

**Results Based on History versus No History of Concussion**

<table>
<thead>
<tr>
<th>A* (hits per minute) (n=97)</th>
<th>History of Concussion (n=28)</th>
<th>No History of Concussion (n=69)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closest Time on System*</td>
<td>90.4 ± 10.20</td>
<td>87.1 ± 9.32</td>
<td>0.08</td>
</tr>
<tr>
<td>Best Time on System</td>
<td>96.3 ± 12.34</td>
<td>92.1 ± 9.19</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Test Conducted on BOSU*</td>
<td>86.3 ± 9.67</td>
<td>82.6 ± 9.07</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RT Time (sec) (n=94)</th>
<th>History of Concussion (n=27)</th>
<th>No History of Concussion (n=67)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closest Time on System*</td>
<td>0.35 ± 0.038</td>
<td>0.35 ± 0.040</td>
<td>0.46</td>
</tr>
<tr>
<td>Best Time on System</td>
<td>0.33 ± 0.034</td>
<td>0.33 ± 0.036</td>
<td>0.39</td>
</tr>
<tr>
<td>Test Conducted on BOSU*</td>
<td>0.37 ± 0.055</td>
<td>0.37 ± 0.055</td>
<td>0.37</td>
</tr>
</tbody>
</table>

$A^*$ = A* Dynavision D2™ test; RT = Reaction Time Dynavision D2™ test

*Closest time on System = the Dynavision D2™ trial conducted on flat ground that occurred closest in time/date to the trial conducted on the BOSU™, may have occurred before or after the dual task trial.

Note: special teams players were included in the offense category; Skilled positions included: quarterback, wide receiver, running back, defensive back, special teams; Non-skilled positions included: defensive line, linebacker, offensive line, tight end/full back

All descriptive data are reported as mean +/- standard deviation.
The unpaired t-test was performed to compare the data from the players’ best A* and RT (with and without the BOSU®) with first D2™ test each athlete performed. The year of ‘first test’ data collection depended upon when each athlete began attending team preseason camps. The results from those athletes with a concussion history and those with no history of concussion were compared. No differences were found between the groups for the RT; however statistically significant differences were noted for the A* in both the flat ground and the BOSU® test conditions. Interestingly, those athletes with a history of concussion performed better than those without concussion history in both testing conditions (Table 3).

DISCUSSION
The incidence and recognition of sport-related concussion has grown tremendously in the last decade. New research on the long-term effects of concussion is now emerging, leading to policy changes and an increased urgency for further research, and development of more comprehensive treatment and prevention programs. Although best practice for concussion management includes both neurocognitive analysis and a balance assessment, the two are often evaluated separately and there is no comprehensive measure that has gained wide acceptance for evaluation and/or concussion treatment.13,14 Many methods for dual task evaluation have been attempted, but none have endeavored to assess a simultaneous upper extremity visuomotor coordination task with balance on an unstable, self-perturbing surface. Much of the previous research in this area has utilized a relatively stable surface that is perturbed externally to create instability; past research shows that neurocognitive performance is altered with changes in stability of the standing surface.19,22,24-26

While the symptoms an athlete experiences following concussion can vary greatly, balance and visuomotor performance are likely among the main sequelae that limit return to full sport performance.12,24 In sport, these two events almost always occur simultaneously; likely due to their interrelationship via the vestibular system. The ability to perform these tasks concurrently in an (largely) unconscious process is essential for successful sport performance. Therefore, it is of great importance to assess and train these systems together and clear the concussed athlete before returning that athlete to competition.

The researchers aimed to examine a comprehensive evaluation tool that would utilize multi-task performance principles and allow for translation to on-field sport-specific skills. The D2™ training system was utilized to assess Division I college athletes in both stable surface and unstable surface conditions. The visual and motor systems of the brain provide the oculomotor control and visuomotor coordination necessary for completion of the study tasks. It was expected, therefore, that some change in D2™ performance would be noted with dual tasking, in this case the addition of a challenge to balance, as this would provide additional sensory input to the brain that would slow overall processing speed.

It is well documented that both balance and cognitive function may decline following a concussive event.25-27 The addition of a visual-cognitive challenge has been shown to increase postural sway in concussed patients, suggesting that postural instability following head injury is likely a result of the contribution of the visuospatial system to balance.24 In 2004, Heitger, et al. found that measurable changes are seen in both eye movement and visuomotor arm movements following a mild traumatic brain injury.11

Extrapolating from the Resch19 and Hunter22 studies, one would expect to see changes in D2™ scores with the addition of a balance challenge in normal, healthy subjects. With an added balance challenge, D2™ scores would likely further decline in a concussed athlete.19 In the current study, however, the authors’ found that a history of concussion did not impact the ability to perform the balance challenge. However, the methods utilized in the current study, would not allow for prediction of whether active concussion symptoms would cause a decline in score. While visuomotor and postural stability declines are expected following concussion2 and dual-task functions are likely impaired, re-training must then include modalities that challenge multi-task performance and return the athlete to their prior level of heightened postural control with cognitive and sport specific tasks. With this knowledge and normative data, the researchers in this study hope to establish new, evidence based protocols using baseline testing.
and objective balance tools for return to play decision-making following a diagnosis of concussion.

All athletes improved their D2™ scores from their first attempt to their final and had a decline in score while doing the BOSU® challenge regardless of their level of experience. However, the magnitude of the decline in scores during the BOSU® challenge was significantly less in upper-classmen (athletes with two or more years of playing experience with the university) compared to younger players. No statistical differences were seen between offensive and defensive athletes in A* scores, while stable ground; differences are noted between the groups in the RT test. No difference are noted in A* or RT performance between skilled and non-skilled players in any testing condition (Table 3).

Table 2 illustrates the progression of both A* and RT scores among the 94 athletes performing their first assessment, their best assessment and the assessment involving the BOSU® challenge. The upper-classmen achieved significantly higher scores for their individual A* runs on stable ground and with the BOSU® (Table 3). The relative change in the D2™ scores for both the A* and RT show a consistent decline in both groups with the addition of the BOSU® challenge. Thus, the impact of the balance challenge was not mitigated or exacerbated by age or level of training.

All players and positions who were tested on the D2™ system showed improvement with training and had a similar percentage of decline in their scores with the BOSU® challenge. This consistent decrement in performance is likely due to the previously mentioned physiology concerning the cerebellar and vestibular systems producing a relatively constant demand that results in an apparently predictable fall in performance. There were no significant differences in the relative decline in scores from the BOSU® challenge in the following group comparisons: offense versus defense, skilled versus non-skilled position players, upper-classmen versus junior players, athletes with a concussion history versus those without. Therefore, balance assessments as part of a challenge or dual task assessment methodology may have predictable changes in the performance parameter being studied. It should be noted that, although an increase in D2™ testing score from first attempt to second attempt is common, no significant learning effect is present with multiple trials on the D2™ system. McCormack et al. found that there is only limited learning effect in visual reaction time with consecutive D2 trials in athletes.28

Recently, the media has placed increasing attention on concussion rates, particularly sports-related concussion.29 With an increasing number of concussions being reported by athletic and governmental agencies, contact and collision sports are garnering negative media attention. This attention has put pressure on health care professionals to develop new tools for evaluation and treatment of concussion symptoms. To this date, to the author's knowledge, no peer-reviewed research has been published that investigates the changes in balance performance with a simultaneous visual motor assessment. Additionally, no researchers have published normative data on the D2™ system coupled with balance tasks, although it is widely used in the neuromusculoskeletal rehabilitation and sports medicine communities for assessment and rehabilitation.30

Despite the extensive use of the D2™ system for assessment and training, evidence for its use is largely anecdotal. Numerous anecdotal accounts state that regular training sessions on the D2™ can assist with sport performance (http://dynavisionD2™.com/). One published article describes improvements in baseball batting average following regular training on the D2™ system.31 Deveau et al showed similar improvements with video-game vision training.32

The current research utilized a normal, healthy population of Division I caliber young athletes. A decrease in performance of approximately 10% was noted in the primary task (D2™ score) when a secondary, balance, task was added. There were no major loses of balance (necessitating upper extremity support) resulting in a fall from the BOSU® by any of the athletes during testing. The results of this study are comparable to those of previously reported studies, where a decrement in performance is noted in healthy individuals when dual tasks are performed.19,22,24-26 Should an individual, post-concussion, have a baseline test with the BOSU® challenge and a known decrement in performance after concussion, that baseline may also help in managing that patient's rehabilitation and making return to play decisions.
Innumerable conscious and unconscious central nervous system (CNS) pathways contribute to the successful completion of an athlete’s performance; therefore, malfunction of any one of these pathways can lead to overall failure of the entire system. When one of the pathways that typically falls under unconscious control suddenly requires additional conscious perception, it will lead to slowed processing of other consciously controlled tasks. The results of the current study illustrate that when an athlete is performing a visuomotor task while their balance is challenged (dual-task performance), the visuomotor processing speed measured with the D2™ tests slows significantly. The authors of the current research suggest that up to a 10% decline in D2™ scores after the addition of the BOSU® challenge is an acceptable change. While further research is needed, based on normal physiologic principals and previous balance testing research, one might presume even larger deficits to be noted with the D2™/BOSU® system following a concussive injury.

The RT is a task where the visual system is waiting to respond to a stimuli and uses one hand at a time to respond, whereas the A* uses both hands simultaneously and the athlete must scan the board and move their body in order to perform the task. The authors’ observed that the tasks (hitting buttons) were decreased by about 10% in both tasks with the BOSU® challenge. This suggests that the dual-tasking activity of balance caused a consistent fall in performance despite the different demands required for the eye-hand performance task being accomplished. It was hypothesized that the added focus required for balance during the BOSU® challenge inhibited eye-hand performance equally during the two tasks.

A decline in performance occurs because of dysfunction within the complex neurophysiologic systems involved in vision and balance. It has been described using animal models that the vestibular system of the inner ear and the connections of the cerebellum are two of the primary regulatory centers involved in coordination of smooth motor movements of both the visual and neuromuscular system. Both the vestibular and cerebellar systems receive input from sensory nerves monitoring the body’s various parts in space. The exact pathophysiologic mechanism of injury to these organs during traumatic brain injury has not been precisely defined but many theories, such as direct injury to the otolith organs of the inner ear, have been described. Because of the constant stream of information being monitored by these systems their regulation is typically under subconscious control. However, after the brain experiences an injury and is not functioning at full capacity, the balance system begins to require more conscious control in order to perform coordinated actions and maintain balance with normal movements. The increase in conscious control of balance subsequently slows down the performance of other central nervous system tasks.

This study utilized D2™ A* and RT to establish a baseline for concussion assessment and management. However, these two tests are unable to specifically assess balance and the vestibular systems of a patient suspected to have a concussion. The addition of the BOSU® ball introduces a balance aspect to the D2™ tests, as a kind of dual-task challenge. Therefore, future studies to assess whether and to what extent the D2™ scores are impacted with the BOSU® challenge in a concussed population should be pursued. A limitation of the current study is the inclusion of all football team members without regard for prior, undocumented, concussion history or lower extremity injury. Also, the survey to assess concussion was a self reporting survey and not confirmed by chart review. When the reported concussion history and non-concussion history groups were compared there were no differences seen. Future studies examining athletes from other sports and of varied ages are needed. Future studies with a D2™ and BOSU® set up might consider analysis of athletes with concussive symptoms or with orthopedic injuries. While these baseline data may be helpful in establishing norms and in future research, the authors acknowledge that the comparison of an individuals’ post-concussive data with their baseline data will be of greater assistance with establishing return to play decisions.

**CONCLUSION**

Results from this study illustrate that the addition of a balance challenge to a visuomotor task produces a consistent and reproducible decrement in performance of A* and RT scores in a population of college football players. With future research targeting...
the use of this type of testing pre- and post-concussion, the data from the current study may be used to assist the clinician in determining multi-task deficits following concussion and may assist in determining appropriate return-to-play decisions. Additionally, the use of a balance challenge (BOSU®) with a quantitative assessment tool such as the D2™ could be useful for assessing performance in subjects at risk of balance or vestibular deficiencies.

REFERENCES


ABSTRACT

Purpose/Background: Division III (D III) collegiate coaches are challenged to assess athletic readiness and condition their athletes during the preseason. However, there are few reports on off-season training habits and normative data of functional assessment tests among D III athletes. The purpose of this study was to examine off-season training habits of D III athletes and their relationships to the standing long jump (SLJ) and single-leg hop (SLH) tests.

Methods: One-hundred and ninety-three athletes (110 females, age 19.1 ± 1.1 y; 83 males, age 19.5 ± 1.3 y) were tested prior to the start of their sports seasons. Athletes reported their off-season training habits (weightlifting, cardiovascular exercise, plyometric exercise, and scrimmage) during the six weeks prior to the preseason. Athletes also performed three maximal effort SLJs and three SLHs.

Results: Male athletes reported training more hours per exercise category than their female counterparts. Mean SLJ distances (normalized to height) were 0.79 ± 0.10 for females and 0.94 ± 0.12 for males. Mean SLH distances for female athletes' right and left limbs were 0.66 (± 0.10) and 0.65 (± 0.10), respectively. Mean SLH distances for male athletes' right and left limbs were 0.75 (± 0.13) and 0.75 (± 0.12), respectively. Several significant differences between off-season training habits and functional test measures were found for both sexes: males [SLJ and weightlifting (p=0.04); SLH and weightlifting (p=0.04), plyometrics (p=0.05)]; females [SLJ and plyometrics (p=0.04); SLH and scrimmage (p=0.02)].

Conclusion: This study provides normative data for off-season training habits and preseason functional test measures in a D III athlete population. Greater SLJ and SLH measures were associated with increased time during off-season training.

Clinical Relevance: The findings between functional tests and off-season training activities may be useful for sports medicine professionals and strength coaches when designing their preseason training programs.

Level of Evidence: 4

Keywords: college, field test, functional test, single-leg hop, standing long jump
INTRODUCTION

Many collegiate athletes train year round to maintain fitness and skills. However, NCAA rules define the quantity of allowed supervised practices (e.g., scrimmage, conditioning sessions) during the off-season, preseason, and regular season.¹ Coaches at the Division III (D III) level are especially challenged to assess and prepare their teams prior to the start of competition, due to 1) frequent inability to afford “high tech”, expensive testing equipment available at Division I (D I) universities, 2) possible inability to employ a dedicated strength and conditioning coach/staff, and 3) the limitations of approximately two and one-half weeks of sanctioned practice prior to the first competition (e.g., sports other than football).¹ Therefore, some collegiate coaches conduct functional tests during the preseason to assess aspects of an athlete’s baseline fitness level.²⁻⁶ The results from these tests are used to assess athletic readiness and evaluate the effectiveness of a team’s training programs.³⁻⁷⁻¹⁰

There is limited literature related to off-season training habits and functional measures in the D III population. Schmidt presented preseason physical characteristics, upper- and lower-body power and strength measures, flexibility, muscular endurance, and speed endurance measures for 78 D III football players with data presented by position.¹¹ Schmidt identified significant differences in hip sled, seated medicine ball put, and bench press performances in starters versus non-starters.¹¹ Hoffman et al⁵ assessed preseason anthropometric measures, aerobic fitness, anaerobic power, strength, speed, and agility in 22 D III female lacrosse players.⁵ They found that defenders were significantly stronger with the 1RM squat than midfielders and that attackers had significantly greater Wingate anaerobic power test measures than other positions.⁵ Barnes et al² compared mean preseason performances of a countermovement vertical jump (CMVJ) and a drop jump test in Division I, II, and III collegiate female volleyball athletes. D I female athletes jumped significantly (p < 0.05) higher during the CMVJ than their D III counterparts.² In sum, studies of baseline fitness levels and athletic readiness in D III athletes have only been described for a few athletic populations.

Several limitations of the aforementioned studies are that they have been confined to a few select sports and have used measures that may be time and cost intensive. Thus, there is a need to collect additional measures of athletic fitness and readiness of D III athletes from multiple sports with inexpensive, quick-to-perform, and easy-to-administer functional tests at the start of the preseason. Additionally, the relationship between an athlete’s preseason performance and his/her off-season training habits has not been reported. Knowledge of athletes’ off-season training habits may help D III coaches design and implement conditioning programs at the start of the preseason.

The purpose of this study was to describe off-season training habits of D III athletes via questionnaire, measure preseason performance of the standing long jump (SLJ) and the single-leg hop (SLH) for distance functional tests, and examine relationships between training habits and preseason athletic characteristics in D III athletes. The authors hypothesized that athletes who reported greater levels off-season training would jump and hop significantly farther than those who reported less time training.

METHODS

Subjects were recruited to participate in the preseason of their respective sport. One-hundred and ninety-three D III collegiate athletes (110 females, mean age 19.1 ± 1.1 y; 83 males, mean age 19.5 ± 1.3 y) from 15 university teams (volleyball, wrestling, women’s lacrosse, baseball, softball; women’s and men’s tennis, track and field, cross-country, soccer, and basketball) participated in this study. An athlete was excluded from testing if she/he was under the age of 18 or was currently restricted from full sport participation by the team physician. The Institutional Review Boards of Rocky Mountain University of Health Professions and Pacific University approved this study. Signed informed consent was received from each subject prior to testing.

Procedures

Study Questionnaire. Prior to the start of the season, each athlete completed a questionnaire collecting demographic information including age, years at university, age starting their sport, and average time spent training per week during the six weeks prior to the start of the preseason (e.g., sanctioned practice) for each of the following activities: weightlift-
ing, cardiovascular exercises, plyometric exercises, and scrimmages.

**Height and weight.** Subject’s height (cloth tape) and weight without shoes (standard medical scale) were recorded for each participant. Height was measured to the nearest half inch and weight recorded to the nearest half pound.

**Dynamic Warm-Up.** After completing the study questionnaire and collecting anthropometric measures, each subject completed a dynamic warm-up prior to performing the functional tests. The dynamic warm-up consisted of 5 to 10 minutes of active lower extremity movements from sideline to sideline on a basketball court or across the width of the tennis court for the tennis players. This warm-up included forward walking, backward walking, heel walking, tip toe walking, forward lunging, backward lunging, and high knee marching.

**Standing Long Jump Testing Protocol.** Athletes were instructed to stand with feet approximately shoulder width apart behind a line (piece of tape) on the court. A cloth measuring tape was oriented perpendicular to the start line and taped to the floor. The athlete was instructed to perform 3 submaximal countermovement SLJs with hands behind her/his back, followed by 3 jumps performed with hands clasped behind the back at maximal effort. An athlete had to land on both legs under control (maintaining center of mass within her/his base of support) holding this position for 5 seconds for a jump to be recorded.12 If an athlete was unable to land successfully (e.g. loss of balance), the trial was repeated. The distance jumped was measured from starting line to the rearmost heel with mean of the three jumps (± SD) scores utilized for data analyses.

**Single-Leg Hop for Distance Testing Protocol.** The six SLH (3 for each lower extremity) for distance tests were performed after the athlete completed three maximal effort SLJ tests. The SLH for distance test was also performed with hands clasped behind the athlete’s back. For a test to be recorded an athlete would have to stick the landing (take-off and land with the same lower extremity) holding the position for 5 seconds.12 If an athlete was unable to land successfully the SLH was repeated. The distance hopped was measured from the starting line to the heel with mean of the three hops on each leg (± SD) scores utilized for data analyses.

**Statistical Methods**

Means (± SD) were calculated for the subjects’ baseline demographic characteristics, anthropometric measures, and SLJ and SLH scores. Mean SLJ and SLH scores were normalized as a percentage of body height. Comparison of means between genders for demographic characteristics and SLJ and SLH scores were calculated by performing independent t-tests. Height, weight, and body mass index (BMI) were categorized as (<-1 SD [shortest, lightest, or lowest]/ Mean [average]/ +1 SD [tallest, heaviest, or highest]). Each of off-season training habits were categorized by the following groups: 0-1 / >1-3 / >3-5 / >5 hours per week. Analysis of variance (ANOVA) was performed to assess mean differences within gender for preseason training habits, height, weight, and BMI. A post-hoc Bonferroni test was performed after ANOVA to identify significant differences between subcategories within a group. Analysis of covariance (ANCOVA) was performed when necessary to control for weight or BMI. An a priori test-retest reliability for the SLJ and SLH was performed using intraclass correlation coefficients (ICCs). Data analysis was performed using SPSS Statistics 17 (Chicago, IL) with alpha level set at 0.05.

**RESULTS**

Baseline characteristics of the study sample are presented in Table 1. Men spent a higher average number of hours per week weightlifting (p ≤ 0.0001) and scrimmaging (p = 0.01) than women during the six weeks prior to the start of their sports season.

Table 2 presents normalized SLJ mean (± SD) distances by age and anthropometric measures (categorized by ± 1 SD) for each sex. The test-retest reliability (ICC3,3) for the SLJ was 0.96 (95% CI: 0.83, 0.97). On average, men jumped significantly farther (0.94 ± 0.12) than female athletes (0.79 ± 0.10) (p ≤ 0.0001). After controlling for BMI (ANCOVA), SLJ distance jumped was still significantly greater among male athletes than female athletes (p ≤ 0.0001). There was no difference in distance jumped with age as a factor for female or male athletes. A significant difference was observed between SLJ distance based on
women's weight (p = 0.05); however, no significant within group differences were found after Bonferroni correction. Male athletes in the shortest height (1.69 m or less) group jumped significantly farther on average than those in the tallest height (1.91 m or more) group when jump distance was normalized for height (p = 0.04). Finally, male SLJ distances differed between the BMI categories (p = 0.03);
however, after Bonferroni correction there were no within group differences.

Mean distance jumped by reported off-season training habits are presented in Table 3. Women who reported performing greater than one and up to three hours per week of plyometric exercises jumped significantly further (p = 0.02) on average than those who performed one hour or less per week. While a significant mean difference (p = 0.01) in distance jumped by females in the scrimmage exercise category was also observed; no significant within group differences in SLJ distances by scrimmage hour categories were found. Men who reported weightlifting greater than five hours per week jumped significantly farther on average than those who reported weightlifting between greater than 1 and up to 3 hours per week (p = 0.04). Normalized SLH distances per age group and anthropometric measures are shown in Table 4. The test-retest reliability (ICC3,3) for SLH distances were 0.95 (95% CI: 0.89, 0.98) on the right and 0.96 (95% CI: 0.89, 0.98) on the left. Mean normalized SLH distances for female athletes were 0.66 (± 0.10) for the right leg and 0.65 (± 0.10) on the left leg. Mean SLH distances for male athletes were 0.75 (± 0.13) for the right leg and 0.75 (± 0.12) on the left leg. Male SLH distances were significantly greater for each leg than their female counterparts (p ≤ 0.0001). There was no within group differences between SLH distances and age category per gender. Female athletes in the mean height range hopped significantly further with the left leg than the tallest female athletes (p = 0.02). Female athletes in the mean BMI range also hopped significantly further with each leg.

Table 3. Normalized Standing Long Jump Mean (± SD) Distances by Off-Season Training Habits of Division III Athletes

<table>
<thead>
<tr>
<th>Variable</th>
<th>Women (n = 110)</th>
<th>Men (n = 83)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>Off-Season Training (hr/wk)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weightlifting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-1</td>
<td>31</td>
<td>0.77 ± 0.10</td>
</tr>
<tr>
<td>&gt;1 – 3</td>
<td>38</td>
<td>0.79 ± 0.10</td>
</tr>
<tr>
<td>&gt;3 – 5</td>
<td>28</td>
<td>0.80 ± 0.12</td>
</tr>
<tr>
<td>&gt;5</td>
<td>13</td>
<td>0.80 ± 0.09</td>
</tr>
<tr>
<td>Cardiovascular Exercise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-1</td>
<td>6</td>
<td>0.83 ± 0.06</td>
</tr>
<tr>
<td>&gt;1 – 3</td>
<td>30</td>
<td>0.77 ± 0.11</td>
</tr>
<tr>
<td>&gt;3 – 5</td>
<td>35</td>
<td>0.79 ± 0.10</td>
</tr>
<tr>
<td>&gt;5</td>
<td>39</td>
<td>0.79 ± 0.09</td>
</tr>
<tr>
<td>Plyometric Exercise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-1</td>
<td>48</td>
<td>0.76 ± 0.09</td>
</tr>
<tr>
<td>&gt;1 – 3</td>
<td>47</td>
<td>0.82 ± 0.11</td>
</tr>
<tr>
<td>&gt;3 – 5</td>
<td>9</td>
<td>0.79 ± 0.10</td>
</tr>
<tr>
<td>&gt;5</td>
<td>6</td>
<td>0.82 ± 0.08</td>
</tr>
<tr>
<td>Scrimmage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-1</td>
<td>40</td>
<td>0.77 ± 0.08</td>
</tr>
<tr>
<td>&gt;1 – 3</td>
<td>26</td>
<td>0.83 ± 0.11</td>
</tr>
<tr>
<td>&gt;3 – 5</td>
<td>22</td>
<td>0.76 ± 0.10</td>
</tr>
<tr>
<td>&gt;5</td>
<td>22</td>
<td>0.82 ± 0.09</td>
</tr>
</tbody>
</table>

*ANOVA=Analysis of Variance
† Difference between 0-1 hrs/wk and >1-3 hrs/wk; p-value= 0.01 post-hoc
‡ Difference between >1-3 hrs/wk and >5 hrs/wk; p-value= 0.04 post-hoc
than female athletes in the highest BMI range. A significant group difference in mean distance hopped by males in the BMI categories (right leg: p = 0.05) occurred; however, after post-hoc correction there were no intragroup differences between BMI categories.

Mean distance hopped by reported preseason training habits is presented in Table 5. Women who reported scrimmaging more than 1 hour and up to 3 hours a week jumped significantly further with the left leg (p = 0.02) than those who scrimmaged less than 1 hour a week. Male athletes who reported performing more than 5 hours of plyometric exercise a week hopped significantly farther on average with their left leg (p = 0.05) than males who reported more than 1 hour and up to 3 hours of plyometrics each week. Male athletes who also performed more than 5 hours of weightlifting each week hopped significantly farther (p = 0.04) with their right leg compared to male athletes who reported more than 1 and up to 3 hours of weightlifting per week.

**DISCUSSION**

This is the first study to report off-season training habits 6 weeks prior to formal preseason training and preseason measures of the SLJ and SLH functional tests for D III collegiate athletes. Male athletes reported exercising more during the off-season than their female counterparts. While total time spent exercising did not describe the quantity (e.g. total sets and repetitions, intensity) or the quality of the exercise performed these data provided insight as to off-season training habits in this population.

A novel feature of this study was the analysis of the differences between off-season training habits and preseason functional measures. Several significant associations between jump (SLJ) and hop (SLH) distance and reported off-season training habits were found. In each instance where a significant difference in jump or hop distance as a factor of off-season training habits occurred, greater reported time devoted to training was observed. While the study’s methodology did not allow for the examination of

| Table 4. Normalized Single-Leg Hop Mean (± SD) Distances Per Age and Anthropometric Measures for Division III Athletes |
| Variable | Females | | Males | |
| | Mean ± SD | p-value* | Mean ±SD | p-value* |
| | N | (R) | (L) | | N | (R) | (L) |
| Age | | | | | | | |
| 18 | 39 | 0.66 ± 0.10 | 0.65 ± 0.11 | (R) 0.84 | 24 | 0.74 ± 0.15 | 0.76 ± 0.14 | (R) 0.11 |
| 19 | 34 | 0.65 ± 0.09 | 0.64 ± 0.09 | (L) 0.68 | 21 | 0.77 ± 0.15 | 0.75 ± 0.13 | (L) 0.16 |
| 20 | 24 | 0.67 ± 0.11 | 0.67 ± 0.11 | | 20 | 0.71 ± 0.07 | 0.71 ± 0.09 | |
| 21 and older | 13 | 0.64 ± 0.14 | 0.63 ± 0.13 | | 18 | 0.81 ± 0.10 | 0.80 ± 0.09 | |
| Totals | 110 | 0.66 ± 0.10 | 0.65 ± 0.10 | | 83 | 0.75 ± 0.13 | 0.75 ± 0.12 | |
| Height (m) | | | | | | | |
| Shortest (-1 SD) | 18 | 0.64 ± 0.10 | 0.65 ± 0.10 | (R) 0.05 | 15 | 0.79 ± 0.14 | 0.79 ± 0.11 | (R) 0.28 |
| Average | 80 | 0.67 ± 0.10 | 0.66 ± 0.10†† | (L) 0.02 | 54 | 0.76 ± 0.13 | 0.75 ± 0.12 | (L) 0.48 |
| Tallest (+1 SD) | 12 | 0.60 ± 0.10 | 0.57 ± 0.10†† | | 14 | 0.71 ± 0.10 | 0.74 ± 0.11 | |
| Weight (kg) | | | | | | | |
| Lightest (-1 SD) | 17 | 0.66 ± 0.10 | 0.65 ± 0.10 | (R) 0.07 | 12 | 0.78 ± 0.14 | 0.77 ± 0.11 | (R) 0.26 |
| Average | 80 | 0.67 ± 0.10 | 0.66 ± 0.10 | (L) 0.06 | 63 | 0.76 ± 0.13 | 0.76 ± 0.12 | (L) 0.50 |
| Heaviest (+1 SD) | 13 | 0.60 ± 0.11 | 0.58 ± 0.12 | | 8 | 0.69 ± 0.10 | 0.72 ± 0.09 | |
| BMI | | | | | | | |
| Lowest (-1 SD) | 17 | 0.64 ± 0.11 | 0.61 ± 0.10 | (R) 0.03 | 8 | 0.70 ± 0.16 | 0.72 ± 0.12 | (R) 0.05 |
| Average | 77 | 0.67 ± 0.09† | 0.67 ± 0.10‡ | (L) 0.02 | 67 | 0.77 ± 0.12 | 0.77 ± 0.12 | (L) 0.08 |
| Highest (+1 SD) | 16 | 0.60 ± 0.12† | 0.60 ± 0.11‡ | | 8 | 0.67 ± 0.06 | 0.68 ± 0.05 | |

*ANOVA= Analysis of Variance; SD= Standard Deviation
†Difference between Mean and +1 SD; p= 0.03 post-hoc
‡Difference between Mean and +1 SD; p= 0.05 post-hoc
††Difference between Mean and +1 SD; p= 0.02 post-hoc

(right: p = 0.03; left: p = 0.02) than female athletes in the highest BMI range. A significant group difference in mean distance hopped by males in the BMI categories (right leg: p = 0.05) occurred; however, after post-hoc correction there were no intragroup differences between BMI categories.
a causal relationship between the off-season training methods and increased distance reached, these exploratory findings might help guide coaches and sports medicine professionals when designing training programs for D III athletes.

Few studies have reported normative values for the SLJ and SLH in collegiate or other sport populations. Thus, the current data may be beneficial to coaches and sports medicine professionals when evaluating their athletes/patients or making comparisons to other populations. Previously reported non-normalized SLJ mean distances in male populations range from 2.01 m (adolescent male athletes) to 3.05 m (± 0.15) (NFL drafted skill players), whereas we observed male D III athletes jumped a mean distance of 1.69 m (± 0.20) (not normalized to height).\textsuperscript{13-16} The observed mean SLJ distance of 1.31 m (± 0.17) (not normalized to height) in our collegiate D III female population was also less than those reported in prior studies: 1.59 m (adolescent female athletes) to 2.28 m (± 0.16) (Division I track and field athletes)\textsuperscript{13,14} The mean (not normalized) hop distance for females in this study [right LE = 1.09 m (± 0.17); left LE = 1.07 m (± 0.17)] was lower than previously reported values from 1.14 m (± 0.3) to 1.23 m (± 0.5).\textsuperscript{17,18} The mean (not normalized) hop distances for males in this study [right LE = 1.35 (± 0.22); left LE = 1.35 (± 0.22)] were also lower than previously reported values from 1.43 m (± 0.27) to 2.04 m (± 1.49).\textsuperscript{18,19} A potential explanation for the difference in means between the D III athlete population in the current study and prior studies may be the difference in testing procedures. In this study, athletes were restricted from performing a countermovement arm swing prior to jumping (hands clasped behind back) consistent with clinical testing recommenda-

<table>
<thead>
<tr>
<th>Table 5. Normalized Single-Leg Hop Mean (± SD) Distances Per Age and Anthropometric Measures for Division III Athletes</th>
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<tr>
<td><strong>Variable</strong></td>
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<td>Plyometric Exercise</td>
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<td>&gt;3-5</td>
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<td>&gt;5</td>
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<tr>
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</tbody>
</table>

\*ANOVA = Analysis of Variance
\†Difference between 0-1 hrs/wk and >1-3 hrs/wk; p-value = 0.03 post hoc.
\††Difference between >1-3 hrs/wk and 5+ hrs/wk; p-value = 0.03 post hoc.
\‡Difference between >1-3 hrs/wk and 5+ hrs/wk; p-value = 0.04 post hoc.
Ashby et al\textsuperscript{12} reported subjects who are able to swing their arms when performing the SLJ were able to jump 21\% farther than when arm motion was restricted [SLJ with arm swing = 2.09 m (± 0.03); SLJ without arm swing = 1.72 m (± 0.03)].

The descriptive data presented in the current study may also be useful for sports medicine professionals when assessing their injured athlete’s readiness to return to sport after injury.\textsuperscript{12} The SLJ and SLH tests are frequently used to assess lower extremity strength and power after injury.\textsuperscript{12,21} Male athletes have been recommended to be able to jump (SLJ) at least 90\% of their height and hop (SLH) at least 80\% of their height (each test with hands clasped behind back) in order to be cleared to return.\textsuperscript{12,21} In the current study, males, on average, jumped 94\% of their height; however, they only hopped 75\% of their height. Likewise, female athletes are recommended to be able to jump (SLJ) at least 80\% of their height and hop (SLH) at least 70\% of their height in order to be cleared to return.\textsuperscript{12,21} In the current study, females, on average, jumped only 79\% of their height and hopped only 65-66\% of their height.\textsuperscript{12,21} Interestingly, in the current study sample, many of the healthy, D III athletes failed to achieve jump or hop minimal distances recommended for injured athletes prior to returning to sport. Thus, future research is warranted to determine if the aforementioned functional testing discharge criteria are appropriate for this population prior to resuming sport.

This study included some important strengths. First, this study has presented data on one of the largest samples of D III collegiate student-athletes. One hundred and ninety-three athletes (females = 110) from 15 teams were tested. Second, the off-season training habit data was collected by an author who was not a member of any coaching staff. This independence may have increased the likelihood of athletes accurately reporting their training habits during the six weeks prior to the start of the preseason. Third, the functional tests assessed in this study, the SLJ and the SLH, were selected for their ease of use and their ability to assess lower extremity strength and power.\textsuperscript{21} The SLJ and the SLH are also utilized frequently by rehabilitation professionals to guide decision making as to whether an athlete is able to return to sport.\textsuperscript{12,18,21,22} These tests have also been used to assess athletic readiness and thus warrant assessment for associations with training habits.\textsuperscript{21}

A few limitations of this study are recognized. First, the data presented here provides preseason functional performance measures for 193 D III athletes from several teams; however, specific analysis by sport is not possible at this time because some sports were represented by small sample sizes. This did not allow for specific subanalyses by specific sports. Future research should collect preseason training habits and functional measures for individual sport teams with larger sample sizes. Second, similarly, although statistically significant findings between off-season training practices were described by gender, the authors advise caution when interpreting the clinical significance of these findings, as some group sizes were small with wide standard deviations. Third, not all athletes at the university were tested. Some athletes had sustained an injury prior to testing (either during the off-season or during preseason prior to data collection) that impaired their ability to perform the tests. It is possible that injured athletes, who were unable to participate in testing, would have started the season with decreased strength or side-to-side differences in SLH measures.\textsuperscript{23} Characteristics of injured athletes who were not assessed may have changed overall mean scores. A fourth limitation of this study is that the associations between preseason training habits and functional measures do not suggest a cause-and-effect relationship. To establish a cause-and-effect relationship, researchers would need to test the athletes prior to a training program intervention (e.g. plyometric training program or weight training program) followed by repeating the SLJ and SLH tests post-intervention. A final limitation is that the athletes were asked to self-report their time spent training during the prior six weeks. It is possible that this method of ascertaining their activities may have led to some recall bias. Future studies may want to have the athletes record their off-season training activities prospectively.

CONCLUSION
This study investigated the relationship between off-season training habits and preseason SLJ and SLH functional test measures in a general D III collegiate athlete population. The study indicates that greater SLJ and SLH measures may be associated with
increased time during off-season training. These findings present data that may be useful for coaches to assess and prepare their athletes at the start of the preseason. D III coaches are limited in the amount of sanctioned training time and may be limited in available resources (e.g. staff, equipment). Appreciating off-season training habits and utilizing normative data that has been described for the SLJ and SLH functional tests may help D III coaches assess athletic readiness and develop training programs for their athletes. In addition, the descriptive functional test data may help guide clinical decision making for sports medicine professionals when assessing return to play status of an injured D III athlete.

REFERENCES


ABSTRACT

Study Design: Controlled laboratory study.

Background and Purpose: Anterior knee pain is one of the most common running symptoms reported in the literature. While the exact etiology is unknown, a lack of hip strength is suggested to contribute to abnormal running mechanics. The purpose of this research study was to evaluate the association between isokinetic hip strength and 3-D running kinematics.

Methods: 33 male high school and collegiate cross country runners participated in this study. Peak isokinetic hip abductor and hip extensor strength were assessed. Each subject also completed a treadmill running protocol at a self-selected speed (mean = 3.8 m/s). 3-D kinematic data were collected at 240 Hz using a 10-camera motion capture system. Pearson correlation coefficients were used to determine the relationship between hip strength and hip range of motion (ROM) during the stance phase of running (p<0.05).

Results: Peak isokinetic hip extensor torque was inversely correlated with transverse plane hip ROM (r = -.387, p = .026) but was not significantly related to sagittal plane hip ROM or frontal plane hip ROM. Peak isokinetic hip abductor torque was inversely correlated with frontal plane hip ROM (r = -.462, p = .008) but was not significantly related to either sagittal plane hip ROM or transverse plane hip ROM. Peak isokinetic hip extensor torque and peak isokinetic hip abductor torque were not significantly related to knee kinematics in any plane.

Conclusions: Peak isokinetic hip extensor torque and peak isokinetic hip abductor torque are associated with transverse plane and frontal plane hip kinematics, but not knee kinematics.

Keywords: cross country, hip strength, isokinetic testing, running biomechanics.

Levels of Evidence: Level 3b

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INTRODUCTION
Running continues to grow in popularity among high school and collegiate athletes. Data from the National Federation of High Schools reports that 451,601 young athletes participated in cross-country during 2010-2011, reflecting a 24% increase in participants since 2003-2004. Concomitant with the increased participation, associated increases in running injuries are common. While injury rates vary, the annual incidence of injury among high school cross-country runners can be as high as 17 per 1000 athletic exposures.

Anterior knee pain is the most prevalent of all running injuries. While the exact etiology of anterior knee pain in runners is unknown, reduced hip strength is suggested to contribute to abnormal running mechanics. An inability to stabilize the hip during the stance phase of running likely increases the dynamic Q-angle, or dynamic lower extremity genu valgum, resulting in aberrant patellofemoral contact pressures. Multiple investigators have retrospectively demonstrated that a lack of adequate hip strength is associated with patellofemoral pain syndrome (PFPS), particularly in females. However, the association between impaired hip strength and PFPS in males has been less extensively studied.

Investigations that evaluated the efficacy of improved strength on functional movement patterns in injured and uninjured subjects provide equivocal evidence. While enhanced hip strength has not been demonstrated to lead to improved running mechanics in adult runners with PFPS, improved kinematics have been reported in uninjured adult runners following a hip strengthening protocol. In uninjured female subjects who underwent combined neuromuscular training and strength training, strength improvements were associated with improvements in knee biomechanics. However, due to mixed methods study design whereby subjects underwent both neuromuscular reeducation and strength training it cannot be definitively stated that improved biomechanics were due to improvements in strength alone. In uninjured adult male subjects, both open and closed kinematic chain strengthening enhanced strength and led to kinematic and kinetic improvements in a running and cutting maneuver task. While the majority of these studies have been in adults, few, if any studies exist establishing the association between hip muscle strength and lower extremity function in competitive, adolescent and young adult male long-distance runners.

The majority of literature that has documented the association between hip weakness and PFPS has utilized isometric dynamometry. A potential limitation of this method is the inability to assess muscular strength and function throughout a range of motion. This may limit the generalizability of the measure to functional tasks such as running. Recently, several authors have undertaken isokinetic testing of the hip musculature in an attempt to address these instrumentation limitations. Potential limitations of these methods include non-functional test positions, limited test speeds, and reduced arcs of motion. Therefore, identification of instruments that accurately quantify hip strength in a more functional position, at higher testing speeds, and through a larger functional range of motion may provide more clinically relevant information in the assessment of risk for future running injuries.

The purpose of this research study was to evaluate the association between isokinetic hip strength and 3-D running kinematics. The authors hypothesized that increased hip strength would be associated with decreased frontal and transverse plane hip motion during running in competitive male high school and collegiate long-distance runners. Further, it was hypothesized that increased hip strength would be associated with reduced frontal and transverse plane motion at the knee joint.

METHODS
Participants and Setting
Running kinematics and peak concentric isokinetic hip abductor and extensor strength were assessed at 120 deg/sec on 33 uninjured male high school and collegiate cross country runners (Mean Age 18.3 +/- 1.9 yrs; Height: 176.9 +/- 6.3 cm; Mass 61.6 +/- 5.0 kg) using an isokinetic dynamometer (Biodex Medical Systems Inc, Shirley, NY). Testing was performed in a laboratory setting. To be considered for the study subjects needed to be male, actively participating in either high school or collegiate cross country, free from any lower extremity injury for at least 6 months prior to the study, report running at least 20
km per week, and be free from any cardiovascular or neurological condition that would preclude safe treadmill running. The Institutional Review Board at Cincinnati Children’s Hospital Medical Center approved the study protocol and the rights of the subjects were protected throughout the study.

**Hip Isokinetic Testing Protocol**

Concentric isokinetic hip abduction strength was measured for each subject using a protocol previously described by Brent and colleagues26 (Figure 1) and torques were normalized to the subject’s body mass. The subject was instructed to stand facing the dynamometer head. The subjects were secured with a strap that originated from the stationary platform on the uninvolved side and extended around the subject’s waist above the iliac crest. The dynamometer head was aligned in parallel with the frontal plane of the body with the axis of rotation of the dynamometer aligned with the center of rotation of the hip. The test limb was secured to the attachment arm with a custom strap and resistance pad extending from the attachment arm positioned immediately superior to the knee. The subjects were instructed to grasp the top of the dynamometer head for support to minimize movement of the torso. The dynamometer was programmed to go through the subject’s full available active hip abduction ROM, approximately 0°-45°.

Concentric isokinetic hip extension strength was measured for each subject using a novel testing design (Figure 2) and torque outputs were normalized to the subject’s body mass. The subjects were instructed to

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**Figure 1.** Method for Measuring Concentric Hip Abduction Isokinetic Peak Torque. (a) Anterior view of hip abduction set-up. (b) Lateral view of hip abduction set-up.

**Figure 2.** Method for Measuring Concentric Hip Extension Isokinetic Peak Torque.
stand facing the chair of the isokinetic machine and to place hands on both sides of the back of the seat. The subjects’ arms were positioned at approximately 90 degrees of shoulder flexion. Using a large goniometer (Patterson Medical, Bolingbrook, IL), the subject was placed in approximately 10 degrees of trunk flexion. In order for the subject to attain the trunk flexion position, a custom triangular plastic wedge (Foam ‘N More, Inc., Clawson, MI) was placed between the subject’s body and the seat-back with additional wedges used as needed for taller subjects. In order to minimize excessive trunk motion, the subject’s trunk and pelvis were secured to the triangular plastic wedge using straps secured to the seat back of the dynamometer. The dynamometer head was aligned in parallel with the center of rotation of the hip at the subject’s greater trochanter. The thigh pad of the moving arm was placed just superior to the popliteal space on the testing limb and was secured anteriorly around the thigh. The heel of the subject’s stance limb rested on a half foam roll while the subject’s tested limb was flexed approximately 90 degrees at the knee. The dynamometer was programmed to move into an arc of approximately 30 degrees of hip extension from the patient’s resting hip position, which equated to an arc of motion from approximately 25° of hip flexion to approximately 5° of hip extension.

Prior to testing, all subjects were provided detailed instructions of each testing protocol. Each subject was provided 5 submaximal practice repetitions on each limb for each test condition. Five maximal repetitions for hip extension and hip abduction were collected concentrically for each strength test. The authors chose 120 deg/sec in an attempt to better approximate the joint torque that the hip joint experiences during the running motion.27 While muscles have been demonstrated to produce greater concentric force at decreased isokinetic testing velocities28, the authors felt 120 deg/sec would adequately capture the torque producing qualities of the muscle groups in question. A pilot study assessed intertester and intratester reliability for the described method of hip extension isokinetic testing through an intra-class correlation coefficient (ICC)29. An ICC value greater than 0.81 was considered excellent.30 The hip abduction testing protocol was performed by one laboratory assistant who has previously established excellent intratester reliability.31

**Treadmill Running Protocol**

Each subject also completed a running protocol, as previously described in detail by Ford and colleagues,32 wearing standardized neutral-cushioned footwear (Adidas Supernova Glide, Adidas, Inc.) on a custom high-speed treadmill at a self-selected speed (SS) (mean = 3.8 m/s). Three-dimensional kinematic data were collected at 240 Hz using a 10 camera motion capture system (Motion Analysis Corporation, Santa Rosa, CA) utilizing a previously established marker set with a minimum of 3 retroreflective markers attached to the pelvis, thorax, and each lower extremity segment (foot, shank, and thigh) (Figure 3).32,33 Thirty consecutive steps were captured bilaterally at each speed, and the first twenty steps during the SS run were used for analysis (Figure 3). Each trial was visually inspected to ensure proper identification of the stance phase, defined as the period between initial foot strike to toe-off. The motion analysis system was calibrated based on manufacturer’s recommendations. Marker trajectories were filtered at a cutoff frequency of 12 Hz (low-pass further order Butterworth filter) prior to calculating knee and hip angles (Visual3d, C-Motion, Inc.).

**STATISTICAL METHODS**

Pearson correlation coefficients were used to determine the relationship between hip strength and hip and knee range of motion (ROM) during the stance phase of running. Correlations were determined to be statistically significant at \( p < 0.05 \).

An exploratory factor analysis using principal axis factoring extraction with a direct oblimin rotation was conducted using sagittal, frontal, and transverse plane angles of the hip and knee joint during stance. Specifically, six variables were entered into the factor analysis: hip internal/external, hip abduction/adduction, hip flexion/extension, knee internal/external, knee abduction/adduction and knee flexion/extension. If any variable had a value <0.5 on the diagonal of its anti-image correlation matrix, that with the lowest value was removed from the analysis in an iterative process until all diagonal values were >0.5. The diagonal of the anti-image correlation matrix was >0.5 for all six variables, and therefore all were included in the analysis. Once a final model was developed, parallel analysis using permutations of the raw data set was used to determine the number of factors to be
retained in the final model. The final model, detailed in the results, contained three factors. Variables with scores >0.5 in the pattern matrix were considered to be key contributors to each factor. Anderson-Rubin factor loading scores were then saved for each subject. Pearson correlation coefficients were used to determine the relationship between the extracted factors to hip strength.

RESULTS
The hip extension isokinetic testing method demonstrated excellent ICC reliability. The mean ICC values for peak torque intra-rater reliability were greater than 0.89 and for inter-rater reliability were greater than 0.85 (Table 1 & 2).

Peak isokinetic hip extensor torque demonstrated a moderate negative relationship with transverse plane hip ROM (r = -0.390, p = 0.012) but was not significantly related to sagittal plane hip ROM (r = -0.057 p = 0.752) and frontal plane hip ROM (r = -0.294, p = 0.097) (Figure 4) in subjects running at a self-selected speed. Peak isokinetic hip abductor torque showed a strong negative relationship with frontal plane hip ROM (r = -0.462, p = .008) but was not significantly related to either sagittal plane hip ROM (r = 0.089, p = 0.630) or transverse plane hip ROM (r = -0.210, p = 0.248) (Figure 4). Peak isokinetic hip extensor torque was not significantly related to transverse plane knee ROM (r = 0.191, p = 0.287) (See Figure 5), frontal plane knee ROM (r = 0.036, p = 0.842), or sagittal plane knee ROM (r = -0.052, p = 0.775). Peak isokinetic hip abductor torque was not significantly related to frontal plane knee ROM (r = 0.206, p = 0.258) (See Figure 5), transverse plane knee ROM (r = 0.258, p = 0.114), or sagittal plane knee ROM (r = 0.089, p = 0.630).

Factor Analysis
The Keiser-Meyer-Olkin measure of sampling adequacy was 0.610, which supported the appropriateness of factor analysis for this data set. The diagonal of the anti-image correlation matrix was >0.5 for all six variables, and therefore all were included in the analysis. Parallel analysis indicated three factors could be retained in the model. Factor 1 accounted for strong loading scores for hip flexion (0.774) and knee flexion (0.842) range of motion. Factor 2 had strong loading scores for hip adduction (0.779) range of motion. Factor 3 had strong loading scores for hip rotation (0.582) and knee abduction (0.661) range of motion. The factor correlation matrix revealed...
There was a significant correlation between hip abduction strength and Factor 2 (r = -0.533, p = 0.002). Hip abduction strength and extension strength were not significantly correlated to any other factors.

**DISCUSSION**

The results of the current study demonstrated that peak isokinetic hip extensor torque and peak isokinetic hip abductor torque are associated with transverse plane and frontal plane hip kinematics, respectively, in healthy, adolescent and young adult male long-distance runners. As the authors hypothesized, runners with lower hip abductor and hip extensor strength exhibited greater frontal and transverse plane hip motion. Hip motion represents femur movement relative to the pelvis. Therefore, this motion may relate to pelvic, femoral, or a combination of motions. However, contrary to the authors stated hypothesis, peak isokinetic hip extensor torque and peak isokinetic hip abductor torque were not associated with transverse plane and frontal plane knee mechanics. Furthermore, a factor analysis was utilized to help describe the variability among related biomechanical parameters during running. Interestingly, the results of the factor analysis identified three unique factors that relate to a sagittal plane pattern (Factor 1), hip adduction pattern (Factor 2) and combined hip rotation/knee abduction pattern (Factor 3). Increased hip adduction range of motion was heavily weighted in factor 2 which was significantly related to hip abduction isokinetic strength. This further indicates that decreased abduction concentric strength may increase the hip adduction motion during stance phase of running.

Decreased hip strength may lead to altered hip mechanics in a young, competitive running population. Altered hip strength has been linked to a variety of lower extremity injuries such as iliotibial band syndrome,34-36 patellofemoral pain syndrome (PFPS),6,9,10,12,15,16,37,38 and tibial stress fracture.39 The association of decreased hip extensor strength and increased hip internal rotation found in this study is in agreement with prior reports indicating this relationship in runners diagnosed with PFPS.5,8 Souza and Powers reported that adult females with decreased hip extension and hip abduction strength demonstrated increased femoral internal rotation during running, a drop jump, and a step down, despite increased gluteus maximus activation.5 The current findings are in partial agreement with a prior report that noted a negative correlation between hip abductor strength and hip adduction angle toward the end of a prolonged run, but not at the beginning of the run, in adult females with PFPS.40

A lack of hip abductor and hip extensor strength appears to be associated with increased hip adduction and hip internal rotation, respectively. Increased

| Table 1. ICC Reliability for Hip Extension Isokinetic Testing Method |
|-------------------|-------------------|-------------------|-------------------|
|                   | Day 1 Tester 1    | Day 1 Tester 2    | Day 2 Tester 1    | Day 2 Tester 2    |
| Right Hip         |                   |                   |                   |                   |
| Subject 1         | 229.7             | 185.1             | 213.6             | 189.2             |
| Subject 2         | 147.6             | 139.5             | 175.9             | 178.1             |
| Subject 3         | 90.9              | 89.3              | 76.3              | 82.7              |
| Subject 4         | 107.7             | 106.7             | 105.5             | 101.5             |
| Subject 5         | 83.5              | 98.5              | 98                | 98.3              |
| Subject 6         | 175.2             | 184               | 202               | 153.8             |
| Subject 7         | 202.8             | 162               | 180.5             | 146.3             |
| Subject 8         | 82.8              | 92                | 94.5              | 78.5              |
| Subject 9         | 98.1              | 87.3              | 79.8              | 84.5              |
| Subject 10        | 147.5             | 128               | 183.3             | 156.9             |
| Left Hip          |                   |                   |                   |                   |
| Subject 1         | 180.7             | 206               | 200.1             | 212.9             |
| Subject 2         | 141               | 154.8             | 125.3             | 184.7             |
| Subject 3         | 74.5              | 96.2              | 73.1              | 85.3              |
| Subject 4         | 98.6              | 124.9             | 103.4             | 112.5             |
| Subject 5         | 96.1              | 90.8              | 81.6              | 102.4             |
| Subject 6         | 136.8             | 217.5             | 160.3             | 157.3             |
| Subject 7         | 160.4             | 145               | 150.1             | 165.2             |
| Subject 8         | 61.1              | 58.5              | 77.8              | 67.8              |
| Subject 9         | 102.7             | 85                | 81.4              | 92.3              |
| Subject 10        | 117.7             | 151.7             | 100.8             | 133.5             |

Hip isokinetic test data used to calculate intra-tester and inter-tester reliability. Values reported in ft*lbs.

| Table 2. Intra-tester and Inter-tester ICC reliability for left, right, and combined sides calculated from peak hip isokinetic strength data |
|-------------------|-------------------|-------------------|-------------------|-------------------|
|                   | Intra-tester ICC (C-1) | Inter-tester ICC (C-1) |
|                   | Tester 1 Tester 2 Mean | Day 1 Day 2 Mean |
| Left              | 0.91 0.87 0.89 | 0.79 0.91 0.85 |
| Right             | 0.92 0.87 0.90 | 0.90 0.93 0.91 |
| Combined          | 0.96 0.90 0.93 | 0.91 0.94 0.93 |
hip adduction has previously been associated with iliotibial band syndrome, patellofemoral pain syndrome, and tibial stress fracture, in adult female long-distance runners. Increased hip internal rotation has previously been associated with iliotibial band syndrome in adult male long-distance runners and patellofemoral pain syndrome in adult female long-distance runners. To the authors’ knowledge, this is the first study that has demonstrated these atypical hip kinematics in a cohort of young, healthy, and competitive male long-distance runners. This indicates that interventions which reduce excessive transverse and frontal plane movements at the hip during running may be clinically relevant.

The findings from this study, that hip strength is not associated with frontal or transverse plane knee kinematics, are in agreement with the findings of previous reports investigating the this association in adult females with PFPS and healthy adult females. Both Ferber et al and Earl et al found that proximal strengthening programs focusing on improving hip abductor strength and hip external rotator strength led to pain reductions but did not lead to changes in knee kinematics. Similarly, Willy and Davis demonstrated that improving hip abductor and hip extensor strength did not alter running kinematics. In contrast, the current findings differ from Heinert et al, who reported that uninjured collegiate female recreational athletes with reduced hip abductor strength demonstrated significantly increased knee abduction angle during the stance phase of running as compared to a stronger cohort.

Several potential factors exist to explain the differences noted in the current study relative to prior reports. First, the subject population consisted of healthy, adolescent and young adult males. Prior investiga-

*Significant correlation

Figure 4. Hip Strength Associated with Hip Range of Motion.
tions have noted differences in running kinematics between adult males and adult female runners, and thus it is possible that gender and age may play a role in contrasting running mechanics. Second, as our subject population was uninjured, it is possible that pain may play a role in mediating running mechanics. While knee pain inhibits quadriceps activity, it is not clearly understood the effect that knee pain may have in altering hip muscle activity or compensatory movement patterns. While adult female runners with PFPS demonstrated delayed and shorter gluteus medius muscle activation than pain-free subjects, it was unknown if these differences were due to pain or were present prior to the onset of their condition. Therefore, the differences in study design and study populations may underlie the divergence of the current results from prior reports. Finally, dynamic knee valgus is the result of several movements, particularly femoral internal rotation, femoral adduction, knee abduction, and knee external rotation. Current evidence suggests a position of dynamic knee valgus, particularly femoral internal rotation, results in altered patellofemoral joint kinematics, which places stress on the patellofemoral joint. This study demonstrates that weak hip abductors and hip extensors are associated with increased hip adduction and hip internal rotation. Therefore, this study may demonstrate a link between altered hip strength and high-risk lower extremity kinematics which may predispose the cohort with weaker hip strength to future injury.

Previous studies that have quantified hip muscle deficits in patients with PFPS have primarily used isometric dynamometry in order to quantify hip strength. Isometric dynamometry allows clinicians to examine the strength of isolated joints at fixed rotational positions. The static condition of isometric dynamometry may allow patients to produce larger peak torques than isokinetic dynamometry at a respective position. During the stance phase

Figure 5. Hip Strength Associated with Knee Range of Motion.
of running, muscles around the hip joint primarily are contracting eccentrically and concentrically, thus isometric dynamometry may lack construct validity. Conversely, isokinetic tests allow patients to progress through a range of motion in a single degree of freedom and can provide an assessment of both concentric and eccentric muscle strength which, in turn, may better measure the construct of hip muscle strength. Disadvantages to isokinetic testing include cost, prolonged set-up time, and access for both clinicians and researchers. While isokinetic testing improves upon measuring the construct of hip strength, at this time it is not possible to measure hip strength in the exact position, joint speed, and contraction type that the muscles are utilized during the running gait cycle.

Recently, various methods of hip isokinetic dynamometry have been utilized in an attempt to address the perceived deficits of isometric dynamometry testing. Souza and Powers utilized an isokinetic hip extension strength assessment protocol similar to this study with respect to positioning and ROM of the testing limb. Their test was performed in prone, which is consistent with manual muscle testing procedures that are conducted against gravity. The novel approach utilized in this study was chosen to simulate the position of running with an upright stance. Souza utilized isometric peak hip extension torque at 30 degrees of hip flexion, and isometric, isotonic and isokinetic dynamometry measures were utilized with isokinetic testing performed at 10 deg/sec. Boling et al also utilized the prone method, however their range of motion was 30 degrees of hip extension from a starting position of 90 degrees of hip flexion and the testing speed for concentric and eccentric contractions was set at 60 deg/sec based on previous research. Boling reported ICC's of 0.79 for their intrasession reliability of peak concentric strength which is below the ICC achieved in the current study. The higher testing speed of 120 deg/sec for the current study was chosen to capture the construct of strength at a faster speed, while still maintaining the ability to reliably evaluate peak torque.

While the method used for measuring peak hip extension torque is novel, the ICC data demonstrated that the methods outlined in this paper have good reliability. ICC values indicated that within-rater and between-rater reliability were both almost perfect. Inter-tester reliability was slightly lower than intra tester reliability. Reliability studies have been previously performed on alternative protocols that examine hip extension isokinetic strength. Previous authors have found that hip extension ICC was 0.84 at 90 deg/sec in young boys and 0.96 at deg/sec at 60 deg/sec. The current data suggests that the reliability of the novel hip isokinetic testing protocol used in the current study is comparable to these previously tested methods and are considered almost perfect based on ICC values.

Limitations to the current study include that kinetic data was not collected during treadmill running which limits interpretation of kinematic data. Additionally, the authors did not measure gluteal muscle activation using EMG. Recent reports demonstrate that alterations in running kinematics in adult female runners with PFPS may be due, in part, to alterations in gluteus medius and gluteus maximus activation, respectively. The underlying factor of motor control is difficult to evaluate since it encompasses not only the strength of the musculature, but also the timing and efficiency with which it is able to control movement. Future research efforts should be directed at assessing the roles that muscle activation and maturation play, if any, in affecting lower extremity kinematics in healthy male runners. Finally, our results should be viewed with caution due to the relative low coefficient of determination ($r^2$) values of our findings (gluteus maximus $r^2 = 0.152$ and gluteus medius $r^2 = 0.213$) as it is likely other variables, in addition to hip strength, also explain the studied hip motions.

**CONCLUSION**

Peak isokinetic hip extensor torque and peak isokinetic hip abductor torque are negatively associated with transverse plane and frontal plane hip motion, but not knee kinematics in male adolescent and young adult long-distance runners. Three unique factors were identified to explain three-dimensional range of motion occurring at the hip and knee during running. The factor with strong loading scores for hip adduction range of motion was significantly correlated to hip abduction strength. This indicates that a potential underlying mechanism for this unique description of running may relate to hip abduction strength in males. However, the factors with strong
loading scores for sagittal plane range of motion (hip and knee) and hip rotation/knee abduction were not significantly correlated with hip strength.

This study uniquely identifies the relationship between peak isokinetic hip strength and 3-D hip mechanics, which may be associated with pathomechanics that have been shown to increase the risk of anterior knee pain in runners. Utilization of isokinetic testing to assess peak hip extensor and hip abductor torque may aid in the identification of runners who may be susceptible for future running injuries. Future prospective studies are warranted to assess the effect that alterations in hip strength, muscle activation, running kinematics, and running kinetics have on both injury occurrence and type of injury in at-risk populations.

REFERENCES


ABSTRACT

Background: Patellofemoral pain is a common condition without a clear mechanism for its presentation. Recently significant focus has been placed on the hip and its potential role in patellofemoral pain (PFP). The majority of the research has examined hip strength and neuromuscular control. Less attention has been given to hip mobility and its potential role in subjects with PFP.

Purpose/Aim: The purpose of this study was to compare passive hip range of motion (ROM) of hip extension and hip internal and external rotation in subjects with PFP and healthy control subjects. The hypothesis was that subjects with PFP would present with less total hip ROM and greater asymmetry than controls.

Design: Two groups, case controlled.

Setting: Clinical research laboratory

Participants: 30 healthy subjects without pain, radicular symptoms or history of surgery in the low back or lower extremity joints and 30 subjects with a diagnosis of PFP.

Main Outcome Measures: Passive hip extension, hip internal rotation (IR) and hip external rotation (ER). A digital inclinometer was used for measurements.

Results: There was a statistically significant difference ($p<0.001$) in hip passive extension between the control group and the PFP group bilaterally. Mean hip extension for the control group was 6.8° bilaterally. For the PFP group, the mean hip extension was -4.0° on the left and -4.3° on the right. This corresponds to a difference of means between groups of 10.8° on the left and 11.1° on the right with a standard error of 2.1°.

There was no statistically significant difference ($p>0.05$) in either hip IR or ER ROM or total rotation between or within groups.

Conclusions: The results of this study indicate that a significant difference in hip extension exists in subjects with PFP compared to controls. These findings suggest that passive hip extension is a variable that should be included within the clinical examination of people with PFP. It may be valuable to consider hip mobility restrictions and their potential impact on assessment of strength and planned intervention in subjects with PFP.

Level of Evidence: 2b

Key Words: Hip, inclinometer, patellofemoral pain, passive range of motion

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INTRODUCTION
Patellofemoral pain (PFP) is a common condition evaluated and treated in the orthopedic setting.1,2 The condition is sometimes referred to as anterior knee pain or patellofemoral pain syndrome.3,4 The etiology of the condition remains unknown although many variables are thought to be contributory. Amongst the considerations are excessive Q angle, excessive foot pronation, weakness of the vastus medialis, misalignment of the patella, maltracking of the patella, joint laxity, and decreased mobility of the hamstrings and or quadriceps.5

Historically the focus of PFP etiology has tended to center upon distal factors, foot and ankle, and muscles directly attaching to the knee, such as the quadriceps muscle.6 However, much of the emergent research has been focused about the hip.7-11 Powers has discussed and provided evidence to support the notion that a significant contributor to PFP may be the hip region.7,12 The fact that the knee and hip region are mechanically linked can be reasonably surmised by their linkage through the femur.13 However, a considerable amount of recent literature still focuses attention primarily on the knee joint as an isolated region in the etiology and treatment of PFP.14-18 A recent study comparing posterolateral hip muscle strengthening as compared to quadriceps strengthening in subjects with PFP found both to be helpful in reducing pain and improving functioning.19 However the hip strengthening was found to be superior. Clearly, both the knee and hip muscles are important variables that need to be taken into consideration in subjects with PFP.

The majority of the current literature on hip region involvement in PFP is centered upon strength and neuromuscular control.20-24 In the past few years several authors have examined the kinematics of the hip and its effect on PFP.25,26 What has been reported is that significant differences can exist in kinematics about the knee and hip in subjects with PFP as compared to controls.27-28 In particular some subjects with PFP have been observed to display increased knee valgus, increased hip IR and increased hip adduction as compared to controls.29 Additional authors have evaluated the gluteus medius and maximus motor activation patterns in subjects with PFP and found significant differences in both fatigue patterns and motor activation patterns.30,31 In particular several investigators have found a direct correlation between PFP and altered hip movement and changes in gait and running.32,33 What appears to be lacking is data on the role that soft tissue and joint mobility may contribute to PFP. The information that is available has focused on structures of the lower extremity such as quadriceps, hamstrings, iliotibial band, and gastrocnemius/soleus.6,34-36 Little information is available that examines hip ROM in individuals with PFP.37 It is reasonable to consider that the ROM of a joint, which is a general measure and takes into consideration all components of the structure, can impact the joint moment and dissipate mechanical loads.38,39 In particular hip extension, hip IR and Hip ER ROM are of interest due to their influence from the gluteus maximus, which is noted to be a significant factor in PFP etiology.21 It has been observed that female subjects with PFP have a significantly decreased hip extension and hip abductor torque production as compared to healthy controls.21 In this author’s opinion the mobility of hip abduction, adduction and flexion do not appear to a major variable in the condition of PFP based on current understandings of the condition, although this needs further investigation. Some evidence is available that supports the notion that static measurements of postural positioning can be predictive of dynamic function.40

The purpose of this study was to compare passive hip range of motion (ROM) of hip extension and hip internal and external rotation in subjects with PFP and healthy control subjects. The authors hypothesized that subjects with PFP would present with less passive hip ROM in hip extension and hip internal and external rotation than controls.

METHODS
A convenience sample of 30 volunteer subjects without PFP (13 males and 17 females; mean age 34.0 +/- 13.1 years; mean height, 171.5 cm +/- 11.9, mean body mass, 72.0 kg +/- 13.9, and 30 subjects with a diagnosis of PFP(9 males and 20 females; mean age 36 +/- 13.7 years; mean height, 171.5 cm +/- 10.7, mean body mass, 69 kg +/- 13.8 were recruited. Control subjects were included if they reported no history of surgery of the spine, hips, knees; no history...
of neurological insult to the musculoskeletal system; and had no current acute pain of the hips, low back, or knees. PFP subjects selected for this study met the following inclusion criteria: generalized anterior, anterior/medial knee or retropatellar pain for 1 month or longer associated with prolonged sitting, ascending/descending stairs, sports activity, and/or running. Exclusion criteria for both groups included a history of patellar dislocation, cartilage or ligamentous damage, surgery for trauma to the knee, and a known history of osteoarthritis. All subjects were informed of the purpose of the study and signed an informed consent document prior to data collection.

Study Design
All data collection took place in research institute. All testing was completed in a single session by the primary investigator. The investigator is a licensed physical therapist with 20 years of experience in the musculoskeletal practice environment. During evaluation, the investigator measured extension (EXT), internal (IR) and external rotation (ER) on both left and right hip. A digital inclinometer was used to measure hip ROM. The digital inclinometer was a Digital Protractor Pro 3600 manufactured by Miutoyo America, Aurora, Illinois with an accuracy of 0.1°. The digital inclinometer has been found to possess good reliability and concurrent validity with the universal goniometer which is the standard tool in clinical practice.41 The reliability of the device in previous work on hip ROM was noted to be .90.42 No practice or warm up was performed prior to measurements. During EXT measurement, the subjects were positioned on their back and a modified Thomas test, typically a test for length of hip flexors to measure hip extension PROM, was performed. The modified Thomas test has been found to possess good reliability.42-44 The hip being measured was positioned at the end of the treatment table and the tested leg was then cantilevered over the edge of table with the end feel resulting from the effects of gravity. No manual contact was made with the tested leg. Instructions were provided for subjects to pull their knee straight toward their head to avoid any abduction. In addition, subjects were provided feedback, both verbal and tactile to maintain a low back flat against table to avoid lumbar and pelvic tilting throughout the evaluation. The inclinometer measurement was taken from the anterior mid femur position with midpoint between the greater trochanter and lateral femoral condyle. Measurements were noted as negative if they were above the horizon (more flexed than neutral position) and positive if they fell below the horizontal position (more extended than neutral position).

For IR and ER measurements, the subjects were positioned in the prone position on the treatment table and the following standard protocol was used.42 The investigator passively flexed both the knees to 90 degrees while both hips were positioned in neutral for measuring hip internal rotation. Next, the investigator instructed the subjects to relax and allowed the shank of both legs out for IR until reaching passive end feel of this joint region under the effects of gravity. For ER, the investigator passively flexed one knee to 90 degrees and then instructed the subject to relax the shank towards the midline and leg crossed over midline until reaching passive end feel, also determined per effects of gravity. The non-measured leg was positioned in extension on the table. The investigator’s assistant stabilized the subject’s pelvis during hip ER measures to prevent pelvic rotation. Additionally, the subjects that displayed with greater ER (motion blocked by presence of opposite leg) had their non-tested leg abducted slightly to allow for full measurement. Measurements with the inclinometer were taken with device placed at midline of medial shaft of tibia between the medial malleoli and medial tibial condyle.

Each measurement was performed three times and the average of the three was calculated and recorded. The order of the collection trial was randomized in each position. Additionally, the inclinometer measurements were verbally given by the investigator and recorded by an assistant.

Statistical Analysis
A two-way analysis of variance (ANOVA) was conducted to determine whether differences in hip range of motion existed between groups. Simple effects analyses were conducted for significant interaction effects. Tukey post-hoc procedures were conducted in the case of significant main effects. Alpha level was set to 0.05.
RESULTS
Mean hip extension for the control group was 6.8° on the left side, and 6.8° on the right. For the PFP group, the mean hip extension was -4.0° on the left and -4.3° on the right. This corresponds to a difference of means between groups of 10.8° on the left and 11.1° on the right with a standard error of 2.1°. A significant difference (p<0.001) was detected in hip extension angle between the control group and the PFP group on both the left and right sides, while no statistically significant differences existed between groups in rotation ranges of motion (Figure 1). Figure 2 illustrates total hip ROM with no significant difference between control and PFP group (p>0.05).

DISCUSSION
The primary purpose of this study was to compare passive hip ROM in controls to subjects with PFP. Our data identified a significant difference in hip extension between the experimental and control groups. The PFP group on average demonstrated with 11° less hip extension than the control group. No additional significant differences were recorded in any of the other hip ROM variables measured in PFP group when comparing affected and unaffected extremity. These findings suggest that hip extension is a variable that should be evaluated when assessing subjects with PFP during clinical assessment.

This study was conducted utilizing a digital inclinometer due to its ease of use and good reliability in measurements of the lower extremities.45,46 The digital inclinometer is noted to be a valid tool in assessing passive hip mobility.42 The known validity and ability to quickly assess hip mobility may encourage clinicians to use the inclinometer on more regular basis.

The paucity of literature on hip mobility and its effects on the knee are puzzling. The ability of the hip to effect knee kinematics has been well established.7 A good portion of literature has focused in particular on the need to address the role of the gluteus maximus in subjects with PFP.21,30,47-49 It is reasonable to consider that if the hip is limited in its mobility that this could affect joint moments.39 The authors of the current study recorded an average of 11° less hip extension in subjects with PFP as compared to controls, with left and right hip averaging -4.0° and -4.3° respectively (meaning the hip was flexed with relation to the neutral position). Several authors have noted that hip extension in healthy subjects varied between +2° to +13.7°.50-53 A lack of hip extension may lead to adaptive shortening of anterior hip structures including, but not limited to, the hip flexor musculature. It could be that the converse situation may occur as well, with anterior hip structure shortening leading to decreased hip extension. Deficits of hip extension therefore may possibly result in two potential negative mechanical outcomes. One, lack of ability to generate full contractile force of the gluteus maximus by altering

![Figure 1. Hip range of motion between control and patellofemoral pain patients comparing left and right hip extension, internal rotation, and external rotation.](image)

![Figure 2. Total hip rotation range of motion between control and patellofemoral pain (combination of external and internal rotation on the same side).](image)
the hip joint moment potential and two, decreased ability to store full potential of elastic strain energy of the anterior hip soft tissue. This second variable could result in decreased energy efficiency and potentially the overuse of anterior hip muscles to initiate swing phase of gait.\textsuperscript{54,55}

Another issue worth consideration is to what degree does passive ROM measures of the hip reflect active or dynamic activity patterns. Schache et al. examined the relationship between passive hip extension, measured with a goniometer using the Thomas test, and anterior pelvic tilt, using a Vicon motion analysis system during running in 14 elite track and field athletes.\textsuperscript{56} They found no significant correlation between passive ROM and hip extension during running. This study however used a small unique subset of individuals running at a submaximal speed that may not be reflective of the general population. Recently Moreside and McGill conducted a study examining the relationship between increased passive hip ROM (extension and rotation) and transfer into functional movement patterns in normal healthy males.\textsuperscript{57} They found no evidence of increased functional ROM despite using interventions that significantly improved passive hip ROM. The conclusion of the authors were that further interventions in the form of motor control strategies to create new movement patterns may be necessary for carryover of passive gains into dynamic activities. This is certainly an area in need of future study for both normal and PFP subjects.

No significant differences were noted in hip rotation between groups. There were no significant differences in ER or IR within the PFP group. A literature review on hip mobility and PFP found little from which to compare this finding. Cibulka noted in a case study involving a 15 year old female with PFP, decreased IR and increased ER on side of involvement.\textsuperscript{58} The majority of literature examining for hip asymmetries in physical medicine have focused on subjects with non-specific chronic low back pain.\textsuperscript{59-61}

It is likely that hip mobility plays a strong role in influencing multiple proximal and distal regions such as the knee and or low back. This concept has been referred to as regional interdependence by Wainner et al.\textsuperscript{13} Regional interdependence, in regards to the musculoskeletal system, is defined as “seemingly unrelated impairments in a remote anatomical region may contribute to, or be associated with, the patient’s primary complaint”.\textsuperscript{13} It could be hypothesized that deficits in hip mobility in multiple planes may result in altered mechanical loading of segments above and below the joint. The questions that arise from this scenario are many and varied. If an individual continues to place large mechanical loads on the body through work or sports related activity, they would need to compensate when mobility within segments are restricted. As an example, this compensation could result in muscle cell damage and potential for myofascial trigger point (MTrP) development.\textsuperscript{62,63} Subsequently, there could be an alteration in motor control as has been demonstrated in the presence of MTrPs.\textsuperscript{64} In one study it has been observed that subjects with PFP have a higher prevalence of MTrPs in bilateral gluteus medius and quadratus lumborum muscles.\textsuperscript{65} This is an area that merits future investigation.

Future studies could examine the relevance of the findings of the current study through simple interventions and outcome measures in those with losses of hip extension in the presence of PFP. Although the current study did not find any differences in hip ER or IR, Cibulka et al noted that correcting asymmetrical hip rotation resulted in good improvement in an individual with PFP.\textsuperscript{37} Cibulka et al have also advised that evaluating for hip rotation asymmetries is important prior to muscle testing and strengthening as asymmetries can influence hip rotator strength.\textsuperscript{66} No studies to the authors’ knowledge have tested this possibility with hip extension. It may be possible that many practitioners are overlooking this variable and proceeding to strengthening. A simple follow up study could examine for hip extension strength in presence and absence of restrictions. This could be followed up with a simple stretching routine to address the tight hip flexors. Studies have demonstrated that correcting for hip flexor tightness is possible with a short course of intervention.\textsuperscript{67,68}

**Study Limitations**

The main limitation during data collection was in proper stabilization of pelvis during measurements. As other authors have noted, stabilizing the pelvis during the modified Thomas test, and for passive hip ROM in general, is very important in order to...
achieve consistency during hip measurement and limit lumbar spine involvement. All efforts were made to limit this involvement and it was felt that verbal and tactile cues given to subjects was sufficient to achieve this goal. Additionally, the main investigator was not blinded to subjects condition. This had the potential to bias measurements and blinding would reduce this risk. Lastly, would be the fact that patellofemoral knee pain was not directly measured. This could have been assessed with tools such as the anterior knee pain scale or the Western and McMaster Universities Osteoarthritis Index (WOMAC).

**Conclusion**

The results of this study indicate that subjects presenting with PFP had significantly less passive hip extension than controls, when measured using the Thomas test. These findings suggest that passive hip extension is an important variable that should be included within the clinical examination of people with PFP. It may be important to consider hip mobility restrictions and their potential impact on assessment of strength.

**REFERENCES**


ABSTRACT

Background: Ankle bracing and rehabilitation are common methods to reduce the rate of recurrent ankle sprain in participants with chronic ankle instability (CAI). CAI participants utilize less muscle activity when performing functional exercises compared to healthy controls. The effect of ankle braces on muscle activity during functional exercises in participants with CAI has not been previously studied.

Purpose: To determine the effect of bracing on motor output as demonstrated by surface EMG amplitudes in participants with CAI during single limb, eyes closed balance, star excursion balance, forward lunge, and lateral hop exercises.

Methods: A descriptive laboratory study was performed. Fifteen young adults with CAI performed functional exercises with and without ankle braces while surface EMG signals were recorded from the tibialis anterior, peroneus longus, lateral gastrocnemius, rectus femoris, biceps femoris, and gluteus medius. The main outcome measures were normalized surface EMG amplitudes (root mean square area) for each muscle, muscles of the shank (distal three muscles), muscles of the thigh (proximal three muscles), and total muscle activity (all six muscles) of the lower extremity. A paired t-test was performed for each dependent variable to compare conditions. The level of significance was set a priori at p ≤ 0.05 for all analyses.

Results: During the forward lunge, bracing significantly reduced muscle activity pre-initial contact in the lateral gastrocnemius and post-initial contact in the peroneus longus. During the star excursion balance anterior reach the peroneus longus, lateral gastrocnemius, rectus femoris, and biceps femoris, and gluteus medius had significantly less muscle activity during braced trials. Bracing significantly reduced thigh and total muscle activity during the anterior reach and gluteus medius activity during the posterolateral reach. There were no differences between braced and unbraced conditions during the single limb eyes closed balance, star excursion balance posteromedial reach, or during lateral hop exercises.

Conclusions: Clinicians should be aware of the decreased muscle activity that occurs during common rehabilitation exercises when patients with CAI complete those activities while wearing ankle braces.

Level of Evidence: Level III

Key Words: Ankle brace, ankle sprain, therapeutic exercise

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INTRODUCTION

Ankle sprains are one of the most common musculoskeletal injuries.\textsuperscript{1-3} Following an initial sprain, patients are more susceptible to future sprains,\textsuperscript{4} and up to 70\% may have residual ankle symptoms that affect their quality of life.\textsuperscript{5,6} Patients that do not fully recover from the initial sprain develop a condition known as chronic ankle instability (CAI).\textsuperscript{7-9} CAI is defined by repetitive bouts of the ankle ‘giving way’ and self-reported functional limitations following at least one significant ankle sprain.\textsuperscript{9}

Self-reported functional deficits in patients with CAI have consistently been related to alterations in joint kinematics, kinetics, and motor control strategies just prior to and following ground contact during gait\textsuperscript{10-15} and jump landing.\textsuperscript{16-19} Patients with CAI have more ankle inversion prior to ground contact,\textsuperscript{11,12} increased lateral loading,\textsuperscript{20} and demonstrate task dependent alterations in muscle activity during walking,\textsuperscript{13} functional exercise,\textsuperscript{15} and drop jump maneuvers.\textsuperscript{21} When performing lunges and lateral hopping exercises, participants with CAI demonstrate decreased preparatory and reflexive muscle activity, which may indicate muscle inhibition or an unconscious protective mechanism by which participants with CAI complete the exercises at lower intensities compared to healthy counterparts.\textsuperscript{15} Currently, neuromuscular re-education and the application of ankle braces are two of the commonly utilized methods for improving outcomes in patients with CAI.\textsuperscript{22}

Neuromuscular re-education is thought to be effective by improving balance and postural control.\textsuperscript{22,23} Rehabilitation protocols for patients with CAI have been able to improve self-reported functional limitations following the intervention.\textsuperscript{24-26} A recent randomized control trial compared neuromuscular training, prophylactic ankle bracing, and a combination of neuromuscular training and ankle bracing.\textsuperscript{27} The risk of recurrent sprain over a 12-month period was 50\% less in patients that wore ankle braces for 12 months when compared to patients that underwent 8 weeks of home-based neuromuscular training.\textsuperscript{27} In this study, the combination group performed 8 weeks of unsupervised home-based neuromuscular training with 8 weeks of concurrent brace wear.\textsuperscript{27} The authors suggested that the effects of neuromuscular training would take full effect by eight weeks and that further brace wear would not be required.\textsuperscript{27} However, concurrent use of prophylactic ankle braces and eight weeks of unsupervised neuromuscular training, did not significantly reduce the risk of ankle sprain reoccurrence when compared to the neuromuscular training group alone or compared to 12 months of prophylactic bracing.\textsuperscript{27}

The exact mechanism by which ankle braces reduce the rate of ankle sprain has yet to be elucidated. Two broad theories for the mechanism are via passive mechanical support and/or improving sensorimotor function.\textsuperscript{28} A meta-analysis by Cordova et al.\textsuperscript{29} illustrates the effectiveness of ankle braces at mechanically restricting range of motion. Ankle braces have also been shown to improve static\textsuperscript{30} and dynamic\textsuperscript{31} balance in participants with ankle instability during single limb stance and the star excursion balance test (SEBT), respectively. However, braces either impair\textsuperscript{30,32} or have no effect\textsuperscript{33} on balance in healthy participants. Hadadi et al.\textsuperscript{30} speculated that the ability of braces to improve balance in CAI subjects, while decreasing balance in healthy individuals may be related to how each group's proprioception and/or motor output is altered with the application of braces.

A recent systematic review illustrated that ankle bracing or taping has no significant effect on proprioceptive acuity as measured by joint position sense or threshold to movement detection.\textsuperscript{34} In terms of motor output, lace-up braces increase the peroneus longus stretch reflex amplitude immediately after application and semi-rigid braces increase the peroneus longus amplitude after eight weeks of prolonged use in healthy subjects.\textsuperscript{35} However, the application of ankle braces does not appear to influence the motor neuron pool excitability of the peroneus longus in healthy subjects during an inversion perturbation.\textsuperscript{36} During walking, Barlow et al.\textsuperscript{37} identified that the application of ankle braces decreases the peroneus longus pre-contact muscle activity and decreases the duration of muscle activation in the peroneus longus and rectus femoris in CAI subjects.

Despite the widespread use and acceptance of ankle braces in patients with a history of ankle sprain, there is limited research investigating the effect of ankle braces on motor output in participants with CAI during functional exercises. Understanding how
ankle braces influence motor output may provide insight into not only how ankle braces reduce the rate of recurrent ankle sprain but also the influence braces have on muscle activity when worn during functional rehabilitation following an ankle sprain or during neuromuscular training for prophylactic injury prevention. Therefore, the purpose of this study was to investigate the effect of ankle braces on motor output during single-limb eyes closed balance, star excursion balance, forward lunges, and lateral hopping exercises in participants with CAI.

METHODS

Design
A descriptive laboratory study was performed in which the independent variable was condition (brace, no brace) and the dependent variables were normalized surface electromyography (sEMG) root mean square (RMS) amplitudes for the tibialis anterior, peroneus longus, lateral gastrocnemius, rectus femoris, biceps femoris, and gluteus medius during single limb eyes closed balance, star excursion balance reach directions (anterior, posteromedial, and posterolateral), forward lunges, and lateral hops. To gain a more comprehensive understanding of lower extremity muscle activation normalized sEMG amplitudes for individual muscles were summed for the distal musculature (tibialis anterior, peroneus longus, lateral gastrocnemius), proximal musculature (rectus femoris, biceps femoris, and gluteus medius), and total lower extremity musculature (all six muscles) between conditions.

Subjects
Fifteen young adults with CAI participated. (Table 1) This study was part of a larger study and the same cohort has been previously reported in another manuscript investigating differences in normalized sEMG between CAI and healthy controls during the same functional exercises. Briefly, CAI participants had a history of more than one ankle sprain with the initial sprain occurring greater than one year prior to study onset and current self reported functional deficits due to ankle symptoms that were qualified by a score of <85% on the Foot and Ankle Ability Measure (FAAM) sport scale. Participants were excluded if they had an ankle sprain within the six weeks prior to study onset, history of lower extremity injury or surgery, balance disorders, neuropathies, diabetes, or other conditions known to affect balance. Subjects provided informed consent and the study was approved by the University of Virginia’s institutional review board.

Instruments
Surface EMG signals were collected from disposable, pre-gelled 10 mm round Ag-AgCl electrodes (EL 503 Biopac Systems, Inc., Goleta, CA) and amplified with a high-gain, differential-input biopotential amplifier with a gain of 1000 and digitized with a 16-bit data acquisition system (MP 150, Biopac Systems) at 2000 Hz with a common-mode rejection ratio of 110 dB, an input impedance of 1.0 MΩ, and a noise voltage of 0.2 mV. Acqknowledge software (v.4.0, Cambridge, England) was used for data collection and processing of EMG signals. The EMG data was collected using real time processing with a 10-500 Hz band pass filter and a 10 sample moving average RMS algorithm. A foot switch (BN-STRIKE-XDCR, Biopac Systems) was used to identify ground contact during the star excursion balance, forward lunge, and lateral hop-
ping exercises. All subjects wore standard athletic shoes for all exercises (New Balance, Brighton, MA, X755WB). During the braced condition, all subjects used the same lace-up ankle brace (McDavid Ultralight 195, McDavid Inc., Woodridge, IL).

Testing Procedures
Using previously described methods and ISEK recommendations, surface electrodes were placed 2 cm apart on all 6 muscles parallel to muscle fiber orientation. Electrodes were placed over the middle of the muscle belly as determined by palpation during a voluntary contraction against manual resistance. All participants performed a warm up by walking at a self-selected pace for 5 minutes. Maximal voluntary isometric contractions against manual resistance were recorded for each muscle for normalization of sEMG amplitudes during testing trials. The order of conditions (brace and no brace) was randomized for each participant. The research team applied the support straps and inspected the brace for an appropriate fit prior to testing. Participants were allowed to tighten the ankle braces prior to testing, based on their level of comfort, and throughout testing if required. Brace tightness was not monitored throughout testing.

The research team and participants were not blinded for any part of this study and participants were given as much time between conditions as needed, however, no participant required more than five minutes of rest.

Exercises
Standardized exercises were performed as described previously. Briefly, participants performed at least three but no more than five practice trials for each exercise. For all exercises, failed trials were repeated until the desired number of repetitions was achieved. The order of brace condition was randomized. Randomization was predetermined to ensure a balanced study design, but the order of the exercises performed within each condition was done in the same order for each participant. Due to the low volume of exercises performed, there was not a predetermined rest period between exercises. The exercises were completed in the order of which they are described below. Only the involved limb was tested for each exercise, however, braces were worn bilaterally.

Five consecutive forward lunges were performed and the lead leg was the test limb. Single limb eyes closed balance was performed on a stable surface for 15 seconds with the stance limb as the test limb. Star excursion balance was performed three times each in the anterior, posteromedial, and posterolateral reach directions with the stance limb as the test limb. Reach distance was not standardized as subjects were instructed to reach as far as possible during each repetition. Lateral hops were performed over a 1.5-inch line at a rate of 110 hops per minute for 20 seconds. Lateral hopping rate was standardized to the beat of a metronome.

Data Processing

Forward Lunges
The middle three lunges of the five consecutive lunge trials were analyzed. A 50 ms epoch immediately prior to initial contact was used to calculate the pre-initial contact area under the RMS curve. A 100 ms epoch immediately following initial contact was used to calculate the post-initial contact area under the RMS curve. Lunge amplitudes were normalized to respective MVIC epochs.

Single Limb Eyes Closed Balance
A three second epoch during the middle of the single limb eyes closed balance trial was analyzed. The area under the RMS curve was calculated and normalized to a three second MVIC epoch for each muscle.

Star Excursion Balance Test
A 500 ms epoch just prior to maximum excursion was averaged over three trials for each of the three reach directions. Maximum excursion was defined as the time at which the contralateral limb's toe touched down for a reach distance to be recorded. The average area under the RMS curve over the three trials was normalized to a 500 ms MVIC epoch for each muscle.

Lateral Hops
Six total consecutive hops (3 in each direction) were selected from the middle of the lateral hopping trial. A 50 ms epoch immediately prior to initial contact was used to calculate the pre-initial contact area under the RMS curve. A 100 ms epoch immediately following initial contact was used to calculate the
post-initial contact area under the RMS curve. Lateral hopping amplitudes were normalized to respective MVIC epochs.

**Distal, Proximal, and Total Muscle Activity**

To gain a more comprehensive understanding of the sEMG activity of the entire lower extremity during each exercise the normalized muscle activity of the distal, proximal, and entire lower extremity were summed and analyzed as separate dependent variables for each exercise as described below.

**Statistical analysis**

The independent variable was condition (brace and no brace) and the main outcome measures were sEMG RMS areas for a predetermined epoch for each exercise. Each individual muscle, the sum of the three distal muscles, the sum of the three proximal muscles, and the sum of all six muscles were treated as separate dependent variables. A paired t-test was performed for each dependent variable to compare conditions. The level of significance was set *a priori* at p ≤ 0.05 for all analyses. Per contemporary statistical recommendations, the p-level was not adjusted for multiple comparisons. Instead, in addition to inferential statistical comparisons, Cohen’s $d$ effect sizes and associated 95% confidence intervals were calculated to estimate the magnitude and precision of condition differences for each measure. Effect sizes were interpreted as ≥ 0.80 was large, 0.50-0.79 was moderate, 0.20-0.49 was small, and <0.20 was trivial. Negative effect sizes indicated decreased muscle activation in the braced condition. Positive effect sizes indicated increased muscle activation in the braced condition. Data were analyzed using Statistical Package for Social Sciences (SPSS) Version 20.0 (SPSS, Inc, Chicago, IL).

**RESULTS**

Participants with CAI had significantly less muscle activity during braced trials pre-initial contact in the lateral gastrocnemius and post-initial contact in the peroneus longus during the forward lunge. (Table 2) No other differences were identified in individual muscles or for groups of muscles during lunge trials. During single limb eyes closed balance trials, no differences were identified between brace and no brace conditions. (Table 3) For the star excursion balance anterior reach the peroneus longus, lateral gastrocnemius, rectus femoris, and gluteus medius had sig-

### Table 2. Effect of Ankle Braces on Muscle Activation Patterns during the Forward Lunge Exercise

<table>
<thead>
<tr>
<th>Muscles</th>
<th>Isolated Muscle Activation</th>
<th>Distal/Proximal Muscle Activation</th>
<th>Total Muscle Activation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Brace Mean±SD</td>
<td>Brace Mean±SD</td>
<td>p-value</td>
</tr>
<tr>
<td>Anterior Tibialis</td>
<td>Pre-IC 0.57±0.46</td>
<td>0.58±0.46</td>
<td>0.87</td>
</tr>
<tr>
<td>Peroneus Longus</td>
<td>Pre-IC 0.24±0.14</td>
<td>0.22±0.13</td>
<td>0.19*</td>
</tr>
<tr>
<td>Lateral Gastrocnemius</td>
<td>Pre-IC 0.39±0.35</td>
<td>0.31±0.37</td>
<td>0.03*</td>
</tr>
<tr>
<td>Rectus Femoris</td>
<td>Pre-IC 0.14±0.09</td>
<td>0.13±0.09</td>
<td>0.98</td>
</tr>
<tr>
<td>Biceps Femoris</td>
<td>Pre-IC 0.14±0.07</td>
<td>0.12±0.06</td>
<td>0.23</td>
</tr>
<tr>
<td>Gluteus Medius</td>
<td>Pre-IC 0.10±0.06</td>
<td>0.11±0.06</td>
<td>0.41</td>
</tr>
</tbody>
</table>

p-values are for paired t-Test Statistical Results – Level of significance set *a priori* at p≤0.05. * denotes significant difference between brace and no brace conditions. ES= Cohen’s d Effect Sizes and CI= 95% Confidence Intervals Note: Negative ES indicates decreased muscle activity in braced condition Positive ES indicates increased muscle activity in braced condition SD – Standard Deviation Pre-IC= Pre-Initial Contact Root Mean Square area 50ms Post-IC= Post-Initial Contact Root Mean Square area 100ms
significantly less muscle activity during braced trials. There was also significantly less muscle activity in the brace condition for the thigh and total muscle activity during the star excursion balance anterior reach. (Table 4) Gluteus medius muscle activity during braced trials was significantly reduced during the star excursion balance posterolateral reach. (Table 4) There were no significant differences between braced and no brace conditions during the star excursion balance posteromedial reach or the lateral hop exercises. (Table 5)

DISCUSSION

Decreases in muscle activity were identified during common rehabilitation exercises in participants with CAI while wearing lace-up ankle braces. Deficits in muscle activity had effect sizes that ranged from trivial to moderate. Ankle braces caused moderate decreases in muscle activity during dynamic balance as well as small decreases in muscle activity pre and post-initial contact during forward lunges. There were no differences in muscle activity during single limb eyes closed balance or during lateral hopping exercises.

Previous authors have indicated that ankle braces undoubtedly restrict ankle ROM\(^{29,41,42}\) and do not appear to influence measures of proprioception.\(^{34}\) Furthermore, ankle braces have been shown to increase the peroneus longus Hoffman reflex while seated with a neutral foot position,\(^{43}\) but have no effect on the Hoffman reflex when analyzed during an inversion perturbation.\(^{36}\) However, this is the first study to analyze the effect ankle braces have on motor output during functional exercises in CAI participants. These findings are relevant to clinicians who prescribe rehabilitation exercises to patients with a history of recurrent ankle sprain or healthcare professionals who promote neuromuscular training for prophylactic ankle sprain injury prevention. Furthermore, these results can help clinicians decide whether it is appropriate for patients with CAI to wear ankle braces when performing functional exercises.

Previous authors have analyzed the effect of ankle braces on static and dynamic balance performance in subjects with ankle instability.\(^{30,31}\) CAI subjects have consistently demonstrated deficits in single limb static balance trials as well as during dynamic balance as measured by the SEBT.\(^{44,45}\) When performing these tasks while wearing ankle braces, CAI subjects demonstrate improvements in postural control.\(^{30,31}\) Even though balance performance was not an outcome analyzed in the current study, reach distances were recorded during star excursion balance, and there were no significant differences in the distance reached between conditions. However, the current results suggest that wearing ankle braces does not enhance motor output while performing these balance tasks.

During the forward lunge, small decreases in lateral gastrocnemius activity were identified prior to ground contact and small decreases in peroneus longus activity following ground contact. At the ankle, dur-
### Table 4. Effect of Ankle Braces on Muscle Activation Patterns during Star Excursion Balance Reaching Exercise

<table>
<thead>
<tr>
<th>Muscles</th>
<th>Reach Direction</th>
<th>No Brace Mean±SD</th>
<th>Brace Mean±SD</th>
<th>p-value</th>
<th>ES (95% CI)</th>
<th>Reach Direction</th>
<th>No Brace Mean±SD</th>
<th>Brace Mean±SD</th>
<th>p-value</th>
<th>ES (95% CI)</th>
<th>Reach Direction</th>
<th>No Brace Mean±SD</th>
<th>Brace Mean±SD</th>
<th>p-value</th>
<th>ES (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior Tibials</td>
<td>Posteromedial</td>
<td>0.63±0.59</td>
<td>0.54±0.35</td>
<td>0.19</td>
<td>-0.19 (-0.90, 0.53)</td>
<td>Posteromedial</td>
<td>1.04±0.38</td>
<td>-0.27 (-0.99, 0.45)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Posterolateral</td>
<td>0.99±0.98</td>
<td>0.94±0.76</td>
<td>0.56</td>
<td>-0.06 (-0.78, 0.66)</td>
<td>Posterolateral</td>
<td>1.52±0.91</td>
<td>-0.08 (-0.79, 0.64)</td>
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<tr>
<td>Peroneus Longus</td>
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<td>0.49±0.20</td>
<td>0.36±0.19</td>
<td>0.65</td>
<td>-0.65 (-1.38, 0.08)</td>
<td>Anterior</td>
<td>1.46±0.87</td>
<td>0.7</td>
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<td>-0.48 (-1.20, 0.25)</td>
<td>Anterior</td>
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<td>1.60±1.15</td>
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<tr>
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<td>-0.38 (-1.10, 0.34)</td>
<td>Posteromedial</td>
<td>1.04±0.38</td>
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<td></td>
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<td>Posteromedial</td>
<td>1.18±0.69</td>
<td>0.94±0.76</td>
<td>0.56</td>
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<td>0.38±0.17</td>
<td>0.40</td>
<td>-0.04 (-0.76, 0.67)</td>
<td>Posteromedial</td>
<td>1.52±0.91</td>
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<td></td>
<td>-0.08 (-0.79, 0.64)</td>
<td>Posterolateral</td>
<td>1.18±0.69</td>
<td>0.94±0.76</td>
<td>0.56</td>
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<tr>
<td>Lateral Gastrocnemius</td>
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<td>-0.18 (-0.90, 0.54)</td>
<td>posteromedial</td>
<td>0.87±0.38</td>
<td>0.87</td>
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<td></td>
<td>posterolateral</td>
<td>1.18±0.69</td>
<td>0.94±0.76</td>
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<td></td>
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<td>-0.16 (-0.88, 0.56)</td>
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<td></td>
<td>posterolateral</td>
<td>1.18±0.69</td>
<td>0.94±0.76</td>
<td>0.56</td>
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<tr>
<td></td>
<td>Posterolateral</td>
<td>0.23±0.10</td>
<td>0.21±0.12</td>
<td>0.16</td>
<td>-0.16 (-0.88, 0.55)</td>
<td>posteromedial</td>
<td>0.87±0.38</td>
<td>0.87</td>
<td></td>
<td></td>
<td>posterolateral</td>
<td>1.18±0.69</td>
<td>0.94±0.76</td>
<td>0.56</td>
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<tr>
<td>Rectus Femoris</td>
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<td>0.42±0.22</td>
<td>0.35±0.22</td>
<td>0.35</td>
<td>-0.35 (-1.07, 0.37)</td>
<td>Anterior</td>
<td>0.76±0.36</td>
<td>&lt;.001*</td>
<td></td>
<td></td>
<td>Anterior</td>
<td>0.76±0.36</td>
<td>0.63±0.33</td>
<td>&lt;.001*</td>
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<tr>
<td></td>
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<td>Posteromedial</td>
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<td>0.63±0.33</td>
<td>&lt;.001*</td>
<td></td>
<td>Anterior</td>
<td>0.76±0.36</td>
<td>0.63±0.33</td>
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<td>0.18</td>
<td>-0.18 (-0.89, 0.54)</td>
<td>Posteromedial</td>
<td>0.63±0.33</td>
<td>0.63±0.33</td>
<td>&lt;.001*</td>
<td></td>
<td>Anterior</td>
<td>0.76±0.36</td>
<td>0.63±0.33</td>
<td>&lt;.001*</td>
<td></td>
</tr>
<tr>
<td>Biceps Femoris</td>
<td>Anterior</td>
<td>0.17±0.07</td>
<td>0.15±0.07</td>
<td>0.24</td>
<td>-0.24 (-0.95, 0.48)</td>
<td>Anterior</td>
<td>0.91±0.36</td>
<td>0.87±0.34</td>
<td>0.44</td>
<td>&lt;0.01*</td>
<td>Anterior</td>
<td>0.76±0.36</td>
<td>0.63±0.33</td>
<td>&lt;.001*</td>
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<tr>
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<td>Posteromedial</td>
<td>0.11±0.06</td>
<td>0.11±0.04</td>
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<td>-0.12 (-0.84, 0.59)</td>
<td>Posteromedial</td>
<td>0.87±0.34</td>
<td>0.87±0.34</td>
<td>0.44</td>
<td></td>
<td>Anterior</td>
<td>0.76±0.36</td>
<td>0.63±0.33</td>
<td>&lt;.001*</td>
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<tr>
<td></td>
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<td>0.16±0.07</td>
<td>0.11</td>
<td>-0.11 (-0.60, 0.83)</td>
<td>Posteromedial</td>
<td>0.84±0.26</td>
<td>0.84±0.26</td>
<td>0.44</td>
<td></td>
<td>Anterior</td>
<td>0.76±0.36</td>
<td>0.63±0.33</td>
<td>&lt;.001*</td>
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<tr>
<td>Gluteus Medius</td>
<td>Anterior</td>
<td>0.17±0.12</td>
<td>0.13±0.08</td>
<td>0.35</td>
<td>-0.35 (-1.07, 0.37)</td>
<td>Anterior</td>
<td>0.26±0.13</td>
<td>0.23±0.12</td>
<td>0.26</td>
<td>-0.26 (-0.98, 0.46)</td>
<td>Anterior</td>
<td>0.26±0.13</td>
<td>0.23±0.12</td>
<td>0.26</td>
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<td></td>
<td>Posteromedial</td>
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<td>0.53</td>
<td>-0.53 (-1.08, 0.37)</td>
<td>Posteromedial</td>
<td>0.23±0.15</td>
<td>0.23±0.15</td>
<td>0.23</td>
<td>-0.26 (-0.98, 0.46)</td>
<td>Posteromedial</td>
<td>0.23±0.15</td>
<td>0.23±0.15</td>
<td>0.23</td>
<td></td>
</tr>
</tbody>
</table>

p-values are for paired T-Test Statistical Results – Level of significance set a priori at p≤0.05, * denotes significant difference between brace and no brace
ES= Cohen’s d Effect Sizes and CI= 95% Confidence Intervals Note: Negative ES indicates decreased muscle activity in braced condition
Positive ES indicates increased muscle activity in braced condition
SD – Standard Deviation
Table 5. Effect of Ankle Braces on Muscle Activation Patterns during performance of the Lateral Hop Exercise

<table>
<thead>
<tr>
<th>Muscles</th>
<th>Isolated Muscle Activation</th>
<th>Distal/Proximal Muscle Activation</th>
<th>Total Muscle Activation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Brace Mean±SD</td>
<td>Brace Mean±SD</td>
<td>p-value ES (95% CI)</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td>Anterior Tibialis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-IC 0.45±0.44</td>
<td>0.57±0.79</td>
<td>0.20 (-0.52, 0.91)</td>
</tr>
<tr>
<td>Peroneus Longus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-IC 0.73±0.29</td>
<td>0.68±0.44</td>
<td>-0.13 (-0.84, 0.59)</td>
</tr>
<tr>
<td></td>
<td>Post-IC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral Gastrocnemius</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-IC 1.21±1.18</td>
<td>1.1±0.84</td>
<td>-0.09 (-0.81, 0.62)</td>
</tr>
<tr>
<td></td>
<td>Post-IC</td>
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<td></td>
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<tr>
<td>Rectus Femoris</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-IC 0.64±0.46</td>
<td>0.63±0.36</td>
<td>-0.01 (-0.73, 0.70)</td>
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<tr>
<td></td>
<td>Post-IC</td>
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<td></td>
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<tr>
<td>Biceps Femoris</td>
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<td></td>
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<tr>
<td></td>
<td>Pre-IC 0.31±0.25</td>
<td>0.30±0.19</td>
<td>-0.03 (-0.75, 0.69)</td>
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<tr>
<td></td>
<td>Post-IC</td>
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<tr>
<td>Gluteus Medius</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-IC 0.61±0.25</td>
<td>0.65±0.35</td>
<td>-0.01 (-0.73, 0.71)</td>
</tr>
<tr>
<td></td>
<td>Post-IC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

p-values are for paired t-Test Statistical Results – Level of significance set a priori at p≤0.05, * denotes significant difference between brace and no brace conditions.
ES= Cohen’s d Effect Sizes and CI= 95% Confidence Intervals Note: Negative ES indicates decreased muscle activity in braced condition
Positive ES indicates increased muscle activity in braced condition
SD = Standard Deviation
Pre-IC= Pre-Initial Contact Root Mean Square area 50ms
Post-IC= Post-Initial Contact Root Mean Square area 100ms
ing the 50 ms prior to initial contact and the 100 ms following initial contact, the forward lunge is comparable to ground contact during gait where a heel to toe pattern is followed. In CAI subjects during gait, bracing elicits a similar decrease in peroneus longus muscle activity pre-initial contact. CAI subjects have been shown to be more inverted just prior to and immediately following heel strike. Activity of the peroneus longus prior to heel strike in CAI subjects has been speculated as a coping strategy to decrease the excessive inversion identified during this phase of gait. While the timing of the bracing effect relative to initial contact (pre vs. post initial contact) is different in the lunge compared to gait, both instances of decreased peroneus longus activity indicate that the ankle brace is aiding in the role of the peroneus longus during heel to toe weight acceptance tasks. This decreased peroneus longus muscle activity suggests that the brace is aiding in the foot and ankle frontal plane alignment prior to initial contact or providing mechanical resistance to inversion at and following ground contact. This theory is supported by previous authors that analyzed the effect of ankle bracing on rearfoot motion during sudden inversion. In this study, lace-up ankle braces significantly limited rearfoot angular displacement and velocity, which without the ankle braces would be dependent upon lateral ankle ligaments and lateral shank musculature. However, if the goal of rehabilitation is to decrease the reliance of the peroneus longus on mechanical support for proper foot alignment and dynamic support of the lateral ankle, then the current results suggest wearing ankle braces during these controlled tasks is not indicated.

Due to the pronounced effect ankle braces have at reducing the rate of ankle sprain, many patients with ankle instability wear ankle braces at all times during exercise, including during neuromuscular training tasks designed for prophylactic ankle sprain prevention and functional rehabilitation while progressing back to sport following initial or recurrent ankle sprain. This same cohort, when compared to healthy counterparts, demonstrated moderate to large decreases in muscle activity during the same exercises analyzed in this study. These previous results indicated that clinicians should introduce various constraints during rehabilitation for patients with CAI to elicit increased muscle activity. Therefore, the decreased muscle activity in participants with CAI while wearing braces may indicate that wearing ankle braces during neuromuscular training may be counterproductive to the goals associated with the prescribed exercises. Future research should analyze changes in muscle activity during functional exercises following a structured rehabilitation program for patients with CAI and after prolonged use of ankle braces.

While the authors' cannot speculate on the effect ankle braces may have on muscle activity in uncontrolled athletic environments, the results suggest that wearing ankle braces during neuromuscular training or rehabilitation exercises does not increase muscle activity. Previous results indicate patients with CAI have less muscle activity during functional exercises and the current results indicate ankle braces do not improve upon that deficit. Similar results were reported by Zinder et al, who found ankle braces increased rotational ankle stiffness in participants with ankle instability, but the increased rotational stiffness was not due to increased pre-activation of ankle musculature. Similarly, in healthy subjects, the application of ankle braces does not improve peroneus longus motor output during lateral shuffling. Cordova and Ingersoll demonstrated that the peroneus longus stretch reflex amplitude is higher immediately following brace application in healthy subjects, but to the authors' knowledge these results have not been replicated in patients with CAI. However, authors have discussed the importance of foot position prior to ground contact as a very important factor that may contribute to ankle sprain prevention, as the peroneus longus stretch reflex does not appear to be quick enough to prevent an ankle sprain from occurring. Wright et al indicated that increased plantar flexion prior to ground contact increases the susceptibility to ankle sprains. Others have demonstrated that external ankle support can decrease plantar flexion at and following initial contact. Furthermore, Eils et al compared various models of ankle braces and found that the braces that restricted inversion most effectively prior to ground contact exhibited less inversion and slower inversion velocities after contact. These previous studies did not concurrently analyze the effect of
bracing or the effect of the altered joint position on muscle activity prior to or following ground contact. These results coupled with the current results, indicate that the more favorable alignment prior to initial contact,\textsuperscript{50,54,55} decreased angular velocities,\textsuperscript{41} and decreased ROM\textsuperscript{29,41,42} seen with bracing are likely due to mechanical restraint and not improvements in muscle recruitment.

**LIMITATIONS**

Limitations of the current study include the short-term application of ankle braces on muscle activity and thus these results cannot be generalized to prolonged ankle brace use. Additionally, this study was part of a larger study that compared muscle activity between CAI and controls during gait. The \textit{a priori} sample size estimate was performed to identify gait differences and the relatively small sample size in the current study increases the potential risk of type II error in comparisons where statistical significance was not found. Specifically, in regards to the star excursion balance and lateral hop analyses, there are five total comparisons with p-values <.11 but >.05, suggesting the potential for type II error exists for those comparisons. However, the effect size calculations for those comparisons range from trivial to small with confidence intervals that are centered around zero, which indicates no meaningful treatment effect due to brace application regardless of statistical significance. Lastly, the current analysis is limited to therapeutic exercises performed in a controlled laboratory setting and these results cannot be generalized to more dynamic uncontrolled athletic environments.

**CONCLUSION**

Participants with CAI exhibit decreased normalized EMG muscle activity during common rehabilitation exercises after the application of ankle braces. If the goal of rehabilitation is to increase motor unit recruitment, patients with CAI should not wear ankle braces while performing the prescribed rehabilitation exercises.

**REFERENCES**


ORIGINAL RESEARCH

THE EFFECTS OF CONVENTIONAL PHYSICAL THERAPY AND ECCENTRIC STRENGTHENING FOR INSERTIONAL ACHILLES TENDINOPATHY

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Michael Williams, PT, OCS
Lisa Jain, DPT, OCS
Marie Barron, PT, OCS
Nick Bird, MPT
Brian Blackwell, PT, OCS
David R. Richardson, MD
Susan Ishikawa, MD
G. Andrew Murphy, MD

ABSTRACT

Study Design: Single-blind, randomized, clinical trial.

Background: The effect of eccentric training for mid-portion Achilles tendinopathy is well documented; however, its effect on insertional Achilles tendinopathy is inconclusive. The primary purpose of this study was to investigate the effect of eccentric training on pain and function for individuals with insertional Achilles tendinopathy.

Methods: All patients received a 12-week conventional strengthening protocol. Patients who were randomly assigned to the experimental group received additional eccentric exercises. Patients completed the Short Form-36 Health and Bodily Pain Surveys, the Foot and Ankle Outcomes Questionnaire, and the Visual Analog Scale at initial evaluation, after 6 weeks of therapy, and at 12 weeks after therapy.

Results: Thirty-six patients (20 control and 16 experimental; average age 54 years; 72% women) completed the study. Both groups experienced statistically significant decreases in pain and improvements in function. No statistically significant differences were noted between the groups for any of the outcome measures.

Conclusion: Conventional physical therapy consisting of gastrocnemius, soleus and hamstring stretches, ice massage on the Achilles tendon, and use of heel lifts and night splints with or without eccentric training is effective for treating insertional Achilles tendinopathy.

Level of Evidence: Level 2

Keywords: Achilles tendinopathy, eccentric training, posterior heel pain

The study was approved by the Institutional Review Board of the University of Tennessee, School of Medicine

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INTRODUCTION

Achilles tendinopathy is a prevalent overuse injury that usually presents between the ages of 30 and 60 years.\(^1\) In recent years, eccentric training has gained popularity as an effective intervention for Achilles tendinopathy.\(^2\)\(^-\)\(^7\) However, clinical outcomes are reported to be more effective in persons with mid-portion Achilles tendinopathy and less effective with insertional tendinopathy.\(^8\)\(^,\)\(^9\) Physical therapy and other conservative interventions for this condition have included activity modification (rest or cross training, such as cycling instead of running), cryotherapy, ultrasound, calf stretches, heel lifts, orthotics, and nonsteroidal anti-inflammatory drugs (NSAIDs).\(^10\)\(^-\)\(^12\) Prolonged stretching, in particular, has been found to decrease heel pain.\(^13\) There are surgical options, but they are costly and generally involve a lengthy recovery.\(^3\)\(^,\)\(^14\)\(^-\)\(^16\)

Although Achilles tendinopathy is common in athletes, particularly runners, the authors’ clinical practice has noted a high incidence of insertional Achilles tendinopathy among patients with diverse levels of activity. Researchers have reported that eccentric training is less effective among persons with high body mass index (BMI), sedentary lifestyle, or female sex.\(^9\)\(^,\)\(^17\) The primary purpose of this study was to investigate the effect of eccentric training on pain and function for individuals with insertional Achilles tendinopathy. It was hypothesized that the addition of eccentric training to a conventional physical therapy program would be more effective than conventional physical therapy alone in regards to pain and function. A secondary purpose was to determine if BMI, activity level, and baseline dorsiflexion range of motion and gastrocnemius/soleus strength had any effect on results.

METHODS

Inclusion and exclusion criteria

The sample population included patients who were referred for conventional physical therapy treatment for insertional Achilles tendinopathy that was diagnosed by orthopaedic foot and ankle surgeons per history and physical findings. Physical findings of Achilles tendinopathy included swelling, pain at the insertion of the Achilles tendon, and start-up pain (pain upon first arising). Inclusion criteria were (1) symptoms present for at least 3 months and (2) age of at least 18 years. Patients were excluded if they had rheumatoid arthritis, generalized polyarthritis, Reiter syndrome, bleeding disorders, severe endocrine disease, tumor, local infection, advanced peripheral vascular disease, or if they were pregnant. In addition, they were not eligible for enrollment if they had previous Achilles tendon surgery, ankle arthrodesis, hindfoot fracture, or leg-length discrepancy of more than one-half inch.

If a patient had symptoms in both Achilles tendons, only the tendon that the patient considered worse at the initial visit was followed in the study.

Randomization

In the physical therapy department, patients were randomly assigned to either a conventional physical therapy (control) protocol or conventional therapy with eccentric strengthening (experimental) protocol. The computer generated randomized identification numbers following a 4:4 assignment so that for every four patients randomized at each location, two would be in each group. A statistician not involved in patient care or data procurement randomized the assignments into envelopes with an identification number labeled on the outside, leaving the physical therapists blinded to the assignment. When a patient came for the initial physical therapy appointment, the physical therapist pulled an envelope with the next identification number to assign a protocol.

Intervention

All patients were seen for four visits: initial evaluation, 1 week later (week 2), week 4, and week 6 but were instructed to follow the home exercise program for a total of 12 weeks. The control protocol consisted of gastrocnemius, soleus, and hamstring stretches, ice massage on the Achilles tendon twice a day (5-10 minutes), use of bilateral heel lifts, and a resting night splint. Patients were instructed to per-
form each stretch for three repetitions (30 seconds) twice daily (Figure 1 A-D). The heel lifts were adjustable, starting at 3/8” and lowered 1/8” every 2 weeks until ultimately no heel lift remained.

The patients in the experimental group followed everything in the control protocol with the addition of two eccentric strengthening exercises. In the first exercise, the patient stood bearing weight on the involved foot in plantarflexion with the knee slightly bent (Figure 2A); the patient then slowly lowered the heel into dorsiflexion to a count of five (Figure 2B). The other leg could be used to assist the patient in returning to plantarflexion. In the second exercise, the patient stood bearing weight on the involved foot in plantarflexion but with the knee straight on the stance leg. Again, the patient lowered the heel to a count of five into dorsiflexion (Figure 2C). If too weak to hold the single leg in plantarflexion, the patient stood with the heel off a step as high as possible (which might be neutral) and slowly lowered the heel...

Figure 1. Conventional stretches for insertional Achilles tendinopathy. (A) Gastrocnemius stretch. With the knee straight and heel on the floor (involved foot back), the patient leans forward. (B) Soleus stretch. With the knee bent and the heel on the floor (involved foot back) the patient leans forward. (C) Hamstring and gastrocnemius stretch. Lying supine, the hands (or a towel) are placed around the posterior aspect of the knee. The knee is slowly straightened until a stretch is felt. Then, keeping this position the foot is pulled toward the face. (D) Sitting in an upright position with the involved knee straight, a towel is placed around the ball of the foot. Using both hands, the patient pulls the towel, bending the foot toward the face.

Figure 2. Eccentric training exercises. (A) First exercise. The patient stands bearing weight on the involved foot in plantarflexion and the knee slightly bent and slowly lowers the heel into dorsiflexion to a count of five (B). (C) Second exercise. The patient stands bearing weight on the involved foot in plantarflexion with the knee straight and lowers the heel to a count of five.
heel to a count of five. Patients were instructed to perform both exercises in two sets of 15 repetitions, twice daily. The patients were instructed to add a weighted backpack if the exercises became easy to perform. This protocol was used to accommodate the tolerance level of patients with various levels of activity, including those participating in recreational sports or those who performed manual labor. No medication was prescribed for any patient.

**Data collection**
Data were collected at four clinic locations of a private orthopaedic practice with physical therapists administering the intervention and physicians collecting most of the data. Trained foot and ankle orthopaedic surgeons blinded to which protocol was being followed made the initial diagnosis and collected the outcome measures at baseline, 6 weeks, and 12 weeks. Baseline data included age, sex, race, body mass index (BMI), presence or absence of calcification, symptoms, and activity levels. Physical therapists recorded ankle range of motion and gastrocnemius and soleus strength at baseline. Subsequent measurements were taken at weeks 4 and 6. A standardized protocol based on Norkin and White’s was reviewed at group meetings and used for body position, goniometer placement, and manual muscle testing.

**Outcome measures**
Patients completed several standardized instruments at initial evaluation, and at 6 and 12 weeks in the physician’s office. These included the following:

1. Short Form Health Survey (SF-36) and the SF-36 Bodily Pain subscale, which are designed to measure general health status in a variety of circumstances. They have a high level of internal consistency with correlation coefficients higher than acceptable levels across medical conditions (minimally clinical important difference [MCID] is 5).\(^{21,22,23,24}\)

2. Foot and Ankle Outcomes Questionnaire (FAOQ), which uses 25 questions to determine pain and stability of the foot and ankle during various activities, the degree to which the foot and ankle interfere with normal work and daily life, and general stiffness and swelling. The FAOQ has been found to be useful in evaluating foot and ankle outcomes, with good internal consistency, retest reliability, and moderate to strong correlation with physician ratings and the SF-36.\(^{21}\)

3. Visual Analog Scale (VAS) for pain consists of a 100 mm line, demarcated in 10-mm intervals, on which the patient records pain with 0 as no pain and 100 as pain so severe you would be in the emergency room. It has been validated by previous research and found to detect MCID in pain (absolute change between 20 and 30 mm on the 100 mm VAS and a 33% decrease of pain is associated with pain relief\(^{15,33}\)).\(^{25,26,27}\)

**Statistical Analysis**
Data were entered in Excel and analyzed using SAS 9.2. The outcome measures had excellent internal consistency. Cronbach alpha for the FAOQ was 0.93 and for the SF-36, 0.90. The SF-36 Bodily Pain subscale had moderate reliability, with an alpha value of 0.75. This strong internal consistency is good for this small sample size and suggests that the data may not be as limited as the small number suggests. The Mann-Whitney U test was used to compare the outcome measures between the control group and the experimental group. The Wilcoxon test compared outcomes to baseline for patients within the protocol.\(^{28}\) Chi-square tests and Mann-Whitney tests were used to check for unintentional biases in completion of study and assignment of protocol. Spearman’s rank correlations were used to assess correlations between interval-level data (e.g., BMI) with the outcome ordinal scales. The t-test and the Wilcoxon signed-rank test were used, respectively, to compare baseline and final range of motion and strength data.\(^{28}\) Statistical significance was set at an alpha level of \(p<0.05\). Intention to treat analysis was used to assess the effect of incomplete protocols on primary outcomes.\(^{29}\)

**RESULTS**

**Baseline data**
Recruitment and follow-up were conducted between February 2007 and October 2010. The majority of patients were middle age, overweight women who had insertional Achilles tendon pain and a slight decrease in dorsiflexion range of motion and gastrocnemius strength. Most patients had attempted other treatments before participation in this study (Figure 3). Thirty-six of 58 patients met inclusion criteria and adhered to one of the two protocols as instructed: 16 in the experimental group (11 women and five men; average age 51.7 years) and 20 in the control group (15 women and five men; average age 51.7 years).
55.3 years) (Table 1). The average body mass index (BMI) was 37.6 in the experimental group and 32.7 in the control group; although not reaching a statistically significant difference between groups, analysis of BMI indicates that the sample population tended to be overweight if not obese (Table 1). Twenty-seven patients (87%) had calcification in the tendon and three had bilateral symptoms (Table 2). Activity levels at baseline varied, but more patients in the conventional group reported higher activity levels than those reported by the experimental group (Table 2).

Patients in both groups had mildly decreased ankle dorsiflexion and plantarflexion both on the involved and noninvolved sides at baseline. Although not statistically significant, the experimental group had less active dorsiflexion on the involved side compared with the control group (Table 2). Some gastrocnemius weakness was noted in both groups on the involved side (Table 2).

### Outcomes

Overall, patients in both protocols significantly improved both in pain and function according to VAS, SF-36 (Bodily Pain), SF-36, and FAOQ, and the mean improvement also was statistically significant using these outcome measures (Table 3). The mean change of the SF-36 was 10 (MCID 5\(^{26,32}\)) and on VAS it was 20 mm or 41.3% (MCID 20-30 mm and 33% decrease\(^{15,33}\)).

No statistically significant differences were found in outcomes between patients in the two groups (Table 4). Although both groups experienced positive change, the conventional protocol group's change was statistically significant in all outcome measures (VAS, SF36 [Bodily Pain], SF-36, and FAOQ), whereas the experimental group's change was significant in the VAS, SF-36 (Bodily Pain), and FAOQ, but not the SF-36 (see Table 3).

No statistically significant differences were found in outcomes by age, race, BMI, duration of symptoms, or prior activity level for either group. However, women improved more than men as measured by the VAS, and this was statistically significant (\(p = 0.033\)) regardless of treatment protocol.

Patients in both protocols had significantly improved ankle dorsiflexion range of motion and gastrocnemius manual muscle strength test at final follow-up (Table 5). Better ankle dorsiflexion range and gastrocnemius strength at baseline were moderately correlated with significantly larger improvements in VAS (Spearman's rho \(r_s = 0.370, p = 0.048\) and \(r_s = 0.396, p = 0.0368\), respectively). Better gastrocnemius strength at baseline showed moderate (statis-

<table>
<thead>
<tr>
<th>Table 1. Patient demographics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Number of patients</td>
</tr>
<tr>
<td>Sex</td>
</tr>
<tr>
<td>Male (%)</td>
</tr>
<tr>
<td>Female (%)</td>
</tr>
<tr>
<td>Mean age (SD)</td>
</tr>
<tr>
<td>Race</td>
</tr>
<tr>
<td>Caucasian (%)</td>
</tr>
<tr>
<td>African-American (%)</td>
</tr>
<tr>
<td>Mean body mass index (SD)</td>
</tr>
</tbody>
</table>
Correlation with improved FAOQ scores ($r_s = 0.5181$, $p = 0.005$).

Complications
One patient required physical therapy for knee pain that occurred after eccentric training. One patient who was removed from the study had a partial Achilles tendon rupture that occurred from activity not associated with the study. Because this complication occurred shortly after enrollment, the patient's participation in the study was not a factor. No other complications were noted.

Check for Biases and Effects
Statistical analyses indicated no bias in the assignment of protocol by age (Mann-Whitney $U=1.0$, $p=0.293$), sex (Chi-square = 0.04, $p = 0.841$), duration of symptoms (Mann-Whitney $U = 0.005$, $p = 0.94$), or activity level prior to injury. Patients assigned to the experimental group had a higher mean BMI ($BMI = 37$) than those in the traditional protocol ($BMI = 32$), but the difference was not statistically significant (Mann-Whitney $U = 3.24$, $p = 0.072$). Because some heavier patients had difficulty performing the eccentric strengthening exercise.

<table>
<thead>
<tr>
<th>Activity level prior to injury* (missing data = 4)</th>
<th>Experimental Group</th>
<th>Control Group</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedentary (%)</td>
<td>1 (7.7)</td>
<td>0 (0.0)</td>
<td>1 (3.1)</td>
</tr>
<tr>
<td>Mod active (%)</td>
<td>5 (38.5)</td>
<td>8 (42.1)</td>
<td>13 (40.6)</td>
</tr>
<tr>
<td>Active (%)</td>
<td>5 (38.5)</td>
<td>10 (52.6)</td>
<td>15 (46.9)</td>
</tr>
<tr>
<td>Very active (%)</td>
<td>2 (15.4)</td>
<td>1 (5.3)</td>
<td>3 (9.4)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Current activity level* (missing data = 5)</th>
<th>Experimental Group</th>
<th>Control Group</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedentary (%)</td>
<td>6 (46.2)</td>
<td>4 (22.2)</td>
<td>10 (32.3)</td>
</tr>
<tr>
<td>Mod active (%)</td>
<td>3 (23.1)</td>
<td>10 (55.6)</td>
<td>13 (41.9)</td>
</tr>
<tr>
<td>Active (%)</td>
<td>3 (23.1)</td>
<td>3 (16.7)</td>
<td>6 (19.4)</td>
</tr>
<tr>
<td>Very active (%)</td>
<td>1 (7.7)</td>
<td>1 (5.6)</td>
<td>2 (6.5)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean duration (months) of symptoms (SD)**</th>
<th>Experimental Group</th>
<th>Control Group</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>18.5 (30.1)</td>
<td>18.3 (31.4)</td>
<td>18.4 (30.7)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Calcification in tendon (missing data = 5)</th>
<th>Experimental Group</th>
<th>Control Group</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>11 (73.3)</td>
<td>16 (100.0)</td>
<td>27 (87.1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Symptoms bilaterally (%)</th>
<th>Experimental Group</th>
<th>Control Group</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 (18.8)</td>
<td>0 (0.0)</td>
<td>3 (8.3)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ankle dorsiflexion involved side (mean SD)</th>
<th>Experimental Group</th>
<th>Control Group</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7.7 (3.8)</td>
<td>9.0 (4.3)</td>
<td>8.5 (4.1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MMT gastrocnemius involved side (mean SD)</th>
<th>Experimental Group</th>
<th>Control Group</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.6 (0.8)</td>
<td>4.6 (1.3)</td>
<td>4.6 (1.1)</td>
</tr>
</tbody>
</table>

*sum percent > 100% due to rounding error

**Note: The large standard deviations are due to three patients who had symptoms ≥ 120 months.

Note: Activity levels were self-reported by patients. Sedentary = desk job, no regular exercise; moderately active = desk job and regular exercise; active = manual labor and regular exercise or recreational sports; very active = heavy work activity, regular exercise and competitive sports. MMT = manual muscle test; SD = standard deviation.

Table 2. Patient baseline data
and others reported doing better at 6 weeks and did not return at 12 weeks, an intention to treat analysis was performed and demonstrated no effects of incomplete follow-through on outcome. An exercise diary was provided for each patient. Most participants had received other treatments prior to this study implying that the success was related to their compliance.

### Table 3. Comparison of outcomes in pain and function at 12 weeks with baseline

<table>
<thead>
<tr>
<th>Outcome measure</th>
<th>Experimental Group</th>
<th>Control Group</th>
<th>Test Utilized, p values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean change</td>
<td>p value</td>
<td>95% confidence interval</td>
</tr>
<tr>
<td>VAS</td>
<td>-2.19       &lt; 0.001</td>
<td>-2.98/-1.43</td>
<td>-2.08 &lt; 0.001</td>
</tr>
<tr>
<td>SF-36 (Bodily Pain)</td>
<td>16.22 0.016</td>
<td>5.0/27.4</td>
<td>16.40 0.026</td>
</tr>
<tr>
<td>SF-36</td>
<td>9.78 0.125</td>
<td>-1.63/21.19</td>
<td>10.27 0.035</td>
</tr>
<tr>
<td>FAOQ</td>
<td>-0.73 0.002</td>
<td>-2.11/-1.05</td>
<td>-0.758 0.0002</td>
</tr>
</tbody>
</table>

**Note:** Improvement in status is indicated by a negative change for the VAS and FAOQ, with a larger negative number indicating a bigger improvement. A positive change for the SF-36 indicates improvement in status, with a larger positive change indicating better improvement in health.

### Table 4. Comparison of outcomes between protocols

<table>
<thead>
<tr>
<th>Scale (12 weeks)</th>
<th>Experimental Group Mean (SD)</th>
<th>Control Group Mean (SD)</th>
<th>Test Utilized, p values</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAS</td>
<td>2.43 (1.99)</td>
<td>1.50 (2.16)</td>
<td>MW=2.30, p=0.129</td>
</tr>
<tr>
<td>SF-36</td>
<td>70.00 (15.95)</td>
<td>70.50 (19.97)</td>
<td>MW=0.07, p=0.789</td>
</tr>
<tr>
<td>SF-36 (Bodily Pain)</td>
<td>72.44 (11.49)</td>
<td>61.82 (27.15)</td>
<td>MW=0.08, p=0.778</td>
</tr>
<tr>
<td>FAOQ</td>
<td>0.78 (0.58)</td>
<td>0.74 (0.75)</td>
<td>MW=0.54, p=0.464</td>
</tr>
</tbody>
</table>

**Note:** VAS = visual analog scale; SF-36 = Short Form-36; FAOQ = Foot and Ankle Outcomes Questionnaire, MW = Mann-Whitney test

### Table 5. Changes in mean ankle range of motion and strength (of involved side)

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Protocol</th>
<th>Baseline (1st visit physical therapy)</th>
<th>Last visit physical therapy (6 weeks)</th>
<th>Test Utilized, p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AROM ankle dorsiflexion, reported in degrees (SD)</td>
<td>Experimental</td>
<td>2.42 (4.68)</td>
<td>7.67 (3.80)</td>
<td>t = -6.72, p &lt; 0.0001</td>
</tr>
<tr>
<td>Control</td>
<td>0.89 (5.97)</td>
<td>9.00 (4.27)</td>
<td>t = -5.27, p = 0.0002</td>
<td></td>
</tr>
<tr>
<td>Manual Muscle Test of gastrocnemius, reported as grade out of 5 (SD)</td>
<td>Experimental</td>
<td>4.31 (0.94)</td>
<td>4.64 (0.81)</td>
<td>S=27.5, p=0.002</td>
</tr>
<tr>
<td>Control</td>
<td>3.49 (1.61)</td>
<td>4.56 (1.25)</td>
<td>S=4.5, p=0.012</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** AROM = ankle range of motion, t = t-test, S = Wilcoxon-signed rank test
DISCUSSION

Eccentric training has been identified as an important part of clinical rehabilitation of chronic tendinopathy, particularly of the Achilles tendon at the midportion. Eccentric training also has been found to be more effective than concentric strengthening for Achilles tendinosis located 2-6 cm from its insertion. The hypothesis that the addition of eccentric training to a conventional physical therapy program would be more effective than conventional physical therapy alone in the treatment of insertional Achilles tendinopathy was not supported by this research. This study found that patients with insertional Achilles tendinopathy experienced significant improvements with conventional physical therapy, with or without eccentric training. Improvement was noted in 86.7% of patients on the VAS, 84.2% on the SF-36, 73.7% on the SF-36 bodily pain subscale, and 93.3% on the FAOQ. The mean amount of improvement in pain and function also was considered clinically significant in the VAS, SF-36, and FAOQ. A change of 5 on the SF-36 has been shown to be a clinically significant improvement; the mean change of the SF-36 was 10 in this study. According to Jensen, Chen, and Brugger, and absolute change between 20 and 30 mm on the 100 mm VAS scale and a 33% decrease of pain on the VAS is associated with pain relief. The mean change in the current study was 20 mm with a mean percentage change of 41.3%, which indicates that the decrease in pain was clinically significant. Better baseline ankle dorsiflexion range and gastrocnemius strength significantly correlated with larger improvements in both groups. It is interesting to note that patients in the control group also experienced statistically significant improvements in gastrocnemius strength even though their protocol did not include strengthening.

The findings in this study differ from those of Fahlström et al as well as those noted in the review by Alfredson and Cook; both of those reports noted that only about a third of patients with symptoms at the insertion responded to treatment within 3 months. In contrast, all patients in this study improved in at least one outcome measure. It is important to note that the percentages of improvement in this study did not measure the same thing as the aforementioned articles. This study measured any improvement along a scale, whereas their articles noted the percentage of patients with functional improvement who were able to return to their previous levels of activity. Alfredson’s and Cook’s review and algorithm referred to a more athletic population than we had in this study, and this may account for the differences in results.

While the outcomes in the current study were better for insertional Achilles tendinopathy than reported in previous studies investigating eccentric strengthening, it is unknown if eccentric training made the difference. The interventions used in the control group have been supported by previous research for mid-portion Achilles tendinopathy, including the use of insoles or heel lifts and Achilles stretches. The night splint has not been found to have additional benefit when added to eccentric strengthening. An airheel brace (a light weight compression brace with interconnected aircells under the arch of the foot and the back of the Achilles tendon to reduce strain), which was not used in this study, also has been found to be beneficial. Most of these patients (75%) had used at least one of these treatments before the study, suggesting that a combination of interventions may be required for effective treatment, as proposed by Angermann and Hovgaard. Unlike previous research that suggests patients with a higher BMI have worse outcomes, this was not so in this study, although obese patients were clinically observed to have more problems performing the eccentric exercises. Patients who reported having osteoarthritis also complained of knee discomfort during eccentric exercises with the knee flexed, and one patient required treatment for his knee after performing the eccentric strengthening protocol. Performing eccentric exercises only with the knee extended (see Figure 2C) or a simple prolonged eccentric stretch as described by Verrall et al may be an appropriate modification for patients with osteoarthritis. Recently, Stevens and Tan reported that a “6-week do-as-tolerated” program of eccentric exercise was as effective but with less discomfort in the process as the recommended 180-repetition exercise program for midportion Achilles tendinopathy. Their program may facilitate strengthening without knee discomfort, which could be appropriate for patients who report osteoarthritis or who are obese and who had trouble executing the eccentric strengthening exercise in the current protocol.
Previous authors have reported that eccentric strengthening is not particularly effective in a non-athletic population,17 however, the subjects in the current study demonstrated no correlation between activity level and outcomes regardless of eccentric training. In addition, women who have been noted previously to have the same or poorer outcomes than men with eccentric training,12,31 reported more improvement in pain than men in all outcome measurements in the current study, and this difference reached a statistically significant difference on the VAS (U = 4.65, \( p = 0.033 \)). Further study would be necessary to determine the reason for this finding.

The patient population in this study differed from the population most often described with chronic Achilles tendinopathy, namely middle-aged, mostly male, recreational athletes. The patients in this study were overwhelmingly women (72%), with varied activity levels. The prevalence of obesity in this study population suggests that this was not a highly athletic population, which raises the question of whether the demographics and the causal factors are the same among persons for mid-portion Achilles tendinopathy as for those with insertional Achilles tendinopathy.

This study has several limitations, including low patient numbers, short follow-up (larger improvements may have been noted at a later point), and that patients performed the physical therapy protocol at home without supervision. In addition, patients did not progress beyond their body weight during the eccentric protocol. Also, no reliable information regarding the patient's use of over-the-counter medications was available, except that they were prescribed none. Having Achilles tendinopathy bilaterally could influence the outcome, but the sample size with this condition (N = 3) was too small for meaningful exploration.

CONCLUSIONS
The results of this study showed that conventional physical therapy with or without eccentric strengthening was effective in the treatment of insertional Achilles tendinopathy in a population with varied activity levels. No statistically significant difference was noted in outcomes between the control group and the experimental group, as they both demonstrated statistically significant improvements. Better ankle range of motion and gastrocnemius strength at baseline correlated with significantly larger improvements. This study suggests that patients with diverse activity levels with insertional Achilles tendinopathy can improve significantly with an appropriate combination of stretches, heel lifts, night splint, and cryotherapy.

REFERENCES


32. van Tetering EA, Buckley RE. Functional outcome (SF-36) of patients with displaced calcaneal fractures compared to SF-36 normative data. Foot Ankle Int. 2004; 25:733-738.


ABSTRACT

Background: Several glenohumeral joint (GHJ) positions have been recommended for assessing and correcting posterior shoulder tightness (PST) however, there is no agreement on which position is better for differentiating posterior muscle tightness from posterior capsular tightness. The purpose of this study was to compare the range of motion change before and after an external humeral rotator muscle fatigue protocol in order to identify a position that shows maximum range of motion change.

Methods: ROM changes across four PST measurements were compared before, immediately after, at 24 hours after, and 48 hours after an external rotator fatigue protocol. Muscle stiffness of the infraspinatus and the teres minor (using a myotonometer) and external rotation force production (using hand-held dynamometry) were measured to verify muscle fatigue.

Results: There was a statistically significant interaction between measurement and condition (F = 2.47, p = 0.02). The planned one factor repeated measure ANOVA for each condition revealed that ROM change was statistically significant between PST measurements for all conditions. Post hoc comparisons indicated statistically significant greater overall ROM changes in a measurement combining GHJ extension and internal rotation compared to other tested measurements. There was also a main effect of time on infraspinatus muscle stiffness (F = 10.5, p < 0.0001). Post hoc comparison indicated a statistically significant increase in infraspinatus stiffness immediately after the fatigue protocol (p < 0.05).

Conclusion: Immediate ROM reduction was observed across all the measurements except horizontal adduction (HAD). Maximum ROM reduction after an external rotation fatigue protocol was measured in a position of GHJ extension.

Clinical Relevance: Posterior muscle tightness may influence the internal rotation range of motion to a greater extent when measured in glenohumeral joint extension.

Keywords: Glenohumeral joint, muscle stiffness, clinical measurement, horizontal adduction, internal rotation.

Levels of Evidence: II-B
INTRODUCTION

Loss of internal rotation range of motion (ROM) of the dominant glenohumeral joint of overhead-throwing athletes is well documented.1-13 This internal rotation (IR) loss is attributed to osseous and soft tissue adaptation and is referred to as posterior shoulder tightness (PST) and develops in response to prolonged exposure to high levels of repeated overloading.1,8,14 Although several positions for assessing and correcting PST have been recommended, there is no consensus on which position is better for differentiating posterior muscle tightness from posterior capsular tightness. Positions for assessing and stretching posterior shoulder tissues usually involve either adducting the humerus across the body or a combination of humeral flexion and IR.14-18 Tyler et al. described a measurement in which the subject is side lying, and the humerus is flexed to $90^\circ$ and is horizontally adducted (HAD). Both Laudner and Myers described another measurement of PST similar to the horizontal adduction position, but performed in supine lying.17,19 A disadvantage of both of these measurements is that it is not known which structure from the posterior shoulder limits the motion.16 Laudner discusses that posterior deltoid, infraspinatus, teres minor and, latissimus dorsi may impact the magnitude of glenohumeral joint (GHJ) motion in horizontal adduction.16 Others have also noted that external rotator (ER) muscles extensibility possibly influences the PST measurement in both the supine and HAD positions.20

Another method to assess PST is by using the Sleeper stretch position. In this position the humerus is elevated to $90^\circ$ and internally rotated with patient in side lying.8,18,21 The strains on the posterior shoulder tissues in a position simulating Sleeper stretch were tested by Borstad and Dashottar using cadaver shoulders.22 They also included a modified version of the Sleeper’s stretch where the humerus was only elevated to $60^\circ$ (named “low flexion”) in order to avoid impinging the rotator cuff muscles during the measurement. Higher strains on the posterior capsule but not on the posterior muscles were reported in both of these positions suggesting that these positions may be better for assessing posterior capsule but may not be optimal for assessing the posterior muscles. In the same study, higher strains on the posterior muscles were reported in two measurements; 1) simulating HAD and, 2) simulating scapular plane humeral abduction to $60^\circ$ (SAB) with internal rotation. In a similar study, Muraki et al aimed to identify the most effective stretching position for rotator cuff muscles by comparing the strains on the posterior shoulder muscles across several GHJ positions.23 Their assumption was that positions that lead to higher strains on the muscles are better for stretching. They reported higher strains on the external humeral rotators in a position of humeral extension and internal rotation (EIR) but not in a position simulating horizontal adduction.23 A limitation of these studies is that strain, which is a valid outcome measure for assessing muscle length change cannot be easily quantified in the clinical setting. Therefore, it is important to assess a clinically quantifiable variable across these positions, such as ROM, before one position can be recommended.22

To study the GHJ ROM changes surgical alteration of the GHJ posterior capsule in a cadaveric model is commonly used. A benefit of using a cadaveric model is that it allows the researchers to alter the length and mechanical properties by plicating24,25 or thermally treating the capsule22,26 and observing the direct effects of capsular alteration on the GHJ ROM. Any such direct manipulation of muscle length or mechanical properties cannot be done on human subjects for testing the ROM changes, however, immediate ROM changes can be induced by acute bouts of repeated eccentric exercises.27 These acute ROM changes are attributed to muscle microstructural damage, edema accumulation,28 and increase in muscle passive tension and stiffness.29 The authors of the current study decided to use this known muscular response to acute eccentric exercise in order to induce ROM changes and compare the effect across four positions recommended for assessing and correcting PST.

In this study, muscle stiffness was used as a way to substantiate muscle fatigue after repeated exercises aimed at the external rotator muscles. Muscle stiffness is quantified by measuring the magnitude of resistance when muscle is compressed perpendicular to its length.30 A myotonometer (Neurogenic Technologies Inc., Missoula, MT, USA) was used to objectively quantify the muscle stiffness in this study. The purpose of this study was to compare the ROM changes before and after external humeral rotator muscle fatigue to identify a position with maximum ROM change. The hypothesis was that following external rotator fatigue,
the magnitude of ROM change will be greater in a measurement combining humeral extension and internal rotation (EIR) of all the measurements tested. This hypothesis was formulated on the basis of maximum strains reported in this position in previous studies.22,23

METHODS

Subjects
Twenty-seven participants (18 females and 9 males) between the ages of 18-40 years (Mean age 27 ± 4.3 years) without shoulder pain were recruited for this study. All but one was right hand dominant. Using G power software (Heinrich-Heine-Universität Düsseldorf), with the power set at 0.8 and α at 0.05, the sample size for a small effect size (0.25) was calculated to be 24. The Ohio State University Institutional Review Board approved this study. All volunteers were informed about the study procedures and provided informed consent to participate.

Procedure

Primary Study
The experiment began with baseline recordings for muscle stiffness and ROM. After these baseline measurements, external rotation force was measured using a hand held dynamometer and subjects were instructed to initiate the fatigue protocol. When the criterion for fatigue (40% reduction) was achieved (determined by external rotation force testing), the muscle stiffness and ROM measurements were repeated. Two examiners performed the measurements; examiner 1 oriented the shoulder joint for measurements and was blinded to GHJ ROM values. In addition, examiner 1 also measured external rotation force and muscle stiffness. Examiner 2 measured and recorded the GHJ ROM values and was blinded to the hypothesis of the study. All measurements were repeated 3 times and the means were used for statistical analysis.

Range of Motion Measurement
Repeated measures of GHJ ROM across four PST measurements were recorded before, immediately after, at 24 hours, and at 48 hours after a fatigue protocol of the non-dominant GHJ external rotators. The order of the PST measurements was randomized using a computer-generated sequence. All measurements were taken at the end of the passive ROM with no overpressure. The effect of gravity on

A goniometer (Baseline evaluation instruments, Fabrication Enterprises Inc. White Plains, NY, USA) was used to control the starting position for each measurement. For EIR, SAB and LF a digital inclinometer (Baseline evaluation instruments, Fabrication Enterprises Inc. White Plains, NY, USA) was aligned with the radial styloids. For HAD the inclinometer was placed on the posterior arm. All the angles were controlled by aligning the arm with a 360° goniometer fixed at 60° and kept in direct line of sight of examiner 1.

Muscle stiffness
Infraspinatus and teres minor muscle stiffness were measured using a myotonometer. The myotonometer is considered a reliable tool for measuring muscle stiffness and, has been used in the past to assess muscle stiffness.30-34 Briefly, the myotonometer measures muscle stiffness by quantifying the amount of tissue displacement as the probe is pushed down perpendicular to the muscle belly. The magnitude of tissue displacement is recorded at eight 0.25 N force increments up to a maximum force of 2 N. Subsequently, manufacturer provided software generates a force-displacement graph and calculates the area under the curve (AUC) of the graph expressed in N.mm.31 Less tissue displacement under the same force results in smaller AUC, indicating a harder tissue. To measure the muscle stiffness each subject was in a sitting position with arms at side. To ensure reproducibility, a standardized measurement location was marked on each subject (Table 2) and, examiner 1 did all the measurements. To verify repeatability of Myotonometer measurements, pre-fatigue muscle stiffness was measured twice in 15 participants. These repeated pre fatigue muscle stiffness measurements were done at an interval of approximately 20 minutes, based on the time it took for participants to finish the experimental protocol.

External rotation force
External rotation force was measured to objectively mark the end of the fatigue protocol. External rotation force was measured using a hand-held dynamometer (Lafayette instruments Co., IN, USA) with participants
Table 1. Tested measurements. All the measurements were performed passively and subjects were instructed to relax their shoulder and arm. Note: No overpressure was applied in scapular plane abduction and low flexion, rather, only gravity was allowed to pull the forearm to the end range. In extension with internal rotation and horizontal adduction tests, scapular movement marked the end of passive range.

<table>
<thead>
<tr>
<th>Position</th>
<th>Experimental Position and Procedure</th>
<th>Figure of the Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extension with internal rotation</td>
<td>In sitting, shoulder joint abducted to 60°* in the plane of scapula (POS) and then horizontally abducted 90° with the elbow maintained in 90° flexion; add GH internal rotation.</td>
<td></td>
</tr>
<tr>
<td>(EIR)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scapular Plane Abduction</td>
<td>In standing, shoulder joint abducted 60° in the POS with the neutral GH IR/ER rotation; add GH internal rotation.</td>
<td></td>
</tr>
<tr>
<td>(SAB)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Flexion</td>
<td>In standing, shoulder joint flexed to 60°; add internal rotation</td>
<td></td>
</tr>
<tr>
<td>(LF)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal adduction</td>
<td>In supine lying, shoulder joint flexed to 90°; adducted across the body. A wedge angled 30° was placed under the scapula to maintain the scapular plane</td>
<td></td>
</tr>
<tr>
<td>(HAD)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Goniometers fixed at 60° and 90° were used to orient the shoulder joint to the starting position of all the measurements.

Table 2. Placement of the Myotonometer, in all the measurements participants were sitting with the arms at the side, forearm pronated and palm resting on thighs.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Placement of the Myotonometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infraspinatus</td>
<td>2.5 cm inferior from the midpoint of the spine of scapula</td>
</tr>
<tr>
<td>Teres Minor</td>
<td>1/3rd of the way on a straight line between the posterior-lateral angle of acromion and the inferior angle of the scapula along its lateral border</td>
</tr>
</tbody>
</table>

positioned in side lying on their dominant side. The non-dominant arm was kept adducted and in neutral rotation with the elbow flexed to 90° while examiner 1 performed an internal rotation break test. The hand held dynamometer was placed on the posterior aspect of the forearm between the ulnar and radial styloids. The external rotation force was recorded prior to and immediately following the fatigue protocol. A force reduction of 40% from the pre-fatigue value was used to objectively define the end of fatigue protocol. A 25% force reduction has also been used to indicate fatigue; however, in pilot testing the authors' found...
that most participants retained the ability to lower the weight under control at 25% force reduction, but lost that ability when they reached about 40% force reduction. Therefore, 40% force reduction was used to define the end of the fatigue protocol.

Each participant performed the fatigue protocol in side lying by repeatedly raising and lowering the forearm from a position of maximum internal rotation while holding a dumbbell equivalent to approximately 5% of their body weight. Oral cues were given to participants to maintain proper form during the protocol. The concentric (external rotation) phase of the protocol was assisted when the participants were unable to externally rotate the arm actively. To emphasize the eccentric contraction, no assistance to the eccentric (internal rotation) phase was given and participants were instructed to lower the dumbbell under control. The movement was considered controlled if the lowering phase lasted at least 2 seconds. Inability to lower the dumbbell under control in two consecutive attempts was used to mark the subjective end of the fatigue protocol, after which external rotation force was immediately measured. If the objective force decrease did not meet the criteria participants resumed the fatigue protocol.

**Secondary Study**

Forearm Rest Angle: A secondary study was conducted to objectively assess the change in the ROM measured in EIR position without relying on the examiners subjective determination of end range passive motion. For this we measured the angle that the forearm makes with the vertical in the starting position of Extension with IR. Briefly, after abducting the arm to 60° in the plane of scapula, 90° of horizontal abduction was added with the elbow maintained in 90° flexion (Figure 1). These measurements were recorded in 20 participants before, immediately after the fatigue protocol, and at 24 and 48 hours post fatigue.

**STATISTICAL METHODS**

**Primary Study**

Range of Motion: The primary dependent variable in this study was GHJ ROM change across the 4 PST measurements. The intra-rater reliability estimates (Intraclass correlation coefficients (3,3) and standard error of measurement) for each ROM measurement at each time point were calculated. The GHJ ROM change for each measurement was calculated by subtracting the post fatigue, 24 hour, and 48 hour ROM from pre fatigue ROM, referred to as condition I (Pre-fatigue ROM – Post-fatigue ROM), condition II (Pre-fatigue ROM – 24 Hour ROM), and condition III (Pre-fatigue ROM- 48 Hour ROM) respectively. The change score was used because the authors were interested in identifying the measurement that shows maximum change in the ROM, and because it normalizes the GHJ ROM across subjects.

To examine the effect of measurement (4 levels) and condition (3 levels) on ROM change, a 2 factor repeated measures ANOVA was run. To assess assumptions of sphericity, Mauchly’s test result was run and evaluated. If assumptions were violated, Greenhouse–Geisser (G–G) and Huynh–Feldt (H–F) corrections were planned.
to determine statistical significance, which was set at p < 0.05. Because the aim was to identify a position that showed greater ROM change, a separate 1 factor (measurement position) repeated measure ANOVA was also planned for each condition.

Muscle Stiffness: The within day reliability of the muscle stiffness measurements was examined by calculating the intraclass correlation coefficient (ICC3,3) among the 2 baseline measures in the subset of 15 participants. The infraspinatus and teres minor muscle AUC over time (4) was analyzed using separate 1 factor repeated measure ANOVA. Tukey-Kramer post hoc comparisons were planned for significant main effects of time.

Secondary Study
Forearm Rest Angle: A separate 1 factor repeated measure ANOVA was run to examine the effects of time on forearm rest angle. Tukey-Kramer post hoc analyses were planned for significant main effects. All statistical analyses were performed using NCSS 2001 (Kaysville, Utah, USA) and the α level was set at 0.05.

RESULTS

Primary Study
Range of Motion: The within day intra-rater ICC's and standard error of measurement (SEM) for ROM measured in each position at each time point are presented in Table 3. In general the ICCs ranged from 0.92 to 0.98 and SEM were lowest for HAD (1.2°-1.7°) and highest for EIR (2.5°-4.4°). There was a mean reduction of 59% in isometric external rotation force immediately after the fatigue protocol.

Two-factor repeated measure ANOVA for ROM change indicated a statistically significant interaction effect between measurement and condition (F=2.47, p = 0.02). Separate one factor repeated measure ANOVA revealed that for condition I, extension with IR measurement showed statistically significant greater ROM change (19.9°) compared to LF (7.5°), SAB (6.8°) and HAD (0.5°). In addition, both LF and SAB ROM change were also statistically significant compared to HAD ROM change. In conditions II and III, extension with IR showed greater ROM change (12.9° and 12.3°) than LF (3.3° and 3.8°), SAB (1.9° and 2.5°) and HAD (-0.9° and 0.0°), respectively and was statistically significant (Figure 2).

Muscle Stiffness: Muscle stiffness was measured as the area under the curve (AUC) of the force displacement graph generated by the Myotonometer. The within day ICC’s (3,3) for the pre fatigue muscle stiffness were 0.95 and 0.97 for infraspinatus and teres minor respectively. One factor repeated measure ANOVA indicated a significant main effect of time for infraspinatus AUC (F = 10.5, p<0.001). Teres minor AUC did not reach statistical significance (F = 0.74, p=0.53) (Figure 4).

Secondary Study
Forearm Rest Angle: Separate 1 factor repeated measure ANOVA for forearm rest angle indicated a statistically significant main effect of time (F = 13.54, p < 0.001). Tukey-Kramer post hoc analysis indicated that the forearm rest angle immediately after fatigue was significantly greater than at 24 and 48 hours (Figure 3).

DISCUSSION
The results of this study demonstrated that the magnitude of ROM change quantified after an external rotator fatigue protocol differs among tested PST measurements. The hypothesis of this study was that maximum ROM changes after an external rotator fatigue protocol would be observed in a measurement combining humeral extension with internal rotation or in horizontal adduction. This hypothesis was generated based on the evidence from cadaver studies where maximum strains on the posterior muscles were observed in these positions.22,23 The results show that after external rotator fatigue maximum ROM reductions were observed in extension with IR but not in horizontal adduction. This finding is supported by a previous cadaveric study that quantified the strain on the infraspinatus muscle and reported that infraspinatus is maximally lengthened in extension with IR.23 The results of the present study taken together with past findings suggests that a position of extension with internal rotation could be useful in assessing the IR ROM loss that might be due to infraspinatus tightness.

Horizontal adduction is often used to assess PST however; in this study HAD ROM after fatigue was not significantly changed. This finding is also supported by previous studies where no significant infraspi-
Table 3. *Intra-rater reliability estimates for range of motion measured across the four measurements at each time point. ICC’s were calculated from the repeated measures of ROM that were done consecutively on each subject by the same examiner.*

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Time</th>
<th>ICC</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extension with IR</td>
<td>Pre-Fatigue</td>
<td>0.98</td>
<td>2.5°</td>
</tr>
<tr>
<td></td>
<td>Post Fatigue</td>
<td>0.93</td>
<td>4.4°</td>
</tr>
<tr>
<td></td>
<td>24 Hours</td>
<td>0.98</td>
<td>2.5°</td>
</tr>
<tr>
<td></td>
<td>48 Hours</td>
<td>0.98</td>
<td>2.5°</td>
</tr>
<tr>
<td>SAB</td>
<td>Pre-Fatigue</td>
<td>0.95</td>
<td>2.4°</td>
</tr>
<tr>
<td></td>
<td>Post Fatigue</td>
<td>0.96</td>
<td>2.2°</td>
</tr>
<tr>
<td></td>
<td>24 Hours</td>
<td>0.92</td>
<td>2.6°</td>
</tr>
<tr>
<td></td>
<td>48 Hours</td>
<td>0.95</td>
<td>2.3°</td>
</tr>
<tr>
<td>HAD</td>
<td>Pre-Fatigue</td>
<td>0.97</td>
<td>1.7°</td>
</tr>
<tr>
<td></td>
<td>Post Fatigue</td>
<td>0.95</td>
<td>1.6°</td>
</tr>
<tr>
<td></td>
<td>24 Hours</td>
<td>0.94</td>
<td>1.6°</td>
</tr>
<tr>
<td></td>
<td>48 Hours</td>
<td>0.96</td>
<td>1.2°</td>
</tr>
<tr>
<td>LF</td>
<td>Pre-Fatigue</td>
<td>0.95</td>
<td>2.1°</td>
</tr>
<tr>
<td></td>
<td>Post Fatigue</td>
<td>0.93</td>
<td>2.3°</td>
</tr>
<tr>
<td></td>
<td>24 Hours</td>
<td>0.96</td>
<td>2.2°</td>
</tr>
<tr>
<td></td>
<td>48 Hours</td>
<td>0.95</td>
<td>2.3°</td>
</tr>
</tbody>
</table>

ICC=Intraclass correlation coefficient; SEM= Standard error of measurement; SAB= Scapular plane abduction to 60°, with internal rotation; HAD= Horizontal adduction; LF= Low flexion, with internal rotation.

Natus strain increases were reported in horizontal adduction. A possible reason for this may be that the motion of the humeral head occurring in horizontal adduction may be limited by posterior deltoid, latissimus dorsi, teres minor, and infraspinatus. In this study the fatigue protocol was aimed at the external rotator muscles however, the muscle stiffness of teres minor was not significantly increased following the fatigue protocol. Posterior deltoid muscle stiffness was not measured in this study. It is possible that the ROM measured in HAD is influenced by teres minor and posterior deltoid and to a lesser degree by infraspinatus. Another explanation for no significant changes in horizontal adduction may be that ROM in this position is influenced by posterior capsule. Harryman et al in a cadaveric study reported increased anterior and superior humeral translations in horizontal adduction after experimental posterior capsular tightening. The increase in antero-superior humeral translation may result in limitation of humeral motion by bony approximation before the infraspinatus is fully lengthened.

In the present study ROM loss was also significant in LF and SAB measurements however the magnitude of the measured differences was much smaller. Because a greater observable change in a measurement may be easier to detect in a clinical setting, the use of extension with IR may be preferable to LF and SAB. The ROM change in supine internal rotation with humerus abducted to 90° was not measured. This decision was made because it has been reported that the IR ROM measured in this position is greatly affected by humeral torsion. The aim of the current study was only to compare the ROM changes that occurred due to muscle fatigue and future studies should explore the influence of humeral torsion on ROM measured in extension with internal rotation position.
An external rotator fatigue protocol was used to induce immediate ROM changes.\textsuperscript{36} These changes have been attributed to microstructural damage resulting in edema, increased muscle passive tension and, muscle stiffness.\textsuperscript{29,39,40} Although the protocol consisted of both concentric and eccentric components, the researchers emphasized the eccentric component by not giving any assistance during the eccentric phase of the protocol. Microstructural damage to the muscle following the protocol was not directly measured however, reduction in the isometric force is considered an indicator of muscle damage.\textsuperscript{41} A mean reduction of 59\% in the isometric external rotation force following the protocol suggests that the fatigue protocol used successfully affected the muscle condition.

Muscle stiffness of infraspinatus and teres minor were analyzed using two separate 1 factor repeated measure ANOVAs. They were analyzed separately because descriptive analysis showed different pre fatigue infraspinatus (AUC 13.2 ± 2 N.mm) and teres minor (AUC 21.2 ± 3.8 N.mm) measures of muscle stiffness (Figure 2). Because the magnitude of muscle stiffness difference between infraspinatus and teres minor was greater than the magnitude of muscle stiffness change over time, including muscle as a factor in ANOVA model would have reduced the power of the test to detect an interaction between muscle stiffness and time. Before the initiation of the fatigue protocol muscle stiffness was measured twice to assess the within day reliability of the hardness measurement. High ICC’s (0.95 & 0.97) among the repeated baseline hardness measurements and a significant change in muscle stiffness after the fatigue protocol suggests that in the present study Myotonometer was able to detect muscle stiffness changes.

There was no objective measure of the force applied by the examiner during extension with IR measurement, which may have introduced examiner bias. To
address the lack of objective measure of the examiner force, a secondary study was conducted. In the secondary study the forearm rest angle rest in the starting position of extension with IR (Figure 1) was measured. Because this measurement excludes examiner force while keeping other conditions the same, the potential for examiner bias is minimized. There was a statistically significant change in the forearm rest angle immediately after the fatigue protocol, corroborating the results of the primary study where maximum ROM change was observed in the EIR position. Although a statistical relationship among the infraspinatus muscle stiffness measurements and forearm rest angle was not explored, it is worth noting that forearm rest angle change coincided with infraspinatus muscle stiffness over time (Figure 3) similar to changes noted in previous studies. The variation of the forearm rest angle with infraspinatus muscle stiffness change suggests that the results of the primary study that ROM measured in EIR were not influenced by the external force applied by the examiner.

The posterior capsule of the GHJ may also affect the ROM in the positions tested in this study however, it is safe to assume that the GHJ posterior capsule did not influence the ROM changes observed. First, if the exercise protocol used in this study did alter the capsule, one would expect increased, not decreased ROM because repeated internal and external rotations are used to precondition the capsule to gain maximum GHJ ROM. Second, the participants were not overhead athletes, a population known to have GHJ posterior capsular adaptations in response to long duration of repeated overloading. Third, any permanent structural or mechanical changes in the capsule would take longer than 48 hour to develop.

The results of the present study should be interpreted in the light of several limitations. First, the electromyographic (EMG) activity of the muscles during the ROM measurement was not recorded. This was done to simulate the ROM measurements, as they will be done in clinics where monitoring EMG activity during the examination is not the norm. Although subject relaxation during the measurements was not quantified, the examiner used his 20 years of musculoskeletal clinical experience to subjectively determine when relaxation was achieved, which parallels standard clinical measurement procedures. Muscle stiffness measured using the Myotonometer may be influenced by subcutaneous tissue thickness. However, use of a within-subject design means that any effect of subcutaneous tissue on muscle stiffness measurements is consistent for each subject. Third, because participants were young adults without shoulder pain, and had no history of participation in overhead throwing activities, the results of the study should not be generalized to elderly or adolescent individuals, to those with shoulder pain, or to overhead athletes who could have increased humeral torsion or altered scapular position that may influence the PST measurements.

CONCLUSION

The ROM changes that were measured across the four tested PST measurements varied after an external rotation fatigue protocol. Maximum ROM change was measured in a measurement combining GHJ extension and internal rotation. The results of this study might help clinicians to evaluate ROM loss due to infraspinatus muscle tightness. However, before the clinical use of extension with internal rotation can be recommended, further evaluation of this measurement in different populations with known humeral torsion and scapular position changes is necessary.

REFERENCES


ABSTRACT

Context: Current literature indicates a correlation between decreased total shoulder range of motion (ROM) and internal rotation (IR) of the dominant arm and increased injury risk in throwers. The optimal method for increasing shoulder ROM, improving performance, and preventing injury is unknown. It is also unknown if treating the non-dominant arm may affect ROM on the dominant side.

Purpose: To explore the effect of the Total Motion Release (TMR®) Trunk Twist (TT) and Arm Raise (AR) on IR and external rotation (ER) of the dominant shoulder in baseball players compared to a traditional dynamic warm-up.

Design: Cohort study.

Setting: University athletic training clinic and baseball field.

Participants: Pitchers (males, n = 10; age, 18.6 ± 1.3) recruited from local baseball teams were randomly assigned to one of two groups: TMR® treatment group (TMRG; n = 5) or traditional warm-up group (TWG; n = 5).

Interventions: Baseline IR and ER goniometry range of motion (ROM) measurements were recorded. The TMRG then completed the TMR® exercises and post-intervention measurements. The TWG completed a traditional static and dynamic warm-up (e.g., lunges, power skips, sprints, sleeper stretch) and then completed post-intervention measurements. Following the completion of those measurements, the TWG completed the TMR® Trunk Twist and Arm Raise protocol and had post-intervention measurements recorded once more.

Main Outcome Measures: ROM measures for IR and ER of the dominant shoulder. Alpha level was set at p ≤ 0.05.

Results: Significant differences were present for IR (p = 0.025) and ER (p = 0.014) between the TMRG and the TWG after initial intervention. Significant differences for IR were present in the TWG between baseline and TMR® intervention and traditional warm-up and TMR® intervention. For the TWG, changes in ER were not statistically significant at baseline, post-warm-up, or post-TMR® intervention. Significant differences were not present for IR (p = 0.44) or ER (p = 0.23) between groups once TMR® had been completed by both groups.

Conclusions: TMR® produced larger increases in IR and ER of the throwing shoulder when compared to the TWG. Generalizability is limited, however, by the low number of participants in each group and a potential ceiling effect of attainable ROM gains. Future studies should examine if using a full TMR® treatment process is more beneficial. Additionally, future research should compare TMR® intervention to other warm-up activities or stretching protocols (e.g., resistance tubing, weighted balls) and examine its effect across other variables (e.g., injury rates, throwing velocity).

Key Words: Baseball, Pitcher, Position Player, Total Motion Release®, Warm-Up

Level of Evidence: Clinical Evidence Based Level 2b
INTRODUCTION

Total Motion Release (TMR®) is an innovative paradigm used to evaluate and treat body motion imbalances that is related to the concept that the body is a unified system striving to maintain a dynamic center of gravity.1 Therefore, pain or dysfunction in one area of the body may be affected by movements that take place elsewhere. Patients use a 1 (i.e., no dysfunction, pain, or asymmetry) to 100 (i.e., complete dysfunction, pain, or asymmetry) scale to describe the imbalances across different measures (e.g., pain, strength, quality/quantity of motion) to generate their score for each of the prescribed motions in the TMR® screening. In standard TMR® treatment, six motions (i.e., arm raise [shoulder flexion], bent arm wall push [single arm push-up], trunk twist [rotation], single-leg sit-to-stand, leg raise [hip flexion], and weight-bearing toe-reach [unilateral bent knee squat]) are compared bilaterally and the motion with the greatest imbalance is treated first, providing that both sides are not perceived as dysfunctional. Total Motion Release® treatment includes repetitions, static holds, or some combination thereof and should be performed to the good side, (i.e., the side of ease) which is a departure from traditional therapies.1 In standard TMR®, the data (i.e., progress) is evaluated every two sets of exercises. Based on the results of the treatment, the clinician decides to continue with that motion, modify the motion, or move to the next area of imbalance. Treatment then progresses to the second highest imbalance score and continues until the six main motions are balanced. A general recommendation is to resolve one upper body, trunk, and lower body imbalance each treatment to maximize treatment effect and retention of gains.1

Baseball players strive to position their bodies in optimal alignment in order to accelerate and decelerate the throwing arm at high velocities during execution of the throwing motion.2 Baseball players require the coordination of large forces from the lower to the upper extremities in order to generate extreme linear and angular velocities at ball release.3 The repetitive throwing motion has the potential to cause increased mechanical stress to the arm due to torque and distraction forces.4,5 The glenohumeral and elbow joints are subjected to these stresses over multiple innings, games, and seasons during the span of a player’s career.6,7 Commonly, baseball players have been noted to possess decreased trunk rotation, shoulder internal rotation (IR) of the throwing arm, external rotation (ER) of the dominant hip, and IR of the non-dominant hip.2,8 Internal rotation of the non-dominant hip may play a role in deceleration of the body during the throwing motion. Thus it may be plausible that decreased IR of the non-dominant hip may transfer some of the demands of deceleration to the shoulder, resulting in less force dissipation through the trunk, thereby increasing forces at the shoulder.8 The presence of range of motion (ROM) deficits and movement compensation may alter arm slot, proper shoulder-hip separation, and rhythmic timing, all of which may contribute to increased risk of injury.9,10 Normal shoulder ROM within the general population include ER ranges from 90-100° and IR ranges from 80-90°, however, baseball players may present with a shoulder ER in excess of 110° and shoulder IR as low as 50-60°.11,12 Glenohumeral Internal Rotational Deficit (GIRD) is a loss in internal shoulder rotation compared to the opposite side and is usually identified when there is a loss of 10% of the total rotational motion of the opposite shoulder or a 25° difference between shoulders.10,13,14 Loss of IR in the shoulder of a baseball player has been attributed to a number of potential factors including a posterior inferior capsular contracture, tightness of the external rotators, and osseous adaptations of glenoid and humerus.15,16,17

While the underlying cause of GIRD may be debated, it is generally accepted that its presence is a predisposition for injury. Specifically, an IR deficit of greater than 25° has been described as having the potential to increase the risk for injury.10,15 Wilk et al.20 demonstrated pitchers with GIRD were nearly twice as likely to be injured and pitchers with total rotational motion deficit greater than 5° had a higher rate of injury compared to those without such deficit. The researchers concluded that, compared with pitchers without GIRD, pitchers with GIRD appear to be at a higher risk for injury and shoulder surgery. Myashita et al.21 also demonstrated that a significant increase in the ratio between ER and maximum shoulder external rotation (MER) is a risk factor for elbow injuries in baseball pitchers.

Another component that may need to be considered is that the deceleration phase of the throwing motion
is initiated by IR of the non-dominant hip. Thus, it is plausible that a lack of IR in the non-dominant hip has the potential to produce the undesirable effect of transferring deceleration demands up the kinetic chain to the shoulder. As a result of decreased force dissipation through the trunk, the athlete may experience increased forces at the shoulder. In turn, the athlete with limited non-dominant hip IR may be at an increased risk for shoulder injury. McCulloch, Patel, Ramkumar, Noble and Lintner demonstrated that pitchers possessed excessive IR on the stance (i.e., dominant) hip and excessive ER on the stride (i.e., non-dominant) hip. As a compensation for inappropriate hip and trunk rotation, the patient may develop increased ER of the dominant shoulder; excessive ER may increase soft tissue forces and predispose the pitcher to shoulder injury.

Baseball specific warm-ups vary in design and selection of exercises based on level of competition, setting, and coaching/medical staff. Common warm-ups may include a progressive run, lunge with rotation and reach variations, explosive skips, shuffles, sprints, and stretching in attempt to prepare the entire body for throwing and injury prevention. Variation exists, however, as some warm-up strategies include light jogging, light throwing, and stretching and others require longer distance jogging (i.e. 5 minutes), joint specific mobility exercise, and dynamic flexibility. Typically, these program take 15 to 20 minutes to complete, with the stated goal of increasing core temperature, decreasing fluid viscosity and increasing hip and trunk mobility. In short, general warm-up baseball protocols tend to vary by team and sports medicine staff without established evidence for effectiveness.

The purpose of this study was to compare the acute effects of a standard baseball warm-up protocol to the implementation of the Total Motion Release (TMR®) Trunk Twist and Arm Raise protocol on internal and external ROM in the dominant arm of baseball players.

METHODS AND PROCEDURES

A pretest-posttest randomized cohort design was utilized, with the sample consisting of male high school and collegiate baseball athletes (males; n=10; age=18.6 ± 1.3 years, age range=16 to 20 years; experience=9 collegiate and 1 high school players; right handed=8, left handed=2). All participants had at least five years of previous baseball experience and were not receiving treatment for a recent upper extremity injury (i.e., within that last 12 months). The study was conducted during the season, in a single session for each group, and was completed prior to baseball/warm-up activities for the day. All participants provided written informed consent/assent and the study was approved by the Institutional Review Board.

Participants were randomly assigned to either a traditional warm-up group (TWG) or the TMR® group (TMRG), with five participants in each group.

PROCEDURES

Baseline IR and ER goniometry ROM measurements were recorded for participants in both groups prior to intervention. Goniometric assessment of shoulder IR and ER was conducted with the participants lying on the exam table, with their shoulder abducted to 90° and their elbow flexed to 90°. The landmarks used for assessment were the olecranon process (fulcrum), long axis of the ulna (movement arm), and the perpendicular axis to the floor (stationary arm). Initial baseline measurements were recorded by a Certified Strength and Conditioning Specialist (CSCS) with a four years of professional experience in collegiate and professional baseball and were validated by an Athletic Trainer with five years of professional experience.

Following baseline measurements, the TMRG completed 3 sets of a 30 second standing Trunk Twist (TT) to their reported “good” side, with a 60 second rest period between each set (Figure 1). Coaching cues were given throughout each set, instructing the athlete to take a deep inhalation followed by deep exhalation when a new barrier was reached and to “unlock” the body segment that the participant perceived to be limiting motion (e.g., flex right knee if twisting to the left shoulder). Following TTs, each participant completed 2 sets of 30 second standing Arm Raise (AR) to the “good” side, with a 60 second rest between each set (Figure 2). Similar instructional cues were used when performing the Arm Raise, but the focus was on the patient reaching further into shoulder flexion. The entire TMR® TT and AR protocol took 8 to 10 minutes to complete depending on
the time needed to explain the TMR® procedure to the participant. After both TMR® movements were completed, post-intervention ROM measurements were recorded for comparison to baseline, in the same manner they were initially recorded.

After baseline measurements were recorded, the TWG participated in a traditional 15-minute dynamic warm-up (Table 1). As there is significant variation in baseball warm-up activities, the researchers utilized this warm-up protocol because it was already being used by the participants to prepare for baseball activities and allowed for the participants to maintain consistency and regularity in sport activity. Once finished, the participants immediately had post-intervention ROM measurements recorded for a baseline comparison, in the same manner they were initially recorded. Upon completing the post-warm-up measurements, the TWG then completed the TMR® protocol (i.e., TT and AR exercises, Figures 1 and 2). After performing both activities, the ROM measurements were recorded once again for the TWG group for comparison to baseline and post-exercise measures. The null hypothesis was the TMR® protocol would produce superior outcomes compared to the traditional warm-up protocol. Based on this and the small sample size of the cohort, the decision was made a priori to perform the TMR® protocol on the TWG to ensure the results did not occur due to the participant groups being different after randomization.

STATISTICAL METHODS
An independent sample t-test was used to calculate the difference between groups from baseline. A repeated measures ANOVA was performed to analyze the difference in the TWG group from baseline to post-warm-up to post-TMR®. An independent sample t-test was used to analyze the difference between group means for the TMRG and the TWG following the completion of the TMR® protocol in both groups.

RESULTS
The TMRG and TWG did not demonstrate differences in age ($18.8\pm 1.79$ vs. $18.4\pm 0.55$ yr, $p=0.65$), IR ($66^\circ \pm 12.06^\circ$ vs. $78.8^\circ \pm 12.15^\circ$, $p=0.13$), or ER ($82.4^\circ \pm 11.33^\circ$ vs. $83.6^\circ \pm 12.22^\circ$, $p=0.87$) at baseline. An independent sample t-test was used to analyze the difference between group means for the TMRG and the TWG following the initial warm-up interventions. Significant differences were present for both internal and external shoulder rotation between the groups ($p<.05$). The use of TMR® produced larger

<table>
<thead>
<tr>
<th>Table 1. Traditional Warm-up Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm-up Exercise</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Walking Knee Hug</td>
</tr>
<tr>
<td>Forward Lunge w/ Rotation</td>
</tr>
<tr>
<td>Reverse Lunge w/ Rotation</td>
</tr>
<tr>
<td>Quad Stretch w/ Reach</td>
</tr>
<tr>
<td>Power Skips</td>
</tr>
<tr>
<td>Lateral Lunges</td>
</tr>
<tr>
<td>Sprint (50%)</td>
</tr>
<tr>
<td>Sprint (75%)</td>
</tr>
<tr>
<td>Sprint (100%)</td>
</tr>
<tr>
<td>Supine Sleeper Stretch*</td>
</tr>
</tbody>
</table>

*Supine Sleeper Stretch with arm at 90° horizontal abduction
**Each set of the Sleeper Stretch was separated with a 60 second rest period**
increases in mean IR (19.2° ± 10.78° vs. 2.2° ± 8.73°, \(p = 0.03\)) and mean ER (13.6° ± 5.98° vs. -1.8° ± 9.20°, \(p = 0.01\)) of the throwing shoulder, irrespective of whether TMR\(^\circ\) was applied to the dominant shoulder (Table 2, Figures 3 and 4). Of note, 60% of the participants in the TMR\(^\circ\) group did not perform the AR pattern to their dominant side, but still experienced the improvement in IR and ER on the dominant side.

A repeated measures ANOVA was used to analyze the difference across time to determine the effect of the traditional warm-up versus the TMR\(^\circ\) warm-up on ROM for the TWG (Table 3 and 4; Figure 5). A significant main effect for time was identified (\(F_{2,8} = 32.8, \ p \leq 0.00, \eta^2 = .891\)) for IR. For the 5 participants in the TWG, the mean IR at baseline (M=78.8°, SD=5.43°) and post-warm-up (M=81°, SD=3.86°) were not statistically significantly different (Table 3). The differences between mean IR at baseline (M=78.8°, SD=5.43°) to post-TMR\(^\circ\) (M=103°, SD=2.36°) and post-warm-up (M=81°, SD=3.86°) to post- TMR\(^\circ\) (M=103°, SD=2.36°) were statistically significantly different (Table 3). A significant main effect for

### Table 2. Group Means Data: Change in IR and ER of the Dominant Shoulder

<table>
<thead>
<tr>
<th>Shoulder ROM</th>
<th>TMRG</th>
<th>TWG</th>
<th>(p) -Value</th>
<th>Cohen’s D</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in IR</td>
<td>19.2° ± 10.78°</td>
<td>2.2° ± 8.73°</td>
<td>0.025</td>
<td>1.73</td>
<td>2.69, 31.30</td>
</tr>
<tr>
<td>Change in ER</td>
<td>13.6° ± 5.98°</td>
<td>-1.8° ± 9.20°</td>
<td>0.014</td>
<td>1.98</td>
<td>4.10, 26.70</td>
</tr>
</tbody>
</table>

Values presented are mean ± SD.

TMRG= Total Motion Release Group; TWG= Traditional Warm-Up Group.

### Figure 3. Pre and Post Intervention Mean IR ROM of the Dominant Shoulder ± SEM for TMRG and TWG.

### Figure 4. Pre and Post Intervention Mean ER ROM of the Dominant Shoulder ± SEM for TMRG and TWG.

### Table 3. Change in IR of the Dominant Shoulder in the TWG over Time

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean Difference</th>
<th>(p) -Value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline to Post-Warm-up</td>
<td>2.20° ± 3.90°</td>
<td>1.00</td>
<td>-13.26, 17.66</td>
</tr>
<tr>
<td>Post-Warm-up to Post-TMR</td>
<td>22.00° ± 1.58°*</td>
<td>0.00</td>
<td>15.74, 28.26</td>
</tr>
<tr>
<td>Baseline to Post-TMR</td>
<td>24.20° ± 3.88°*</td>
<td>0.01</td>
<td>8.84, 39.56</td>
</tr>
</tbody>
</table>

Values presented are mean ± SD. * denotes statistically significant difference.

TMRG= Total Motion Release Group; TWG= Traditional Warm-Up Group.
Table 4. Change in ER of the Dominant Shoulder in the TWG over Time

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean Difference</th>
<th>( p )-Value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline to Post-Warm-up</td>
<td>-1.80° ± 4.12°</td>
<td>1.00</td>
<td>-14.50, 18.10</td>
</tr>
<tr>
<td>Post-Warm-up to Post-TMR</td>
<td>10.80° ± 4.93°*</td>
<td>.028</td>
<td>-8.74, 30.64</td>
</tr>
<tr>
<td>Baseline to Post-TMR</td>
<td>9.00° ± 2.30°</td>
<td>.052</td>
<td>-0.12, 18.12</td>
</tr>
</tbody>
</table>

Values presented are mean ± SD. * denotes statistically significant difference.

TMRG= Total Motion Release Group; TWG= Traditional Warm-Up Group.

Figure 5. Baseline, Post-Warm-up, and Post-TMR Mean Internal and External Rotation of the Dominant Shoulder ± SEM for the TWG.

An independent sample t-test was used to analyze the difference between group means in IR and ER of the dominant shoulder for the TMRG and the TWG following the completion of the TMR\(^\circ\) protocol in both groups. Significant differences were not present for either internal (19.2° ± 10.78° vs. 24.2° ± 8.67°, \( p = 0.44 \)) or external shoulder (13.6° ± 5.98° vs. 9.0° ± 5.14°, \( p = 0.23 \)) rotation between the groups following the completion of the TMR\(^\circ\) protocol. The use of TMR\(^\circ\) produced essentially equal increases in IR and ER of the throwing shoulder, irrespective of whether the TMR\(^\circ\) protocol was applied to the dominant shoulder, applied in isolation, or applied after the warm-up between groups (Table 5, Figures 6 and 7). Additionally, the use of TMR\(^\circ\) corrected and improved any loss of ROM experienced following the use of the traditional warm-up protocol.

DISCUSSION

In this study, a significant increase in ROM in bilateral shoulder internal and external rotation occurred in the TMRG compared to the TWG was observed. Additionally, ROM deficits (i.e., decreased ER) recorded following the traditional warm-up were improved upon with the addition of the TMR\(^\circ\) protocol. Another interesting outcome is that the TMR\(^\circ\) warm-up took over 5 minutes less time to complete than the traditional warm-up and was often performed on the non-dominant

Table 5. Group Means Data. Change in IR and ER of the Dominant Shoulder for Complete Intervention

<table>
<thead>
<tr>
<th>Shoulder ROM</th>
<th>TMRG</th>
<th>TWG</th>
<th>( p )-Value</th>
<th>Cohen’s D</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in IR</td>
<td>19.2° ± 10.78°</td>
<td>24.2° ± 8.67°</td>
<td>0.44</td>
<td>-0.51</td>
<td>-19.27, 9.27</td>
</tr>
<tr>
<td>Change in ER</td>
<td>13.6° ± 5.98°</td>
<td>9.0° ± 5.14°</td>
<td>0.23</td>
<td>0.82</td>
<td>-3.51, 12.71</td>
</tr>
</tbody>
</table>

Values presented are mean ± SD.

TMRG= Total Motion Release Group; TWG= Traditional Warm-Up Group.
The AR pattern was performed on non-dominant arm in 60% of the TMRG participants and 40% of the TWG participants. The use of the TMR® protocol to produce significantly greater ROM improvement in less time, without clinician assistance, and while treating the non-dominant side provides potentially meaningful clinical and practical implications for intervention strategies aimed at improving IR and ER of the dominant arm in baseball players. Also, unlike the results found in the TWG after utilizing the traditional warm-up program, the use of TMR® (which is performed to the good side) did not appear to create further ROM discrepancies, but rather improved total ROM and the ratio between IR and ER of the shoulder. Irrespective of the order, both groups experienced similar results after completing the TMR® protocol. Clinically, this is significant because a short intervention, applied to the "good" side, can produce a large ROM increase in the dominant shoulder and resulted in improvements to both IR and ER; however, the long-term effects and impact on performance of this TMR® protocol are unknown.

Laudner, Sipes, and Wilson26 examined the acute effects of the clinician-assisted sleeper stretch and found performing 3 sets of a 30-second stretch resulted in 3.1° and 2.3° improvement in IR ROM and horizontal adduction ROM of the shoulder, respectively. Oyama, Goerger C, Goerger B, Lephart and Meyers27 utilized a passive stretch protocol that consisted of a horizontal cross-arm stretch, a standing sleeper stretch with the arm at 90° of abduction, and a standing sleeper stretch with the arm at 45° abduction. All of the stretches were performed for 3 sets with a 30-second hold that resulted in a mean improvement of 4.3° in internal shoulder rotation. Sauers, August, and Snyder28 produced a statistically significant change in ER (average gain of 7.6°) and IR (average gain of 9.2°) using the Fauls modified stretching routine to produce acute increases in shoulder complex ROM. Moore, Laudner, McLoda, and Shafer29 used a single application of Muscle Energy Technique (MET) that consisted of a 5-second isometric contraction at 25% maximal against examiner provided force, followed by the examiner applying a 30-second active assisted stretch for a total of 3 repetitions to improve shoulder IR ROM. Participants gained an average of 4.2° following the intervention.28

In the current study, the TWG experienced ROM changes similar to previously published research examining traditional techniques to improve acute ROM after the initial warm-up protocol.27,28,29 The TMRG, in contrast, experienced changes that were largely superior for increasing IR and ER ROM of the shoulder. Additionally, the TWG experienced larger increases in ROM following TMR® treatment; however, the ER changes were not statistically significant. The lack of a statistically significant change may be due to the small sample size or the potential ceiling effect in ER as this population is known to have increased ER when compared to the general population.30 Following the completion of the TMR® protocol, both groups experienced similar gains which provides support for TMR® warm-up (protocol) being an effective intervention at addressing ROM.
deficiencies in this group of participants. Although not a purpose of this study, participants also reported feelings of increased ease during throwing and anecdotal reports of increased velocity following TMR® interventions. These anecdotal reports warrant further investigation in future research studies.

LIMITATIONS AND FUTURE RESEARCH
As with all studies, limitations were present. The small sample size presents the risk of an unintentional sampling bias and increases the risk of Type II error. The small standard deviations and strong effect sizes (e.g., Cohen’s D), however, provide a level of confidence that the results are true for our sample, are the result of the intervention applied, and are likely to continue to be found if a larger sample had been studied. Additionally, the lack a position-specific warm-up protocol may limit the generalizability to all baseball players or warm-up protocols. Future studies that examine if using a full TMR® treatment process is more beneficial and if TMR® treatment is region specific (e.g., using the TT primarily increases shoulder ROM versus hip ROM) are needed. Additionally, future research should compare TMR® intervention to other warm-up activities or stretching protocols that include more position and activity specific movements (e.g., resistance bands) in the general baseball population. The results, however, are encouraging, with potentially the most interesting results being the increases in both IR and ER, since most previous interventions have documented an indirect correlation between IR and ER changes with some eliciting no change. Currently, it is not known how this simultaneous increase affects throwing velocity, injury rates overtime, and the retention of ROM increases. Future study of TMR® should assess its effect across multiple variables (e.g., ROM increase retention, injury rates, throwing velocity).

CONCLUSION
In this study, Total Motion Release® appeared to be an effective, hands-free intervention for improving dominant shoulder ROM in the overhead throwing athlete when compared to a traditional warm-up protocol. The simplicity of the two Total Motion Release® movements utilized during this study made it easy for the participants to identify the “good” side during the TT and AR motions. The TMR® interventions do not require large amounts of space, can be performed anywhere, are not dependent upon another individual to perform the therapy (apply a stretch), and often require less time than traditional warm-up/stretching protocols. While the participants experienced statistically significant changes for IR and ER ROM that far exceeded the published expectations for improving shoulder ROM after utilizing TMR®, further research is needed to determine the duration of effect of a TMR® warm-up such as was utilized in this research.

REFERENCES


ABSTRACT

Purpose/Background: The Upper Quarter Y Balance Test (YBT-UQ) was developed as a way to identify upper extremity and trunk mobility in the open kinetic chain in the reaching limb as well as midrange limitations and asymmetries of upper extremity and core stability in the closed kinetic chain on the stabilizing limb. Performance on the YBT-UQ is similar between genders and between limbs; however, this has not been examined in athletes who participate in sports that result in upper extremity asymmetries. The primary purpose of this study is to determine if differences exist between the throwing vs. non-throwing sides in high-school baseball and softball athletes on the YBT-UQ.

Methods: In order to complete this forty-eight male high school baseball players and seventeen female high school softball players were tested on the YBT-UQ. Reach distances were normalized to arm length (% AL). Comparisons were made between the throwing (T) and non-throwing (NT) arm for each direction as well as the composite score.

Results: No significant differences were observed between the T and NT arm for the medial (NT: 98.4 ± 8.6 %AL, T: 99.1 ± 8.6 %AL, p = 0.42), inferolateral (NT: 90.8 ± 11.8 %AL, T: 90.3 ± 11.5 %AL, p = 0.61), superolateral (NT: 70.6 ± 10.9 %AL, T: 70.4 ± 11.1 %AL, p = 0.91) reaches, or the composite score (NT: 87.2 ± 8.9 %AL, T: 86.6 ± 8.1 %AL, p = 0.72). Similarly, no differences were observed between the male baseball and female softball players (p = 0.30-0.90).

Conclusions: Based on these findings, it was concluded that there was no difference in performance on the YBT-UQ between throwing and non-throwing limbs in high school baseball and softball players.

Level of Evidence: 3

Key Words: Functional testing, movement, screening, stabilization
INTRODUCTION
Shoulder injuries have been estimated to occur at a rate of 2.27 per 10000 to athlete exposures across high school sports. High school baseball and softball athletes exhibited some of the highest injury rates (4.5 per 10000 athlete exposures) with the majority of these injuries being overuse in nature. In high school baseball players, the throwing shoulder is the most common site of injury with a rate of 17%. Pitching accounts for 13% of the injuries in this group. These injuries have been associated with elevated pitch counts and limited range of motion in the shoulder complex. During the rehabilitation of these injuries it is suggested that the injured tissues are progressively loaded while integrating in local joint specific rehabilitation components with body region movements, core stabilizing exercises/activities, and eventually, functional patterns. The role of anatomical variation of the humerus on normal arthrokinematic changes and its relationship to shoulder biomechanics has been extensively reported upon in the literature, however there is less reported on basic closed kinetic chain tests of the upper extremity that may have relevance in progressing a patient during rehabilitation who participates in throwing sports.

There are currently few tests that assess closed chain upper quarter function, as opposed to sports specific tests, and only one prior study has examined throwing athletes. The primary non-sport specific tests of basic closed chain upper extremity function are the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST), the One-arm Hop Test, and the Upper Quarter Y Balance test (YBT-UQ). The CKCUEST scores how often an individual can tap the floor past the contralateral hand while maintaining an upright pushup position with their feet and stabilizing hand in contact with the ground while keeping their hands 36 inches apart. In comparison, the One-arm Hop test measures a more powerful movement by recording how long it takes an individual to hop with their hand onto a 10.2 cm step 5 times from a 3-point plank position (contralateral hand placed behind back). Finally, the YBT-UQ examines how far an individual can reach with one hand in the medial, inferolateral and superolateral directions while maintaining a 3-point plank position on the opposite hand. Isolating unilateral closed chain function may be beneficial in identifying unilateral upper quarter performance limitations in order to optimize intervention strategies during rehabilitation of athletes who participate in movement activities where left and right upper extremities serve different roles. Based on expected performance requirements alone, it is likely that a continuum of testing exists that would suggest examining basic stability with the CKCUEST prior to testing a relatively low speed closed kinetic chain task (YBT-UQ) before finally examining a more powerful closed kinetic chain task (One Arm Hop). Utilization of the YBT-UQ may have a broader application in the adolescent and youth setting due to the reduced need of upper quarter power to perform the test. Research on all of the aforementioned tests has suggested that performance does not differentiate between sides; however, the subjects during the study did not participate in sports that result in the large upper extremity asymmetries associated with throwing activities. Reliability on all of the aforementioned tests has been established, however, the inherent validity of these tests is still being established. The primary benefit of these data is to provide an understanding of normal asymmetry on tests of upper quarter function, however, none of the aforementioned studies have examined a cohort that participates in activities that promote upper quarter asymmetry, such as baseball and softball, thus research in this area is beneficial. It may be that these glenohumeral adaptations associated with participating in baseball and softball may bias performance on a unilateral basic test of shoulder complex closed chain function.

Previous research on upper extremity symmetry supports the concept of side-to-side differences, however, to date little is known about bilateral differences in scores of basic closed-chain differences in scores of basic closed-chain shoulder function in baseball and softball athletes. As a result, the primary purpose of this study is to determine if differences exist between the throwing vs. non-throwing sides in high-school baseball and softball athletes. A second purpose of this study is to examine performance differences between male baseball and female softball athletes scores of the YBT-UQ. Based on previous research it is not expected that differences will exist between throwing and non-throwing sides or across genders.
METHODS
Sample size estimates for the current study were developed by using an $\alpha = 0.05$, $\beta = 0.20$ and a meaningful difference of 10% using previously published work.\textsuperscript{24} Sample size estimates across the multiple reach directions were calculated manually and revealed that 28-42 subjects would be needed to adequately power the study. As a result the research team aimed to obtain data from 50 baseball and softball players in order to count for potential dropout. Athletes at two high schools completed the testing as part of their standard pre-participation physical testing ($n = 48$, 15 pitchers, age: $15.8 +/- 1.2$ years) and softball ($n = 17$, 4 pitchers, age: $15.2 +/- 1.1$ years). Any athlete who was currently painful (has pain but was participating in normal training), exhibited pain during the testing, or was currently injured (currently not participating do to injury) was excluded from the study. All other athletes who were currently participating in full team activities were included in the study. The data were entered into a centralized database from which de-identified data were extracted and analyzed. The research protocol was approved by the institutional review board prior to data analysis. Forty-eight high school baseball players and seventeen high school softball players comprised the final sample, upon whom testing was performed during pre-season physicals. The average age of the baseball players was $15.8 +/- 1.2$ years and the average age of the softball players was $15.1 +/- 1.1$ years. The average upper limb length of the athletes was $90.8 +/- 4.0$ cm for the baseball players and $83.7 +/- 4.2$ cm for the softball players.

Procedures
The YBT-UQ test was utilized in order to examine upper quarter closed chain function in the high school baseball and softball players. The YBT-UQ has previously been established as a reliable functional test of the upper quarter and it has been determined that gender or bilateral differences do not exist in an active adult population.\textsuperscript{24,25} Previous research on the YBT-UQ has suggested that performance on the test exhibits moderate correlation with established shoulder and core stability measures.\textsuperscript{25} Reliability measures for the research team were established across the testers in order to maximize testing validity (Inter-rater ICC: 0.99-1.00, Inter-session ICC: 0.92-0.95). Prior to the testing, the upper quarter limb length of each athlete was measured with the athlete standing with their feet together and their shoulder in 90 degrees of abduction in the frontal plane per protocol. In this position, a cloth tape measure was used to determine the distance (cm) from the spinous process of the 7th cervical vertebrae to the tip of the right middle finger. The YBT-UQ examines the ability of an individual to perform a unilateral activity while maintaining a three-point plank position (one hand and two feet in contact with the ground) with the feet shoulder width apart. During the test, the athlete reaches in the three reach directions (medial, inferolateral, and superolateral [cm]) in a systematic order. Each trial of the YBT-UQ consisted of the athlete reaching in the three reach directions (cm) then subsequently returning to the starting position in a controlled manner (Figure 1). In order for the trial to be acceptable the following criteria had to be maintained: 1) three points of contact had to be maintained between the floor and the hand and feet, 2) the athlete could not use momentum to move the reach box (i.e. push the box), 3) the athlete could not let the reach hand touch the ground during the trial, 4) the athlete could not use the top of the reach box or the testing equipment to help stabilize their body. In order to orient the athlete to the testing procedure, two practice trials were completed on the right side followed by two practice trials on the left side. The tested side was named based on which hand was providing support during the trial. After the practice trials were completed three performance trials were completed for each side, right followed by left. All of the athletes were asked if pain was present during the practice and performance trials. A Y Balance Test Kit (Move2Perform, Evansville, IN) and the YBT-UQ protocol was used during the testing sessions.\textsuperscript{24}

The primary variables of interest for the study were the maximum reach in the medial, superolateral, and inferolateral directions for the throwing and the non-throwing sides as well as the symmetry between the throwing and non-throwing sides for each independent reach direction. In order to complete this analysis the maximum score for each reach direction was extracted to represent the end range of each individual’s performance. The average maximum normalized reach across the three directions was calculated for each side in order to record a composite score for each subject.
Statistical Analyses

The data collected from the study were statistically analyzed with SPSS (version 17.0, Chicago, IL). Comparisons on the YBT-UQ between the throwing and non-throwing sides were completed using a dependent samples t-test. All statistically significant differences were identified at p < 0.05. Effect size indices (ESI: absolute value of [Mean Softball – Mean Baseball]/ Pooled SD) were also calculated for all comparisons due to a lower number of softball players in comparison with the baseball players. Any ESI over +/- 0.7 would be considered large and any lack of statistical significance with an ESI of this size may be attributed to limitations in sample size.

RESULTS

No differences were found for any of the reach directions or the composite score between the throwing and non-throwing sides. (p = 0.42-0.91, ESI: 0.01-0.08, Table 1, Figure 2) Performance on the test was greatest for the medial reach, followed by the inferolateral reach, and superolateral reach when examining the normalized reach scores. The composite score was also not statistically significant (p = 0.72) with values being 87.2 +/- 8.9 % limb length (LL) for the non-throwing side and 86.6 +/- 8.1 % LL for the throwing side.

No difference in performance was observed between the genders for any of the reach directions or the composite reach (p = 0.30-0.90, ESI: 0.09-0.16, Table 1, Figure 3). Both male and female subjects exhibited higher scores in the medial and inferolateral directions when compared with the superolateral. The composite reach for males and females was...
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87.1 +/- 8.6 % LL and 86.3 +/- 8.4 % LL respectively, which was not a statistically significant (p=0.63) difference either.

DISCUSSION

Upper quarter injuries are common in athletes, particularly in sports involving a high level of repetitive overhead activity. However, few closed kinetic chain tests have been identified for the upper quarter to identify athletes with deficits of performance in this region, which can be of particular relevance when progressing an athlete through rehabilitation of an injury. The YBT-UQ has previously been identified as being a reliable test to assess basic closed kinetic chain ability of the upper quarter in a 3-point plank position. The purpose of the current study was to identify if performance on the test was affected by which side was utilized to stabilize the body during the performance. The results of the current study suggest that no difference exists between the throwing and non-throwing sides when performing the YBT-UQ. In addition, there does not appear to be an inherent gender difference attributed to performance on the YBT-UQ test.

Few studies have examined upper extremity measures of closed chain performance. Falsone and colleagues reported that no difference existed on the One Arm Hop test between dominant and non-dominant sides when tested in college athletes. Similar findings were recently reported on the YBT-UQ. Gorman and researchers examined a group of active male (n = 51) and female (n = 45) adults and observed no statistically significant differences between the men and women as well as no statistically differences between left and right sides. Similar work was conducted by Westrick and colleagues who examined a cohort of male (n = 24) and female (n = 6) soldiers using the YBT-UQ and observed no statistically differences between genders although the study had a limited female sample size. To date, however, no other studies have examined performance on this test in high school throwing athletes.

The results of the present study suggest that inherent differences between sides do not exist during a basic closed kinetic chain task. Since performance on the YBT-UQ did not occur at end range joint range of motion it is hypothesized that end range adaptations in joint function would not have a significant effect on performance of this test. Larger asymmetries in local glenohumeral function has been observed in more experienced athletes (college and professional) and as a result it is relevant to conduct additional testing in these populations. In addition, it may be that athletes who exhibit different levels of spinal mobility (i.e. gymnasts, divers, or wrestlers) that are required for successful skill specific tasks may perform differently on the YBT-UQ. The sport-based difference in performance has previously been observed on the star excursion balance test and thus may warrant investigation on the YBT-UQ.

The current study is one of few that has examined whether gender differences exist in upper quarter functional testing. There are currently no published research studies examining the effect of gender on the CKCUEST or one arm hop test. Two prior studies on the YBT-UQ revealed no differences between genders in a group of active adults, which is similar to the findings of the current study. It is important to reiterate that this is likely due to the fact that the reach distances are normalized. One study examining higher-level performance measures did reveal that females perform lower than males in tasks that required a higher level of upper extremity strength and power. The findings of this study suggest that performance deficits in females may not become apparent until achieving a certain level of loading. However, additional work needs to be conducted in

Figure 3. Differences in performance on the Upper Quarter Y Balance Test between the female and male subjects (* designates p<0.05, % LL = % limb length).

![Figure 3](image-url)
this area particularly when loads and performances are normalized to anthropometric properties.

Since it has been suggested that performance varies on the lower quarter version of this test (Star Excursion Balance Test and Lower Quarter Y Balance Test) based on competition level, gender and sport, it would be reasonable to expect that performance on the YBT-UQ would demonstrate similar variance. Future studies should examine if there are gender differences for other sports and at other competition levels as well as if performance is different across different competition levels and sports alone.

Several limitations exist with the current study and its application. Primarily, the cohort is small, particularly the softball group, and limited in heterogeneity since all of the data were collected across two sites and as a result the external validity of the study is limited. The small sample size in the study may have increased the potential of a type II error, however based on the effect size index calculation any potential difference due to limited sample size alone would be small in nature and may have limited clinical relevance. Additional research with larger samples and different populations should examine these relationships in athletes who participate in sports where overhead function is asymmetrical. In addition, athletes of higher performance level(s) should be tested and compared to better understand how athletic strength, skill and experience influences the results of this type of testing. It may be that athletes with more ingrained motor programs would demonstrate larger asymmetries in these basic closed kinetic chain upper quarter patterns compared to high school aged athletes. Finally, it should be acknowledged that the YBT-UQ tests closed kinetic chain function in mid range while simultaneously examining open kinetic chain function across a range of motion and thus serves primarily to examine the basic movement ability as opposed to the skill specific task. Inclusion of additional local measures of glenohumeral joint function, e.g. internal rotation range of motion and total arc of motion, to the current study would have been of benefit in order to understand how local glenohumeral function effects basic upper quarter closed kinetic chain performance.

Upper quarter functional testing research has many facets that still need to be examined. Currently the results of the test can serve as an indicator of average upper quarter function when looking for reference measures during the rehabilitation in high school athletes recovering from an upper quarter injury. It is important to understand how performance on the YBT-UQ varies in other sports that involve a high frequency of overhead activity and to see if the same trends hold true with respect to gender and side-to-side differences. While, the average side to side difference reported in this study was not statistically different, 15% of the athletes did exhibit a difference of >10% which may suggest that inherent symmetry on this test cannot be assumed. It is also relevant to examine how these relationships change in athletes as years of experience increase. Performance on the test is likely based on a combination of joint mobility, motor control and proprioception and it would be helpful to understand if any of these factors dominate the overall performance on this test. It is likely that performance on the test is not only multi-factorial for a given joint but it is also expected to be multi-segmental. In the interim it may be beneficial to utilize the YBT-UQ as a continuous measure of upper quarter closed kinetic chain stabilization, to follow CKCUEST testing and proceed One Arm Hop testing, which would be beneficial to normalize in order to maximize performance of the peripheral segments in achieving the high velocity associated with throwing.

**CONCLUSION**

In conclusion, performance on the YBT-UQ does not appear to be affected by which hand is used to stabilize the body when testing overhead throwing high school athletes. In addition, there are no inherent differences between genders in high school aged athletes albeit additional research should be conducted in this area due to the lower number of softball athletes examined in this study. Current clinical application of the YBT-UQ could consist of utilizing the test to determine if The results of the current research suggest that no statistically significant bilateral differences in upper quarter closed kinetic chain function exist in high school baseball and softball players. Initially this would suggest that baseball and softball players during rehabilitation should not exhibit significant asymmetries on the YBT-UQ, regardless of a preferential throwing side.
REFERENCES


CASE REPORT

DIAGNOSIS AND MANAGEMENT OF ACUTE MEDIAL TIBIAL STRESS SYNDROME IN A 15 YEAR OLD FEMALE SURF LIFE-SAVING COMPETITOR

Max Pietrzak, PT, BPhy, PGDipSPY

ABSTRACT

Background and Purpose: As the profound health and cost benefits of physical activity to society are established and participation guidelines implemented, health practitioners are increasingly expected to utilize efficacious and justified injury management and prevention strategies. The complex and multifactorial nature of sports injury makes elucidation of multiple risk factors and how they may subtly and variably interact, difficult. The purpose of this case report is to discuss the differential diagnosis, acute management and rehabilitation of a case of medial tibial stress syndrome (MTSS) in a surf life-saving athlete, in the context of sports injury prevention.

Case Description: The subject of this case study, a 15 year old female surf life-saving competitor, presented to the physiotherapist (PT) with recent onset, first episode, bilateral, diffuse posteromedial shin pain. Differential diagnosis, acute management, rehabilitation and preventative strategies for the subject are presented.

Discussion: Emerging injury surveillance research in surf life-saving suggests minor and major trauma as primary causative factors, however, the significance of high training volumes is likely underestimated. The influence of biomechanical, and subtle arthrokinematic dysfunctions on established risk factors for MTSS injury and prevention of re-injury for this subject, are also discussed. Furthermore, the concept of preventing tibial stress fracture (TSF) by successfully managing acute MTSS, is presented. Lastly, a critical analysis of reliability of clinical assessment methodologies utilised with the subject is provided.

Level of Evidence: Level 5; Single case report

Key Words: Bone stress injury, differential diagnosis, medial tibial stress syndrome, sports injury prevention, tibial stress fracture

Qualifications: Bachelor of Physiotherapy, University of Queensland (BPhy), Post-graduate Diploma, Sports physiotherapy, University of Bath (PGDipSPY).

Case study affiliations: Case study was written up as part of MSc Sports physiotherapy program, University of Bath. Author was appointed club physiotherapist at Maroochydore Surf Life Saving Club, Maroochydore, Queensland, Australia, for the 2011/2012 season.


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**BACKGROUND AND PURPOSE**

The health and cost benefits of physical activity and sport are well accepted with physical activity now accepted as potent medicine. However, the costs associated with sports related injury is not insignificant, both at recreational and professional levels. As physical activity implementation strategies evolve, significance of sports injury prevention is likely to further increase, with a growing number of health disciplines expected to demonstrate efficacious management, in an ever increasingly competitive market.

Sports injury is complex, multifactorial and variable, with a myriad of risk factors, both intrinsic and extrinsic, modifiable and non-modifiable, likely precipitating a single injury during an ‘inciting event’. This has led research methodology to adopt a multivariate analytical approach to sports injury surveillance, however, as the number of interrelated risk factors increases, the strength of their associations likely decreases. This renders authors of prospective injury risk factor studies often unable to identify small to moderate associations, due insufficient injury numbers. Nonetheless, sports injury prevention practice is also evolving towards establishing efficacy.

**Surf lifesaving** is an international sport/movement aimed at reducing injury and death around beaches, supported by a comprehensive competitive program. In Australia, it is largely an amateur, multi-discipline sport involving athletes from 15 years of age to “open” age, underpinned by a comprehensive junior or ‘nippers’ development program. Athletes are eligible for ‘Masters’ competition once they are over 30 years of age. Surf Life Saving Australia (SLSA) is the major organiser of surf sport competition in Australia, with over 310 affiliated surf lifesaving clubs and over 158,000 members nationwide. Club, regional, state, national and international competitions, typically called ‘carnivals,’ are held throughout the year, with the domestic Australian season spanning September through March. Carnivals are typically held on weekends, increase in frequency throughout the season and culminate in State and National Championships. Athletes typically train and compete in club squads. Surf sport disciplines include beach and flag sprints, swimming based events, surf craft (surf board and surf ski), surf boat racing, inflatable rescue boat (IRB) racing or other events such as ironman and ironwoman, a combined swim, ski and board event. Many events involve short, unshod, beach sprints for transitions and finishes, effecting high impact and torsional loads on athlete’s lower limbs, likely potentiating medial tibial stress syndrome (MTSS).

A description of events relevant to the case study is presented in Table 1, however, for a complete description of surf life-saving events the reader is directed to [www.sls.com.au/members/surf-sport/disciplines](http://www.sls.com.au/members/surf-sport/disciplines). The accepted definition of MTSS is pain along the posteromedial border of the tibia, typically in the distal third, worse during or just after exercise, with tenderness on palpation of at least 5cm and absence of stress fracture or ischaemic symptoms. Likely perpetuating factors for MTSS symptoms in this subject, including potential associations between ankle/foot arthrokinematics, sub-optimal kinetic chain function and excessive foot pronation, are described. The current understanding of the pathophysiology of MTSS, as well as the potential of preventing tibial stress fracture (TSF) through ‘successful’ management of MTSS, on a bone stress injury (BSI)

<table>
<thead>
<tr>
<th>Event &amp; Description</th>
<th>Illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Swim Surf Race</strong> – the Surf Race involves swimmers starting on the beach and then running, wading and swimming about 170 metres to sea around a set of buoys and then returning to the beach. The event concludes with a run finish to flags placed on the beach.</td>
<td><img src="Image" alt="Surf Race Illustration" /></td>
</tr>
<tr>
<td><strong>Single surf ski race</strong> – from a floating start, competitors paddle their surf ski around three buoys and return to the beach. The finish is judged when any part of the surf ski crosses the finish line with the competitor and their paddle all in contact.</td>
<td><img src="Image" alt="Surf Ski Race Illustration" /></td>
</tr>
<tr>
<td><strong>Surf board race</strong> – Standing start from the beach, each competitor enters the water with their surf board, paddles around all buoys and returns to the beach. The winner is judged by the first competitor to cross the finish line on their feet and in contact with their board.</td>
<td><img src="Image" alt="Surf Board Race Illustration" /></td>
</tr>
<tr>
<td><strong>Ironwoman</strong> - The Ironwoman event is conducted over a course consisting of three components, including a swim, a surf ski, and a surf board. The race concludes with a beach sprint to the finish line. The order of the legs may vary and is decided by draw prior to the event. Permission for use and images supplied courtesy of Surf Life Saving Australia.</td>
<td><img src="Image" alt="" /></td>
</tr>
</tbody>
</table>
continuum, with respect to the current scientific body of evidence, is also discussed.\textsuperscript{22-23}

The purpose of this case report is to discuss the differential diagnosis, acute management, and rehabilitation of a case of medial tibial stress syndrome (MTSS) in a surf life-saving athlete, in the context of sports injury prevention.

**CASE DESCRIPTION**

The subject of this case report is 15 year old female surf lifesaving competitor who presented with bilateral MTSS. The subject participated in the swimming surf race, single surf ski, surf board, and ironwoman competitions. Common to many junior surf sport athletes, she participates in individual age and open categories, plus relays, potentially competing in 20 events in one day. Mid-week training is bi-daily including strength and conditioning and running-based fitness work. All beach training and competition is conducted barefoot, whereas road/grass/hill running is carried out shod. The athlete’s weekly training schedule is presented in Table 2. The subject approached the physiotherapist (PT) during a carnival near the start of the season, reporting insidious onset, first episode, bilateral, distal third posteromedial shin pain, which started two days earlier after her second hill running session of the season. She did not present to staff for assessment during these two days, retrospectively reporting mild symptoms only, noticeable after running or prolonged walking. She reported a significant worsening of symptoms during the carnival with successive events, until she determined that she was unable to compete effectively. At that time she presented to the PT for this injury. An injury timeline is presented in Appendix1.

**INITIAL EXAMINATION**

Assessment revealed moderate diffuse tenderness in the distal third of both left and right tibias posteromedially, pain reported with a simple numerical rating scale (SNRS) was 6-7/10 bilaterally on light palpation, utilizing an adapted 3 point force of palpation scale of light, moderate, and firm.\textsuperscript{25-30} The soft tissues adjacent to the implicated area of the distal posteromedial tibia were also tender to palpation, however, this was deduced to be substantially less for the soft tissue compared to the bony tissue (2-3/10 on moderate palpation). Tibial traction periostitis (TTP) through the soleus, tibialis posterior or flexor digitorum longus, is a popular inflammatory based pathophysiological theory for MTSS, however, this is not supported by studies showing absence of attachment of these muscles in the distal tibia, the most common site for MTSS.\textsuperscript{22-23,31-32} An in-vitro examinatioin of three cadaveric shanks demonstrated TTP through the deep crural fascia, however, histological and imaging studies are largely unsupportive as fascial or periosteal inflammation are seldom identified.\textsuperscript{33-35} This potentially identifies a separate and less common pathophysiological process or transitory state between muscle fatigue and BSI.\textsuperscript{23,36-38} Conversely, evidence suggesting MTSS as a non-focal BSI is stronger, including evidence of diffuse periosteal and bone marrow stress, and local osteopenia which has been shown to resolve concurrently with symptom resolution.\textsuperscript{35,37,38-43} The subject showed no signs of significant inflammation, her symptoms were local to the distal third of tibia, and muscle length and resistance testing were unprovocative, suggesting MTSS rather than TTP.\textsuperscript{22,44}

Concomitant subjective examination revealed no significant medical history, no reports of non-mechanical symptoms such as night or resting pain, no current or previous history of low back pain, nor altered sensation or muscular weakness, indicating that systemic or proximal lumbar causes were highly unlikely and neurological examination unnecessary at that point in time.\textsuperscript{45} Given absence of resting or night pain, and lack of focal tenderness usually associated with TSF, it was not highly suspected.\textsuperscript{22-23,46} Differential diagnosis of early chronic exertional compartment syndrome was provisionally excluded as symptoms were worse rather than better immediately post exercise, and lacked the typical characteristics of muscular tightness, burning sensation or neurological symptoms.\textsuperscript{22-23,47} Similarly, popliteal artery entrapment syndrome was not strongly suspected at this time.\textsuperscript{46-48} Provisional diagnosis of MTSS was made utilising ‘decision analyses’ in calculating post-test probabilities of the conditions.

<table>
<thead>
<tr>
<th>Day</th>
<th>Training</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mon</td>
<td>0500-0645 Swim, 1630-1700 Run, 1700-1800 Board.</td>
</tr>
<tr>
<td>Tue</td>
<td>0500-0645 Swim, 1615-1745 S&amp;C, Run</td>
</tr>
<tr>
<td>Wed</td>
<td>Rest AM, 1630-1700 Run, 1700-1800 Board</td>
</tr>
<tr>
<td>Thu</td>
<td>0500-0645 Swim, 1630-1730 Ski, 1730-1800 Run</td>
</tr>
<tr>
<td>Fri</td>
<td>0500-0645 Swim, 1300-1400 Gym, 1630-1700 Run, 1700-1800 Board</td>
</tr>
<tr>
<td>Sat</td>
<td>Iron: Ski, Swim &amp; Board, most of the day.</td>
</tr>
<tr>
<td>Sun</td>
<td>Rest Day.</td>
</tr>
<tr>
<td>Other training:</td>
<td>No.</td>
</tr>
</tbody>
</table>
in this subject’s differential diagnoses, by factoring pre-test probabilities in the clinical demographic factored by estimated likelihood ratios of subjective and physical examination findings. A discussion of this process is presented in subsequent sections and is consistent with literature reporting careful history taking and physical examination as the current gold standard for the identification of MTSS.

Radiographs were not requested as they are unreliable in detecting MTSS. Magnetic resonance imaging (MRI), Computerised Tomography (CT) or Three Phase Bone Scan (TPBS) are of limited value in diagnosing MTSS, due to large variability between sensitivity and specificity (Table 3), and currently undetermined relevance to clinical and functional outcomes. Exception to this is where differential diagnosis is relatively uncertain and imaging may alter the management. For example, MRI and TPBS can be used to exclude TSF, inter-compartmental pressure testing is utilized for assessment of exertional compartment syndrome, and indirect or direct angiography utilized for suspected popliteal artery entrapment syndrome.

**INITIAL INTERVENTION**

As the provisional diagnosis was MTSS rather than TTP, cryotherapy was prescribed to help attenuate symptoms through hypalgesic effects. Advice on application was ice bag with moist cloth for 15 minutes up to every two hours. Acetaminophen was permitted as required, however, non-steroidal anti-inflammatory drugs were actively discouraged due apparent absence of inflammation, increased side effect profile, and potential to hinder tissue healing.

The subject was known to have a high weekly training volume (Table 2). She was instructed to rest from further competition that weekend so as not to further exacerbate symptoms and advised she could participate in swim and surf craft training during the week but to avoid any running until formal PT

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**Table 3. Reported sensitivity and specificity ranges for imaging used in diagnosing MTSS**

<table>
<thead>
<tr>
<th>Imaging Modality</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPBS</td>
<td>74-90%</td>
<td>33-100%</td>
</tr>
<tr>
<td>MRI</td>
<td>57-100%</td>
<td>33-100%</td>
</tr>
<tr>
<td>CT</td>
<td>42-100%</td>
<td>88-100%</td>
</tr>
</tbody>
</table>

TPBS= Three-phase bone scan; MRI=Magnetic Resonance Imaging; CT=Computerized Tomography

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**Table 4. Staged Running Guidelines**

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>Unrestricted running at training and competition.</td>
</tr>
<tr>
<td>Level 2A</td>
<td>Training restricted. Running restricted at training under direction coach/physio/doctor.</td>
</tr>
<tr>
<td>Level 2B</td>
<td>Competition restricted. Running restricted under guidance from coach/physio/doctor. (set as a percentage of maximum effort or limited number of repetitions or sets).</td>
</tr>
<tr>
<td>Level 3</td>
<td>No running with squad. Full weight bearing, no running in competition or squad training. May have separate staged running program under direction of PT separate to squad. May train other disciplines under guidance coach/physio/doctor.</td>
</tr>
<tr>
<td>Level 4</td>
<td>Protected weight bearing. On crutches plus or minus protective orthosis/cast. Training other disciplines to be discussed with coach/physio/doctor.</td>
</tr>
</tbody>
</table>

Notes: Level 4 for restricted weight bearing. Progress to level 3 when full weight bearing but NO running with squad. Progression to 2A when full surf sport competition is allowed, but running impact loading in training is restricted. 2B is special category where athlete may be allowed to compete but running impact loads are restricted during beach transitions. Level 1, unrestricted. All progressions should be made with full consultation of the multidisciplinary team.

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**Examination #2 (0.5 weeks after initial examination)**

The subject reported being compliant with management advice, had not run and only felt mild symptoms (SNRS VAS 1-2/10) after walking for approximately 1 hour. Symptom progression throughout management course is presented in Table-5. She again reported no neurovascular symptoms, resting or night pain, consistent with the initial examination. A quick lumbar screen of active range of movement, combined movement, passive straight leg raise, and passive accessory intervertebral motion was normal, therefore further neurological examination was not deemed necessary at that time. Palpation to the distal posteromedial tibias produced verbal SNRS of 1-2/10 with light palpation and 5-6/10 with moderate palpation.

Muscle length assessments of the lower limb were within normal limits. However, despite a normal
active and passive physiological ankle dorsiflexion range of motion of approximately 20 degrees bilaterally, talocrural dorsiflexion in knee extension and subtalar neutral was restricted by soft tissue to approximately 20 degrees short of neutral/plantar grade, bilaterally.65-68 The range approached neutral when the knee was allowed to flex thus the gastrocnemius was primarily implicated. This was likely perpetuating excessive compensatory pronation to achieve adequate segmental dorsiflexion between shank and foot.66-69 Excessive pronation is a cited risk factor for MTSS, potentially through increased tibial bending or torsion.24,70 All muscle length range assessments by the PT were made using visual estimates of successive midpoints between the horizontal and vertical planes.71 Although instrumented joint angle assessment is advocated wherever possible and practical, particularly for inter-rater measures, very good intra-rater reliability of visual estimate of joint range of motion has been demonstrated by experienced clinicians.71-73

Utilising elements of the Foot Posture Index in standing and calcaneus to tibial alignment during jogging, the subject was classified as an overpronator in static and dynamic weight bearing, respectively, (Table 6).24,74-77 The subject reported she had previously been prescribed the use of foot orthoses, while shod, by a PT and podiatrist for a previous bout of anterior knee pain (AKP), but had discontinued their use for the previous six months. Not utilising these during shod walking and running was a possible contributor to her developing MTSS symptoms.22-23,78

As squad athletes had already been screened with a training and vocation related injury questionnaire, created by the PT, at the beginning of the season, the subject had been identified with a history of a previous single episode of bilateral anterior knee pain associated with running, resolved with physiotherapy and podiatry intervention. Kinetic chain screening by the PT during strength and conditioning sessions, identified a tendency to display mild dynamic knee valgus (DKV) bilaterally, particularly with one leg squat, lunging and running.79-80 The screening was an adapted three point quality of movement scale (‘good’, ‘fair’ or ‘poor’) for observed quality of movement during functional weight bearing activities such as squats, one leg squats, lunges, walking and running, with DKV correspondingly rated as ‘absent’, ‘mild’, or ‘pronounced’.81-82 DKV likely potentiates MTSS through excessive tibial rotation resulting from excessive pronation and torque conversion at the sub-talar joint, providing partial explanation for similarities in higher MTSS incidence in females, amongst other lower limb injuries such as patellofemoral pain syndrome, illiotibial band syndrome, and anterior cruciate ligament compromise.22,24,67,80,83-84 Static muscle testing of muscles of the hip was 5/5 and gluteal function was rated as ‘fair,’ also utilising the PT’s adapted movement quality and target muscle recruitment scale based on visual observation, palpation, and subjective reporting of sensation.

**Table 5. Symptom progression throughout management course**

<table>
<thead>
<tr>
<th>Examination</th>
<th>Subjective complaints (SNRS/function)</th>
<th>Objective measure (SNRS/palpation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>3-4/10 immediate with walking, increased attempts to run during carnival</td>
<td>6-7/10 on light palpation of bony tissue</td>
</tr>
<tr>
<td>2</td>
<td>1-2/10 with walking approximately 1 hour</td>
<td>1-2/10 on light palpation</td>
</tr>
<tr>
<td>3</td>
<td>1-2/10 with walking &gt; 1 hour</td>
<td>0-1/10 on light palpation</td>
</tr>
<tr>
<td>4</td>
<td>Initial flare up post run 1-2/10 with walk &gt; 15 minutes Resolved within 3 days to 1-2/10 with walk &gt; 1 hour</td>
<td>0-1/10 on light palpation</td>
</tr>
</tbody>
</table>

Reference Values: Normal 0 to +5; Pronated +6 to +9; Highly Pronated +10 or >; Supinated -1 to -4; Highly Supinated -5 or <. Abbreviations: TNJ (talonavicular joint); MLA (Medial longitudinal arch); Ab (abduction); Ad (Adduction).
in muscle activation and fatigue, performed in side lying hip abduction, clamshell exercise, and single leg bridge.80-82,85

**Intervention #2**
Approximately 6-8 minutes of light to moderate pressure myofascial release interspersed with 5-15 second bouts of moderate digital ischaemic pressure was administered to the superficial and deep posterior compartments of each leg, as illustrated by Hutchinson and colleagues,44 aiming to increase talocrural dorsiflexion range and potentially attenuate compensatory hyperpronation.67,66 A home program of calf stretches was prescribed in order to augment an increase in range of talo-crural dorsiflexion, together with instruction to resume wearing her foot orthoses while shod.69,78,87-88 Calf stretching was initially prescribed at four repetitions of 15 seconds, alternating sides, four times per day, utilizing a modified weight bearing stretch which is postulated to increase talocrural dorsiflexion and calf stretching by maintaining integrity of the medial longitudinal arch through preferential tension and loading of the plantar fascia (Figure-1).67-68,88,-94 The same stretch but with the knee slightly flexed was prescribed but at decreased frequency, as the soleus was deemed less implicated in this case. All therapeutic exercise parameters including progressions from start point to end goal and preventative maintenance levels are presented in Appendix 2.58- 59.

Remedial gluteal retraining was begun in side lying hip abduction, clamshell exercises and during training sessions with the goal of achieving a ‘good’ rating on the quality of movement scale. Functional integration in one leg squats were introduced next but at low reps, due to the acute nature of the injury.58-59 The above exercises aimed to improve kinetic chain biomechanics and attenuate DKV, which is a likely neuromuscular driver of foot pronation through ‘torque conversion’ at the sub-talar joint.67,95-96. Due to their more dynamic nature compared to single-leg squats, lunges were withheld at this stage to avoid potentially greater impact and torsional loading forces which were deemed a greater risk for exacerbation of the subject’s MTSS symptoms.49,58-59

Discussion and agreement between PT and coaching staff initiated the subject at level 3 of the staged running guidelines at least until symptoms settled further.58-59 This allowed full training (swim, surf ski, surf board), while restricting all running impact loads, tying in well with a natural three week break from competition, as there were no carnivals scheduled during that period.

**Examination #3 (1.5 weeks after initial examination)**
The subject reported she was training swim and surf craft without symptoms and complying with non-running status, as instructed. She resumed utilising her foot orthoses while shod, which was also emphasised as preventative maintenance.24,78 She reported pain SNRS of 1-2/10 after walking over an hour otherwise she was symptom free. Pain on light palpation was 0-1/10 whereas pain on firm palpation was 2-3/10.

Whole foot dorsiflexion was unchanged on visual assessment, however, talocrural dorsiflexion in knee extension and subtalar neutral was only 5-10 degrees from neutral/plantar grade. This represented a substantial improvement towards normalisation of this arthrokinematic index, as in the author’s clinical experience, it rarely reaches neutral, without significant soft tissue resistance in non-children.67,97 Dynamic valgus control of the knees was improved and was rated as ‘good’ in single leg squat, however, still tended to display mild DKV without the subject’s conscious attention to the set task. During assessment of calf raise strength and endurance, the subject demonstrated fatigue and deterioration of form from ‘fair’ to ‘poor’ at 8-10 repetitions. Assess-

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**Figure 1.** A. Gastrocnemius stretch, B. Soleus stretch. Shod weight at level of metatarsal heads and calcaneus utilizing a step, avoiding forefoot abduction.
ment of deep posterior compartment strength in calf raise with excursion from eversion to inversion over a step (Figure-2) showed poor form and inability to perform more than 3-4 repetitions.

Treatment #3
Due to apparent efficacy in improved talocrural dorsiflexion in subtalar neutral and knee extension, manual soft tissue release and digital ischaemic pressure therapy of the superficial and deep posterior compartments was again administered at 8-10 minutes per leg with moderate to firm pressure. The subject was instructed to continue gastrocnemius stretching at least bi-daily. Furthermore, strength and endurance training of the deep and superficial posterior compartments were begun, to offset and prevent muscle fatigue related bone stress, and potentially attenuate overpronation through their actions over the sub-talar and mid-tarsal joints.38, 46,67,.98 Kinetic chain retraining was progressed to include lunging but was initially restricted to two sets of 5 repetitions on each leg, every other day.58-59

As the next carnival was two weeks away, coaching staff and the athlete agreed to maintain the subject on 3 of the staged running protocol.58-59 This ensured she would not run with the squad, however, was able to start running under the strict guidance of the PT. This was begun as 5 minutes of shod light jogging on a grass surface, every other day, with a 2 minute progression each day. At that point in time the injury was considered in the sub-acute stage, with some potential to irritate symptoms, hence the subject was instructed to cease the running program immediately if symptoms were at all more noticeable than prior to starting running.49,58-59 This is consistent with treating symptoms of MTSS symptomatically unless symptoms are significant and persistent, or TSF is suspected, whereby a minimum rest period irrespective of symptoms should be enforced.46,49,58-59

Examination #4 (2.5 weeks after initial examination)
The subject reported ceasing the graduated running program after the first jogging session due to resulting mild symptom provocation. This was reported as 1-2/10 pain with walking longer than 10-15 minutes (Previously 1-2/10 pain with walking for an hour) which resolved to previous level within two to three days. Palpation of the posteromedial Tibias again revealed diffuse tenderness in the distal third, rated on SNRS as 0-1 on light palpation and 2-3/10 on firm palpation. Talocrural dorsiflexion in knee extension and sub-talar neutral was also in status quo to Examination #3. Static and through range resisted muscle tests were again unprovocative. Diagnosis of MTSS was unchanged and the subject was considered to have sustained a mild flare up resulting from running, which appeared to have settled to previous levels within a week.

Intervention #4
Soft tissue release and digital ischaemic pressure were repeated as per previous session. Remedial gluteal retraining, one leg squats and lunges were reviewed and progressed. Remedial core exercises such as single leg bridging, planking, and side planking were introduced as trunk stability likely plays an important role in lower limb biomechanics and injury.80,99-103

Due to low suspicion of TSF and only minor running elements to the subject’s surf sport disciplines, the PT, coach and athlete agreed to progress her status to Level 2A in the staged running protocol.58-59 This would limit the overwhelming majority of impact loading related to running, however, would allow the subject to compete and prepare for State and National Titles. In order to maintain athlete safety, she was given strict instruction that she was able to compete only if her MTSS symptoms were gradually improving from week to week, and if symptoms were not improving she must report it to staff.49,58-59

Figure 2. A. Plantarflexion/inversion strengthening exercise, start position. B. End position
Subsequent Interventions and Outcomes
The subject competed the following week with symptoms remaining in status quo. MTSS symptoms gradually abated and were fully resolved at approximately 8 weeks after initial onset. She competed in at least another two carnivals during this period. The subject gradually resumed running with the squad at 10 weeks and was upgraded to Level 1 of the staged running guidelines at 12 weeks post injury, and thereafter trained and competed asymptotically for the rest of the season.

DISCUSSION
Not until recently have surf lifesaving injury incidence patterns been reported. A list of the most commonly reported injuries and primary contributing factors are presented in Tables 7&8, respectively. The overwhelming majority of injuries reported appear related to minor or major trauma, however, this may be somewhat skewed by the nature of the injury reporting methods utilised. Many athletes training for multiple disciplines or endurance events, where overuse symptoms may affect training or competition performance, often will not present to formal first aid stations, thus underestimating the incidence and prevalence of injury. Furthermore, traumatic injuries reported may merely represent the inciting event or the interplay of a myriad of preceding risk factors, including overuse. This potentially provides a future injury research agenda for the sport.

Propositional risk factors for MTSS identified with this subject were female sex and excessive foot pronation. Although presently not propositionally supported as risk factors for MTSS, decreased talocrural dorsiflexion in sub-talar neutral and DKV were considered relevant to injury onset, successful rehabilitation and future prevention of re-injury in this subject, likely thorough their effects on pronation. It is difficult to ascertain whether temporally the primary driver is DKV causing excessive pronation and subsequently perpetuating calf tightness, or, vice versa. The two mechanisms may be synergistic or part of the same biomechanical dysfunction in certain individuals, increasing tissue loading and potentiating injury. However, once the calf musculature is restricting talocrural dorsiflexion in the neutral sub-talar joint position, the likely 'path of least resistance' to achieve adequate dorsiflexion between shank and foot is compensatory excessive foot pronation. Prospective research has not identified calf tightness as a risk factor for MTSS, however, measuring whole foot dorsiflexion may not fully elucidate these subtle arthrokinematic relationships. Similarly, the inter-relationships between potential MTSS risk factors such as training parameters and footwear, are yet to be propositionally elucidated.

Outcome in this case was full resolution of symptoms at eight weeks post injury, resumption of unrestricted running with squad training at 12 weeks, and uninterrupted participation throughout the entire competitive season. It could be argued that the symptom resolution rate in this case of MTSS was rather modest, however, it may at least be partially explained by maintenance of this subject’s competitive status throughout, while restricting her running impact loads during training, due to mild residual symptoms, prolonging their course. There were several focal lower limb BSI amongst the female squad members, thus club wide preventative educational strategies on stress fractures and female athlete triad were undertaken. But how relevant was this to MTSS? MTSS is a form of diffuse or non-focal BSI, which has been shown to progress to linear micro crack formation with progressive loading in animal and a limited number studies of human subjects. These stress responses likely vary with age and loading direction, and are probably confounded by factors such as gender, bone micro-

| Table 7. Five most common primary contributing factors reported as associated with injury occurrence during Surf Life-saving competition and training |
|-----------------------------|------------------|------------------|
| Nature of Injury            | %Incidence Competition | %Incidence Training |
| 1. Bruise/Contusion         | 15.2              | 14.9             |
| 2. Strain                   | 14.8              | 11.2             |
| 3. Inflammation/Swelling    | 12.3              | 12.1             |
| 4. Sprain                   | 11.9              | 11.0             |
| 5. Open wound/laceration    | 9.7               | 10.9             |

| Table 8. Five most common primary contributing factors reported as associated with injury occurrence during Surf Life-saving competition and training |
|-----------------------------|------------------|------------------|
| Contributing Factor         | % Reported Competition | % Reported Training |
| 1. Returning to shore        | 19.5              | 15.1             |
| 2. Negotiating the break     | 17.5              | 24.7             |
| 3. Collision with            | 9.8               | 4.5              |
| 4. Lost control own craft    | 7.0               | 8.1              |
| 5. Other person lost control of craft | 5.5 | 3.9 |
structure, nutrition, biomechanics, training terrain, footwear and pain perception. Combined with research showing abnormal imaging in asymptomatic subjects, this suggests current difficulty in predicting if any one individual with MTSS will progress to TSF. However, amongst populations and sports where numbers of cases presenting with MTSS is high, such as running and the military, it is not improbable that successful management of acute MTSS could prevent progression to TSF in some of these cases.

Finally, a critical discussion on the methodology in the differential diagnosis of MTSS in this case study is warranted. The use of ‘decision analysis’ in estimating post-test probabilities of the conditions in the differential diagnoses by factoring pre-test probability of the clinical demographic with likelihood ratios of subjective and objective examination tests, requires elaboration. For example, utilizing a Nomogram and a conservative estimate of pre-test probability of MTSS in this subject (50%), and a positive likelihood ratio for positive diffuse, distal third posteromedial tibial tenderness on palpation (2.0), the post-test probability of MTSS being present is approximately 7 in 10. Conversely, utilising the same methods with a liberal pre-test probability estimate for TSF in this clinical demographic (20%), factored by the same magnitude but negative likelihood ratio, (-2.0), for absence of focal tenderness, yields a post-test probability of less than 1 in 10 that TSF is present. Furthermore, there is moderate evidence to suggest a thorough subjective examination should provide larger positive and negative values for likelihood ratios than the physical examination. This becomes a form of diagnostic test clustering which is likely to accentuate post-test probabilities. However, it must be acknowledged that pre-test probabilities are often estimated conservatively based on clinical experience rather than propositional data, and likelihood ratios, in this case, were estimated from the limited data available.

Secondly, a limitation of the case report was that physical examination was primarily dependent on subjective reporting on a SNRS whilst the PT administered conventional manual palpation of an estimated force magnitude of mild, moderate or firm. Bendtsen & Co-workers (1996) demonstrated good intra-rater reliability for constant force conventional muscular palpation compared with instrumented palpometry, however, they utilised a modified Total Tenderness Scoring system rather than a SNRS. Similarly, a recent study by Kothari & colleagues found no significant differences in variability between with manual palpation with left or right hands, middle or index fingers, soft or hard surface, and 2 versus 10 second palpation. These authors did consistently demonstrate significantly lower coefficients of variation (CV) for all instrumented test conditions utilising a palpmeter (Mean CV: 4.8%; Range: 2.7%-5.8%), compared to standard manual palpation (Mean CV 13.0%; Range: 10.0-17.8%). However, applying their highest CV for manual palpation (17.8%) to their outer range and median palpation pressures of 0.5kg, 1.75 kg and 3kg, as representing a light, moderate or firm palpation rating, respectively, is unlikely to affect reliability. The above data is consistent with the premise that objective instrumented palpation may be required for constructs where inter-rater reliability is necessitated, for example, research, or atypically formal assessment, whereas astute manual palpation by the same clinician is likely sufficient for day to day clinical practice. Lastly, the limitations of goniometric assessment of ankle dorsiflexion range of motion has been described above, and visual estimates of joint range of motion are generally not accepted in research literature.

**CONCLUSIONS**

Sports injury is multifactorial, complex, and variable, which presents a challenge to health practitioners in establishing efficacious and propositionally justified sports injury management prevention strategies. This case describes the differential diagnosis, acute management and rehabilitation of MTSS in a 15 year old female surf life-saving athlete, in the context of sports injury prevention. Concurrently, a case supporting the notion of some MTSS cases as precursors of TSF is presented.

**REFERENCES**


87. Loudon, J., & Dolphino, M. Use of foot orthoses and calf stretching for individuals with medial tibial


### Appendix 1. Injury Timeline

<table>
<thead>
<tr>
<th>Examination</th>
<th>Days from Initial examination</th>
<th>Progress/Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>0 days</td>
<td>Symptoms at their worst. Cease further competition that weekend, no running at least until mid-week full assessment, Able train swim and surf craft, cryotherapy, simple analgesics prn</td>
</tr>
<tr>
<td>Exam #2</td>
<td>3 Days</td>
<td>Significantly improved, mild symptoms. Soft tissue release, calf stretching, remedial gluteal work begun, advised to resume wearing foot orthoses, Level 3 on staged running proforma (no running with squad, able to train surf craft), no carnivals scheduled for 3.5 weeks, cryotherapy prn</td>
</tr>
<tr>
<td>Exam #3</td>
<td>10 Days</td>
<td>Significantly improved, symptoms minimal. Continue soft tissue work, stretching, foot orthoses, progress hip stability exercises, add lunges. Maintain Level 3 running proforma: no squad running but prescribed 5 minute light jog on grass. Next carnival 2.5 weeks away.</td>
</tr>
<tr>
<td>Exam #4</td>
<td>17 Days</td>
<td>Mild flare up with initial session of graduated jogging program, settled within the week. Next carnival 1.5 weeks away. Due to subjects low running demands during competition, athlete, coach &amp; PT agree to place on 2A of running proforma (full competition, no running at training) Gradually progress above exercises, add trunk stability.</td>
</tr>
<tr>
<td>Subsequent Exams</td>
<td>Weekly throughout season</td>
<td>Symptoms gradually abated. All exercises progressed. Competes in subsequent weeks with nil ill effect. Asymptomatic at 8 weeks, running at training gradually re-introduced from week 10, upgraded to Level 1 of running proforma at 12 weeks. Competes asymptotically for the rest of season. Preventative maintenance strategies.</td>
</tr>
</tbody>
</table>

Note: PT exams and treatment were scheduled weekly during strength and conditioning sessions, PT was available on call between scheduled sessions, as required.
### Appendix 2. Details of therapeutic exercise interventions

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Start dose</th>
<th>Progression (as tolerated)</th>
<th>End goal</th>
<th>Preventative maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastrocnemius stretch</td>
<td>4 x 20secs each leg, alternating, 4x/day plus after activity</td>
<td>4 x 20secs each leg alternating 2/day plus after activity</td>
<td>Neutral talocrural dorsiflexion in subtalar neutral</td>
<td>4x 20secs after activity. Allowed pre-activity as part of sport specific warm-up</td>
</tr>
<tr>
<td>Hip abduction side-lye</td>
<td>2 sets, 6-8 reps, daily</td>
<td>2-3 reps per session, daily unless fatigued</td>
<td>2-3 sets, 20 reps</td>
<td>1-2/week</td>
</tr>
<tr>
<td>Clamshell exercise lye</td>
<td>2 sets, 6-8 reps, daily</td>
<td>2-3 reps per session, daily unless fatigued</td>
<td>2-3 sets, 20 reps</td>
<td>1-2/week</td>
</tr>
<tr>
<td>One leg squats</td>
<td>2 sets, 5 reps each leg, daily</td>
<td>2-3 reps each session, every other day when reps &gt;10 or if fatigued</td>
<td>2-3 sets, 20 reps</td>
<td>1-2/week</td>
</tr>
<tr>
<td>Calf raise (straight and bent knee)</td>
<td>2 sets, 6 reps, each leg, daily</td>
<td>2-3 reps each session, every other day when reps &gt;10 or fatigued</td>
<td>2-3 sets, 20 reps</td>
<td>1-2/week</td>
</tr>
<tr>
<td>Eversion to inversion calf raise for deep posterior compartment</td>
<td>2 sets, 2-3 reps, each leg, daily unless fatigued</td>
<td>1-2 reps each session, every other day when reps &gt;10 or fatigued</td>
<td>2 sets, 15-20 reps</td>
<td>1/week</td>
</tr>
<tr>
<td>Lunges</td>
<td>2x5 each leg every other day, unless fatigued or increased symptoms</td>
<td>2-3 reps per session</td>
<td>2-3 sets 20 repetitions</td>
<td>1-2 per week</td>
</tr>
<tr>
<td>1 Leg Bridge</td>
<td>10secs (L) then (R) = 1 rep, start 4-5 reps, daily</td>
<td>1-2 reps per session</td>
<td>10 reps</td>
<td>1-2/week</td>
</tr>
<tr>
<td>Plank (elbow feet)</td>
<td>5 x 20secs, daily unless fatigued</td>
<td>5secs per session up to 5x45secs then elbow/1foot</td>
<td>5 x 45secs</td>
<td>1-2/week</td>
</tr>
<tr>
<td>Side plank (elbow/leg)</td>
<td>5x20 secs, daily unless fatigued</td>
<td>5secs/session up to 5x 45 secs, then elbow/foot</td>
<td>5 x 45secs</td>
<td>1-2/week</td>
</tr>
</tbody>
</table>
ABSTRACT

Introduction and Background: Lateral ankle sprains (LAS) are common in sports medicine and can result in a high rate of re-injury and chronic ankle instability (CAI). Recent evidence supports the use on mobilizations directed at the ankle in patients who have suffered a LAS. The Mulligan Concept of Mobilization-with-Movement (MWM) provides an intervention strategy for LASs, but requires pain-free mobilization application and little literature exists on modifications of these techniques.

Purpose: To present the use of a modified MWM to treat LASs when the traditional MWM technique could not be performed due to patient reported pain and to assess outcomes of the treatment.

Case Description: The subject of this case report is a 23 year-old female collegiate basketball player who had failed to respond to initial conservative treatments after being diagnosed with a lateral ankle sprain. The initial management and subsequent interventions are presented. After re-examination, the addition of a modification of a MWM technique produced immediate and clinically significant changes in patient symptoms. The use of the modified-MWM resulted in full resolution of symptoms and a rapid return to full athletic participation.

Outcomes: After the initial application of the modified-MWM, the patient reported immediate pain-free ankle motion and ambulation. Following a total of 5 treatments, using only the modified MWM and taping technique, the patient was discharged with equal range of motion (ROM) bilaterally, a decreased Disablement in the Physically Active (DPA) Scale score, and an asymptomatic physical exam. Follow-up exam 6 weeks later indicated a full maintenance of these results.

Discussion: Recent evidence has been presented to support the use of mobilization techniques to treat patient limitations following ankle injury; however, the majority of evidence is associated with addressing the talar and dorsiflexion limitations. Currently, little evidence is available regarding the use of the MWM technique designed for LASs and the expected outcomes. This case adds to the emerging evidence supporting the use for MWMs to treat ankle pathology and introduces a modification that may be applied in cases where patient reported pain prevents traditional application.

Level of Evidence: Level 5; Single case report.

Key Words: Lateral ankle sprain, mobilization with movement
BACKGROUND

Ankle sprains, a common pathology suffered during physical activity, occur at an estimated rate of more than 23,000 per day in the United States. Based on recent literature reports, ankle sprains occur at an incidence rate of 2.15 per 1,000 person-years in the United States. Approximately 49.3% of ankle sprain occur during athletic related activities, with basketball contributing up to 41.1%. In basketball, it has been reported that approximately 60% of all injuries involve the lower extremity and approximately 25% of these injuries are ankle sprains.

Due to the anatomical structure of the ankle, the anterior talofibular ligament (ATFL) is the most commonly injured ligament and is most susceptible to injury during a plantarflexion (PF) and inversion (IV) mechanism. The combined motion of PF and IV is a common mechanism of injury (MOI) and routinely leads to the diagnosis of a lateral ankle sprain (LAS). Brian Mulligan has theorized, however, that this MOI may result in a positional fault of the fibula, instead of a LAS. According to his theory, the ATFL pulls on the fibula at the distal tibiofibular joint creating a positional fault between the tibia and fibula. The positional fault, as opposed to the ligament sprain, is the main source of pain, dysfunction, and decreased range of motion.

Under this hypothesis, Mulligan proposed that the Mobilization with Movement (MWM) treatment for LASs corrects the positional fault that may occur as a result of the PF and IV mechanism. The technique consists of a pain-free sustained anterior-posterior (AP) cranial glide of the lateral malleolus on the tibia. With the glide maintained, the patient then performs active PF and IV with clinician overpressure at end range. Following the MWM, the glide is maintained with a specific tape application applied in the direction of the MWM to help maintain the corrected position of the fibula. The entire application of the technique should be pain-free for the patient and should produce immediate and long-lasting benefits. The resolution of the patient's symptoms during the MWM application would be the clinical indication of a positional fault and would guide the clinician in choosing to apply this intervention.

With acute LASs, however, a patient may be too tender to allow performance of the traditional MWM technique. The principles of MWM application require pain-free application of the technique and guide the clinician in adjusting hand placement, force application, and the line of drive of the mobilization to produce the desired outcome. Additionally, padding may be applied to help alleviate point tenderness at the distal fibula. Tenderness to pressure may delay the use of this intervention and, in turn, delay healing and return to function. Therefore, a modification of the MWM joint mobilization and taping technique that allowed for earlier pain-free application of the technique would be beneficial.

The purpose of this case report is to present the use of a modified Mobilization-with-Movement to treat a patient diagnosed with a LAS.

CASE DESCRIPTION

Subject Characteristics

The subject, a 23 year-old female collegiate basketball player, reported ankle pain following a PF and IV mechanism that occurred during a basketball game. The patient removed herself from competition and reported directly to her athletic trainer. She had participated in competitive basketball for over 13 years and had a history of repetitive LASs. The most recent LAS had occurred approximately one year earlier and had resolved over the course of 1 to 2 weeks with traditional conservative care. The patient did not report having any ankle complaints prior to the most recent injury.

Clinical Impression

When the patient initially reported to her athletic trainer at the team bench, she stated that her pain was a 7 out of 10 on the Numeric Rating Scale (NRS). While she was able to bear weight and walk at the time of injury, weight-bearing exacerbated her pain. Observation did not reveal signs of significant pathology (e.g., gross deformity, ecchymosis, edema) and the patient only reported tenderness to palpation over the sinus tarsi area on the affected limb during the courtside examination. The patient displayed limited and painful range of motion (ROM) when examined actively and passively in all directions. The anterior drawer and inversion talar tilt tests were positive for pain and mild laxity, but produced a firm-end feel. Kleiger's Test was negative for laxity and pain. The remainder of the initial court-side
exam (e.g., negative Ottawa Ankle Rules, normal dermatome assessment, etc.) was consistent with a sprain of the anterior talofibular ligament (ATFL) and calcaneofibular ligament (CFL). The immediate working diagnosis was a Grade 1+ right ATFL and CFL ligament sprain. The patient was immediately treated with rest, ice, compression, and elevation (RICE), while also being fitted for crutches to allow for non-weight-bearing ambulation until a full reexamination could be conducted the next day.

During follow-up examination the next day, the physical exam findings were consistent from the court-side evaluation across the palpation, ROM, and special test assessments; however, observation revealed the patient now presented with visually observed mild edema and ecchymosis at the sinus tarsi. As a result of these findings, the patient began a traditional conservative rehabilitation program. Initial treatment during the acute inflammatory phase included the continued use of RICE and crutches. The use of electrical stimulation for pain control, gentle active ROM, and isometric strengthening exercises were also utilized. After the acute inflammatory phase, traditional range of motion and strengthening exercises, as well as gentle massage techniques were added to the rehabilitation protocol for the next week (Table 1).

Revised Clinical Impression
After completing 10 days of conservative treatment from the time of injury, the patient reported pain levels that had only minimally improved during ROM or weight bearing activities (Figures 3 and 4). Additionally, her ROM deficiencies had not improved and she was unable to progress in her rehabilitation protocol. As a result, it was determined that a reexamination was needed and a second opinion was sought. During the reexamination, 10 days after initial injury, the patient rated her pain as a 7 with weight bearing (i.e., double limb stance) and a 6 during active IV and PF. The physical exam still revealed the same findings as the previous exam (e.g., tenderness to palpation at the sinus tarsi, consistent ROM deficiencies, consistent special test results), except edema and ecchymosis had resolved. The Disablement in the Physically Active (DPA) Scale was given to the patient to determine a patient-centered outcome baseline and she reported an initial score of 29 out of 64, with her greatest areas of dysfunction being impaired motion and muscle function (3 out of 5) on the individual sections of the scale. The use of the Mulligan Concept MWM for lateral ankle sprains was then applied as an assessment technique to determine its efficacy in this subject. Despite the use of different types of padding materials and adjustments to hand placement, force application, and line of drive, the patient's tenderness to palpation prevented the application of the traditional MWM. As such, the MWM was modified by applying the technique approximately 2 inches proximal to the lateral malleolus (Figure 1). The Mulligan Concept protocols (e.g., line of drive, pain-free application) were followed for the application of this technique and the modified MWM abolished the patient's reported pain during PF and IV activities. As a result, the use of this modified MWM was recommended as the appropriate treatment for the patient's dysfunction associated with the LAS presentation.

Subject reported outcome measures included the NRS and the DPA Scale. The NRS is commonly applied with the patient rating their pain from 0 (i.e., “no pain”) to 10 (i.e., “worst pain imaginable”). The NRS has been found to be reliable and valid across many patient populations/situations and the minimal clinically important difference (MCID) value is regularly reported to be 2 points or 33%. The DPA Scale is a patient-centered scale designed for the physically active patient and is used to assess measures of impairment, functional limitation, disability, and health-related quality of life on a 0 (i.e., floor) to 64 (i.e., ceiling) scale. Patients answer 16 questions (e.g., “Do I have pain?”) across 11 disablement categories (e.g., pain, stability, overall fitness, well-being, etc.) on a rating scale from 1 (i.e., no problem) to 5 (i.e., severe). The scores from each question are added together and then 16 points are subtracted to produce the final DPA Scale score. Vela and Denegar have indicated the scale is valid and reliable, while also reporting that the MCID value is 9 points in acute cases and 6 points in chronic cases.

Intervention/Outcomes
On Day 10, the modified MWM was administered utilizing a pain-free sustained glide, followed by pain-free full PF and IV with clinician generated over-pressure
at end-range for a single set of 10 repetitions. Upon completing the 10 repetitions, the patient reported that she was no longer experiencing pain during active PF and IV. Additionally, the patient's active ROM was now equal to the uninjured side in all directions. The patient was then asked to step down from the plinth and walk around the clinic to determine the effect of the intervention with weight bearing activities. The patient reported a resolution of her pain while walking and squatting in the clinic.

Following the results of the modified MWM application, tape was applied at the same site of the modified MWM using Mulligan Concept taping principles. The tape application began with a strip of non-woven adhesive bandage being applied approximately 2 inches proximal to the lateral malleolus, and angled in the same direction as the MWM, while the glide was applied. The bandage was brought behind the distal tibiofibular joint, ending proximally to the beginning of the bandage without the ends

| Table 1. Therapeutic & Rehabilitation Timeline |
|---|---|---|
| **Time** | **Intervention(s)** | **Settings/Parameters** |
| Day 1-3 | RICE, ROM exercises & isometric exercises | 1) Cryotherapy - 10 min.  
2) AROM Exercises  
   a. Toe dexterity exercises (i.e., marble pick-up, towel curls) – 3 x 10  
   3) Seated Circle Board (Clockwise & Counter Clockwise) - 2 x 10  
   d. Seated Calf Raises (Double Leg) - 3 x 8  
 3) Isometrics (manual resistance at neutral in all directions)  
4) Effleurage - 5 min.  
5) Compression and Cryotherapy - 20 min. |
| Day 4-7 | Resistance Bands, Proprioception/Balance exercises, PNF exercises, Effleurage, Ice & Electrical Stimulation (Sensory level pain; 80-150pps) | 1) Bike - 10 min.  
2) AROM Exercises  
   a. Toe dexterity exercises (i.e., marble pick-up, towel curls) – 3 x 10  
   b. Ankle INV & EV – 3 x 10  
   c. Seated Circle Board (Clockwise & Counter Clockwise) - 2 x 10  
   d. Seated Calf Raises (Double Leg) - 3 x 8  
 3) 4-Way ankle exercises with resistance bands (Light resistance) – 2 x 10  
 4) Rebounder; unstable surface (Single Leg) - 2 x 12  
 5) Ankle PNF strengthening (manual resistance, diagonal patterns) – 1 x 10  
 6) Effleurage - 5 min.  
 7) IFC & Ice - 20 min. |
| Day 8-10 | Resistance Bands, Proprioception/Balance exercises, PNF exercises, Effleurage, Ice & Electrical Stimulation (Sensory level pain; 80-150pps) | 1) Bike - 10 min.  
2) 4-Way ankle exercises with resistance bands (Moderate resistance) – 2 x 10  
3) Balance board squats w/isometric hold – 2 x 10  
4) Rebounder; unstable surface (Single Leg) - 2 x 12  
5) Double leg cross jumps - 3 x 30 seconds  
6) Single leg stop jumps – 2 x12  
7) Ankle PNF strengthening (manual resistance, diagonal patterns) – 1 x 10  
8) IFC & Ice - 20 min. |
| Day 10 | Re-examination; initiation of modified MWM and taping technique | Modified MWM treatment (1 set of 10 repetitions) followed by tape application. |
| Day 11 | Modified MWM and taping; Full participation at practice | Modified MWM treatment (1 set of 10 repetitions) followed by tape application. |
| Day 12-15 | No Treatment. | Patient participated in away competitions; Ankle was taped with a traditional ankle tape application only. |
| Days 16-18 | Patient returned from away competitions; modified MWM treatments and taping applied. | Modified MWM treatment with tape – 1 x 10 (Day 16 and 17 only). Patient discharged on Day 18. |
| Day 60 | Follow up; No treatment | Patient reported being able to complete the remainder of the competitive season without a reoccurrence of symptoms and as being asymptomatic in activities of daily living. |
over-lapping. A strip of rigid tape was then cut to the same length as the bandage. The rigid tape was then applied over top of the bandage in the same direction as the MWM during a sustained glide. A second strip of the rigid tape was then applied in the same fashion (Figure 2). Upon completion of the tape application, the patient reported a continued resolution of pain and was told to continue to wear the tape until she reported to the clinic for follow-up examination the next day.

The following day, the patient reported a continued resolution of her symptoms with activities of daily living. The patient was still tender to palpation over her distal lateral ankle, but displayed equal ROM in all directions at the ankle bilaterally. The modified MWM was re-applied for a single set of 10 repetitions and the patient was again taped using the modified taping technique. Following the application of the intervention, the patient continued to report resolution of her pain with weight-bearing activities. As such, she was asked to complete various balance and functional activities (e.g., sets of squatting, duck walks, single and double leg hops) in order to determine her ability to return to practice. She completed the activities without a return of her symptoms and the patient was cleared to participate in practice that day with the caveat that she only performed activi-
ties that did not produce pain. The patient completed practice without a recurrence of her symptoms and was cleared to travel with the team for two away competitions beginning the next day.

The patient reported to the clinic on Day 16, after having competed in two games with her team. During this time period, she had been able to participate in competition while only receiving a traditional ankle tape application. While she still reported a resolution of her pain with activities of daily living (Figures 3 and 4), she indicated experiencing mild discomfort during game activities and was still tender to palpation over the area of her sinus tarsi. As a result, the use of the modified MWM intervention and taping technique was continued in attempt to produce full resolution of her symptoms during her sport specific activities. The patient received the modified treatment over the next two days while fully participating in team activities.

On Day 18, the patient reported that she did not experience any symptoms during competitive activities on the previous day. As such, a full physical examination was completed. During this examination, the patient did not report any pain during palpation, ROM activities, or functional testing. Her active, passive, and resistive ROMs were equal bilaterally. The anterior drawer and inversion talar tilt tests did not produce pain or abnormal end-feels. The patient also reported an overall DPA Scale score of 12, which achieved an MCID; however, the patient still reported some deficits on the scale. The patient also reported the disablement categories of pain, changing directions, maintaining positions, skill performance, participation in activities and overall fitness as a 2 (i.e., “does not affect”), motion and muscle function as a 3 (i.e., “slightly affects”), while the remaining areas/questions were all rated a 1 (i.e., “no problem”). As a result of the asymptomatic physical exam and a DPA Scale score in the range reported for the uninjured population, the patient was discharged to full competition without further treatment at this time. The patient was able to complete the remaining basketball season without a recurrence of symptoms and was still symptom free over 60 days post-discharge.

DISCUSSION
Despite the regularity of LASs and the common use of many intervention techniques, debate still exists regarding which intervention is the most appropriate and when each intervention should be applied to appropriately address the patient’s presentation. Much of this debate arises because mechanical ankle instability may be present for weeks to months following rehabilitation, and the most common predisposing factor for suffering a LAS is a history of previous ankle sprain. Additionally, despite the use of common rehabilitation strategies, a previous history of LASs may predispose a patient to chronic ankle instability. The efficacy of various rehabilitation techniques has been investigated in order to elucidate which interventions are most effective, but the majority of studies have focused on the short-term outcomes (e.g., pain, range of motion, return to competition) and little research has focused on the use of mobilizations.

Typically, acute LASs are managed with the use of RICE during the acute inflammatory stage. In more severe cases, immobilization is recommended for optimal healing of the affected ligaments. Despite common use, insufficient evidence exists to support the effectiveness of the application of RICE in the treatment of LASs. Additionally, as the various components of RICE are applied simultaneously, it is difficult to determine which component provides the most effective outcomes for the patient. Neuromuscular training strategies (e.g., Proprioceptive Neuromuscular Facilitation exercises, closed kinetic chain balance activities) have been hypothesized to be effective during the proliferation phase of healing to improve functional ankle balance. Intervals of walking and jogging, once the patient can ambulate long distances without gait alterations, have also been recommended. The use of rehabilitation programs incorporating these interventions has demonstrated some ability to reduce the number of future ankle sprains and be helpful in the prevention of CAI. The benefits, however, usually occur over weeks to months as the therapy model is built on the concept of pathoanatomical healing believed to be required following a diagnosed LAS when additional factors may need to be considered.

Recently, researchers have described that an anteroposterior mobilization of the fibula, combined with RICE, provided significant improvements in ROM compared to the application of RICE alone. The combined intervention resulted in increased stride speed within the
first and third treatment sessions. Similarly, RICE combined with an osteopathic manipulative treatment led to improvements after a 1-week follow-up in patients with unilateral ankle sprains, when compared to RICE alone.15 Given the results of studies such as these, combined with anecdotal reports, it may be necessary to examine other potential theories of pathology and treatment for LAS to facilitate the most appropriate treatment for each individual patient.5,6,19

One potential explanation for mechanical ankle dysfunction following a diagnosed LAS is the existence of positional fault between the fibula and tibia.5,19 The positional fault hypothesis has been supported through the demonstration of an anteriorly positioned fibula when compared to the tibia. Evidence of this position fault has been found when using an external measurement device, fluoroscope, and magnetic resonance image to measure positioning of the fibula in relation to the tibia.19-22 Laboratory research demonstrated the existence of positional faults in patients suffering from chronic and subacute lateral ankle sprains, while clinical research efforts have supported the existence of positional faults in acute pathology.20-22 Investigators have suggested greater amounts of edema may result in a greater amount of fibular displacement when compared to the tibia.21,23 Additionally, it has also been indicated that patients with CAI may suffer from an anterior positional fault of the talus in the sagittal plane.24 As such, applying interventions to address this malposition, whether through a biomechanical or neuroscience paradigm, may be necessary to provide the most effective outcomes for patients.

Improvement of clinical outcomes examining pain and dysfunction following LASs support the use of MWMs. Hetherington25 applied the LAS MWM following acute ankle sprain and noted improved gait, pain-free inversion ROM, and balance in patients. Stubbs et al.26 utilized the same MWM to produce an immediate resolution of a collegiate soccer player’s symptoms following a week of minimal improvement after suffering an acute LAS. The patient was able to return to activity the next day and completed the collegiate soccer season without recurrence of symptoms or re-injury.26 O’Brien and Vicenzino27 also reported rapid improvements in ROM and reported pain following the use of this MWM to treat a LAS. Evidence also exists to support the potential use of the MWM tape application to reduce the occurrence of LASs in athletes.28 The tape application, however, does not appear to affect performance in either static or dynamic balancing tasks in relation to chronic ankle injuries in a significant way when compared to traditional methods.29

The MWM for the LAS has not been the only MWM technique used to treat patients who have suffered a LAS. Vicenzino et al.30 indicated the posterior MWM for the talus produced statistically significant increases in dorsiflexion in patients suffering from CAI. Wikstrom et al.31 produced similar results by demonstrating that a single MWM treatment provided improvements in dorsiflexion range in motion, while also resulting in a restoration of normal arthrokinematics and osteokinematics. Green et al.14 also reported a more rapid return to pain-free ankle dorsiflexion among patients who received this MWM when compared to patients that did not when treating an acute ankle sprain. Similarly, Collins et al.32 reported a significant improvement in ankle dorsiflexion following this treatment in patients who had sustained an ankle sprain. Based on the current literature, it appears MWM joint mobilizations are effective as a means to decrease pain, improve function, improve ROM, and produce more rapid returns to activity in patients suffering from acute and chronic ankle sprains.16,19,27,30-32 What is unclear at this time, however, is the mechanism of action (e.g., positional fault hypothesis, non-opioid hypoalgesia) by which the MWM produces these outcomes.8

In the case presented, the modified MWM produced an immediate change greater than what is required to produce a minimal clinically important difference (MCID) on the NRS (2 points)9 and DPA Scale (9 points)10 on initial treatment. Over the course of 5 treatments, the technique resolved the patient’s complaints, while allowing her to return to competition. Additionally, the modified-MWM outcomes allowed the patient to participate in sport activities that day without a return of her symptoms. The potential advantage of the modified MWM is that the mobilization can be administered earlier when chemical pain may prevent the application of the traditional MWM due to patient sensitivity to pressure at the lateral malleolus. As the modified technique still followed Mulligan principles, the early application of
the technique posed little risk to the patient, while allowing earlier application of the MWM to improve patient outcomes and potentially decrease the risk of a patient developing chronic ankle instability.29

CONCLUSION
The outcomes from this case report provide evidence for the incorporation of MWM into the rehabilitation protocol in patients who have suffered a LAS. Additionally, it provides support for the modified-MWM technique that may be applied if the traditional technique cannot be used due to patient reported pain. Further research is needed, however, to determine if the modification consistently produces similar outcomes to the traditional MWM or if there is only a subgroup of patients that will respond to this technique more effectively (e.g., when the patient is too point tender to perform at the lateral malleolus). Patient outcomes on a larger population need to be collected to determine its reliability and validity, while further elucidation is needed to understand the mechanism of action by which the outcomes are produced. Additional research is also needed to determine its long-term effects on chronic ankle instability, and if the modification decreases the period of disablement.

REFERENCES


ABSTRACT

Part 1 of this two-part series (presented in the June issue of IJSPT) provided an introduction to functional movement screening, as well as the history, background, and a summary of the evidence regarding the reliability of the Functional Movement Screen (FMS™). Part 1 presented three of the seven fundamental movement patterns that comprise the FMS™, and the specific ordinal grading system from 0-3, used in their scoring. Specifics for scoring each test are presented.

Part 2 of this series provides a review of the concepts associated with the analysis of fundamental movement as a screening system for functional movement competency. In addition, the four remaining movements of the FMS™, which complement those described in Part 1, will be presented (to complete the total of seven fundamental movements): Shoulder Mobility, the Active Straight Leg Raise, the Trunk Stability Push-up, and Rotary Stability. The final four patterns are described in detail, and the specifics for scoring each test are presented, as well as the proposed clinical implications for receiving a grade less than a perfect “3”.

The intent of this two part series is to present the concepts associated with screening of fundamental movements, whether it is the FMS™ system or a different system devised by another clinician. Such a fundamental screen of the movement system should be incorporated into pre-participation screening and return to sport testing in order to determine whether an athlete has the essential movements needed to participate in sports activities at a level of minimum competency.

Part 2 concludes with a discussion of the evidence related to functional movement screening, myths related to the FMS™, the future of functional movement screening, and the concept of movement as a system.

Key Words: Function, movement screening, movement system

Level of Evidence: 5

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INTRODUCTION
The purpose of movement screening using fundamental movements is to attempt to identify deficient areas of mobility and stability in the asymptomatic active population that may be overlooked with typical impairment-based testing. The ability to predict which athlete or active individual might become injured is highly relevant, and the authors believe, equally as important to rehabilitation professionals as the ability to evaluate and treat injuries. The difficulty in preventing injury appears related to the inability to consistently determine which athletes are predisposed to injury, despite knowing some of their risk factors. This difficulty has been illustrated in the large body of literature that addresses the contributing factors to ACL injury and subsequent attempts by researchers and authors to describe and implement prevention strategies. Algorithms and regression equations exist that attempt to combine risk factors in order to determine who may be at risk of sustaining an ACL injury, however, for many injuries and general disorders, such equations do not exist. Meuwisse suggested that unless specific markers are identified for each individual, the ability to determine who is predisposed to injury remains very difficult.

The vast differences in utilization of many physical and performance tests during pre-participation or return to sport assessments illustrate the difficulty in identifying individuals at risk for injury. Although physical and performance tests are commonly reliable and have some level of normative data, they typically do not expose specific kinetic chain weaknesses. These two evaluation methods offer little insight into individualized fundamental movement strategies that affect the whole of sport performance. Numerous sports medicine professionals have suggested the need for specific screening techniques that utilize a more functional approach in order to identify movement deficits. The authors of this commentary suggest that the type of screening tasks that comprise the Functional Movement Screen™ (FMS™) may be a method of determining such markers that describe a "movement competency baseline".

The FMS™ is an attempt to capture movement pattern quality, and screen for movement competency in uninjured individual, using a simple, ordinal grading system. It is not intended to be used for testing or assessment, but rather to demonstrate limitations or asymmetries with respect to common, fundamental human movement patterns. Tests and assessments are additional tools that can be used to further evaluate impairments of functional movements. The intent of the creators of the FMS™ was to develop a screen of movement that would expose functional limitations, which could in turn lead to an improved proactive approach to injury prevention.

The FMS™ may be used in the pre-participation physical examination, or be used as a stand-alone screening system to determine deficits that may be overlooked during the traditional rehabilitation process, medical, and performance evaluations. In many cases, mobility, stability, strength, or neuromuscular control imbalances may not be identified during traditional screening and assessment. These problems, previously acknowledged as significant risk factors, can be identified using the FMS™. The movement-based assessment serves to pinpoint functional deficits (or biomarkers) related to motor control, mobility, and stability faults. Thus, this system could also be used at the end of the formal rehabilitation process in order to assist (along with strength, power, and functional performance tests when appropriate) in determining an athlete’s readiness to return to function.

Scoring the Functional Movement Screen (FMS™)
The scoring for the FMS™ was provided in detail in Part 1 of this series. However, the exact same instructions for scoring each test are repeated here to allow the reader to score the additional tests presented in Part 2 without having to refer to Part 1. The scoring for the FMS™ consists of four discrete possibilities. The scores range from zero to three, three being the best possible score. The four basic scores are quite simple in philosophy. An individual is given a score of zero if at any time during the testing he/she has pain anywhere in the body. If pain occurs, a score of zero is given and the painful area is noted. This score necessitates further assessment by the professional, and an alternate functional movement assessment system developed for patients with known disability, injury, or pain is called the Selective Functional Movement Assessment (SFMA). Although beyond the scope
of this clinical commentary, the SFMA is a clinical assessment that is designed to systematically identify causes of movement dysfunction while taking pain into consideration, using an algorithmic approach. A score of one is given if the person is unable to complete the movement pattern or is unable to assume the position to perform the movement. A score of two is given if the person is able to complete the movement but must compensate in some way to perform the fundamental movement. A score of three is given if the person performs the movement correctly without any compensation, complying with standard movement expectations associated with each test. Specific comments should be noted describing why a score of three was not obtained.

The majority of the tests in the FMS™ examine both the right and left sides in order to determine if symmetry is present or absent, and it is important that both sides are scored. The lower score of the two sides is recorded and is counted toward the total; however it is important to note imbalances that are present between right and left sides.

Three FMS™ tests presented here in Part 2 (the shoulder mobility test, the trunk stability push-up, and the rotary stability test) have additional clearing screens that are graded as positive or negative. These clearing movements only consider pain, thus, if a person has pain during the screening movement, then that portion of the test is scored positive and if there is no pain then it is scored negative. The clearing tests affect the total score for the particular tests with which they are associated. If a person has a positive clearing test then the score will be zero for the associated test.

All scores for the right and left sides, and those for the tests that are associated with the clearing screens, should be recorded (Appendix A). By documenting all the scores, even if they are zeros, the sports rehabilitation professional will have a better understanding of the impairments identified when performing an evaluation. It is important to note that only the lowest score is recorded and considered when tallying the total score. The best total score that can be attained on the FMS™ is twenty-one. It should be noted that movement screening is not about determining whether someone is moving “perfectly”, it is about whether a person can move above an established minimal standard on basic, fundamental movements. Scores serve to tell the professional when a person needs more investigation or assessment. Movement screening is about observing a series of sample movements and creating a “movement profile” of what a person can and cannot do. It is crucial that rehab professionals profile movement before attempting performance or sport specific testing or prescribing exercises.

**DESCRIPTION OF THE FMS™ TESTS**

The following are descriptions of the final four specific test movements used in the FMS™ and their specific scoring strategies. Each test is followed by tips for testing developed by the authors as well as clinical implications related to the findings of the test. It should be noted that the descriptions of the movements or their test criteria/scoring criteria have not changed substantially since their initial descriptions in the literature, and therefore, are repeated here.

**Shoulder Mobility**

**Purpose:** The shoulder mobility screen assesses bilateral and reciprocal shoulder range of motion, combining internal rotation with adduction of one shoulder and external rotation with abduction of the other. The test also requires normal scapular mobility and thoracic spine extension.

**Description:** The tester first determines the hand length by measuring the distance from the distal wrist crease to the tip of the third digit in inches. The individual is then instructed to make a fist with each hand, placing the thumb inside of the fist. They are then asked to assume a maximally adducted, extended, and internally rotated position with one shoulder and a maximally abducted, flexed, and externally rotated position with the other. During the test, the hands should remain in a fist and the fists should be placed on the back in one smooth motion. The tester then measures the distance between the two bony prominences. Perform the test as many as three times bilaterally. (Figures 1-3)

**Tips for Testing:**

- The flexed shoulder identifies the side being scored.
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• If the hand measurement is exactly the same as the distance between the two points, score the subject low.

• The clearing test, if positive, overrides the score on the rest of the test.

• Make sure the individual does not try to “walk” the hands toward each other.

Clearing Exam: A clearing exam should be performed at the end of the shoulder mobility test. This movement is not scored; rather it is performed to observe a pain response. If pain is produced, a score of zero is given to the entire shoulder mobility test. The clearing exam is necessary because shoulder impingement can go undetected by the shoulder mobility testing alone. The individual places his/her hand on the opposite shoulder and then attempts to point the elbow upward (Figure 4). If there is pain associated with this movement, a positive (+) is recorded on the score sheet, and a score of zero is given. It is recommended that a thorough evaluation of the shoulder complex be performed. This screen should be performed bilaterally.

Clinical Implications for Shoulder Mobility: The ability to perform the shoulder mobility test requires mobility in a combination of motions including abduction/external rotation, flexion extension, and adduction/internal rotation. This test also requires scapular and thoracic spine mobility.

Poor performance during this test can be the result of several causes, one of which is the widely accepted explanation that increased external rotation is gained at the expense of internal rotation in overhead throwing athletes. In addition, excessive development and shortening of the pectoralis minor or latissimus dorsi muscles can cause postural alterations including rounded or forward shoulders. Finally, scapulothoracic dysfunction may be present, resulting in decreased glenohumeral
mobility secondary to poor scapulothoracic mobility or stability. When an athlete achieves a score less than a “3”, the limiting factor must be identified. Clinical documentation of these limitations can be obtained by using standard goniometric measurements of the joints as well as muscular flexibility tests such as Kendall’s test for pectoralis minor and latissimus dorsi, or Sahrmann’s tests for shoulder rotator tightness and additional examination techniques for assessment of capsular tightness. This test also requires asymmetric movement because the arms travel in opposite directions. Both arms must move simultaneously, which requires postural control and core stability. Previous testing has identified that when an athlete achieves a score of a “2”, minor postural changes or shortening of isolated axio-humeral or scapula-humeral muscles exist. When an athlete scores a “1” or less, a scapulothoracic dysfunction may exist.

The Active Straight Leg Raise

**Purpose:** The active straight leg raise (ASLR) tests the ability to disassociate the lower extremity from the trunk while maintaining stability in the torso.

The ASLR test assesses active hamstring and gastrosoleus flexibility while maintaining a stable pelvis and core, and active extension of the opposite leg.

**Description:** The individual first assumes the starting position by lying supine with the arms in anatomical position, legs over the 2 x 6 board, and head flat on the floor. The tester then identifies the midpoint between the anterior superior iliac spine, and the midpoint of the patella of the leg on the floor, and a dowel is placed at this position, perpendicular to the ground. Next the individual is instructed to slowly lift the test leg with a dorsiflexed ankle and an extended knee. During the test the opposite knee (the down leg) must remain in contact with the ground and the toes pointed upward, and the head in contact with the floor. Once the end range position is achieved, note the position of the upward ankle relative to the non-moving limb. If the malleolus does not pass the dowel, move the dowel, much like a plumb line, to equal with the malleolus of the test leg, and score per the criteria. (Figures 5-7)

**Tips for Testing:**
- The moving limb identifies the side being scored
- Make sure the non-moving leg (on the floor) maintains a neutral position (no hip external rotation)
Clinical Implications for Active Straight Leg Raise: The ability to perform the ASLR test requires functional hamstring, gluteal, and iliotibial band flexibility, all of which are required for training and competition. This is different from passive flexibility, which is more commonly assessed. The athlete is also required to demonstrate adequate hip mobility of the opposite leg and pelvic and core stability. Poor performance during this test can be the result of several factors. First the athlete may lack functional hamstring flexibility. Second, the athlete may have inadequate mobility of the opposite hip, stemming from iliopsoas inflexibility associated with an anteriorly tilted pelvis. If this limitation is gross, true active hamstring flexibility will not be realized. A combination of these factors will demonstrate an athlete’s relative bilateral, asymmetric hip mobility. Like the hurdle step test, the ASLR test reveals relative hip mobility; however, this test is more specific to the limitations imposed by the muscles of the hamstrings and the iliopsoas.

When an athlete achieves a score less than a “3”, the limiting factor must be identified. Clinical documentation of limitations can be obtained by using Kendall’s sit and reach test, or the 90-90 active straight leg raise test for hamstring flexibility. The Thomas test can be used to identify iliopsoas inflexibility. Previous testing has identified that when an athlete achieves a score of “2”, minor asymmetric hip mobility limitations, moderate isolated, unilateral muscle tightness may exist, or a stability dysfunction of the non-moving limb may be present. When an athlete scores a “1” or less, gross relative hip mobility limitations are common.

The Trunk Stability Push-Up

Purpose: The trunk stability push-up tests the ability to stabilize the core and spine in an anterior and posterior plane during a closed-chain upper body movement. The test assesses trunk stability in the sagittal plane while a symmetrical upper extremity push-up motion is performed.

Description: The individual assumes a prone position with the feet together. The hands are placed shoulder width apart at the appropriate position per the described criteria. During this test, men and women have different starting arm positions. Men begin with their thumbs at the top of the forehead, while women begin with their thumbs at chin level.

- Both knees must remain extended, and the leg on the floor must remain in contact with the floor
- If the dowel resides at exactly the mid point, score low.

Figure 6: Performance of the active straight leg raise test, scored as a “2”. Note the vertical line of the malleolus of the tested leg resides between the mid-thigh and the knee joint line. The non-moving limb must remain in the neutral position.

Figure 7: Performance of the active straight leg raise test, scored as a “1”. Note the vertical line of the malleolus of the tested leg resides below the knee joint line. The non-moving leg must remain in the neutral position.
The knees are fully extended and the ankles dorsiflexed. The individual is asked to perform one push-up in this position. The body should be lifted as a unit; no “lag” (or arch) should occur in the lumbar spine when performing the movement. If the individual cannot perform a push-up in this position, the thumbs are moved to the next easiest position, chin level for males, shoulder level for females, and the push-up is attempted again. The trunk stability push-up can be performed a maximum of three times. (Figures 8 a, b, c, d)

**Tips for Testing:**

- The athlete should lift the body as a unit.
- Make sure that the original hand position is maintained and that the hands do not slide down as they prepare to lift
- Make sure that the chest and stomach come off of the floor at the same time
- When in doubt, score low
- A positive clearing test overrides the test score, making the score a 0.

**Clearing Exam:** A clearing exam is performed at the end of the trunk stability push-up test. This movement is not scored; the test is simply performed to observe a pain response. If pain is produced, positive is recorded on the score sheet and a score of zero is given for the test. This clearing exam is necessary because back pain can go undetected during movement screening. (Figure 9)

**Clinical Implications for the Trunk Stability Push-Up:** The ability to perform the trunk stability push-up requires symmetric trunk stability in the sagittal plane during a symmetric upper extremity movement. Many functional activities in sport require the trunk stabilizers to transfer force symmetrically from the upper extremities to the lower extremities and vice versa. Movements such as rebounding in basketball, overhead blocking in volleyball, or pass blocking in football are common examples of this type of energy transfer. If the trunk does not have adequate stability during these activities, kinetic energy will be dispersed and lead to poor functional performance, as well as the potential for micro traumatic injury.

Poor performance during this test can be attributed to poor stability of the trunk/core stabilizers. When an athlete achieves a score less than “3”, the limiting factor must be identified. Clinical documentation of these
The limitations can be obtained by using tests by Kendall,9 Richardson et al,12 Sahrmann,10 or bridging tests11 for both upper and lower abdominal and trunk strength. However, it should be noted that the strength tests by Kendall requires either concentric or eccentric contraction, while the trunk stability push-up requires an isometric (stabilizing) contraction (more like a bridge test) to avoid spinal hyperextension during the raising phase of the push-up. A stabilizing contraction of the core musculature is more fundamental and appropriate than a simple strength test, which may isolate one or two key muscles. At this point in the FMS™, the muscular deficit should not be assessed and a complete diagnosis rendered, rather, the examiner should note that performance on the screening test simply implies poor trunk/core stability in the presence of a trunk extension force, and further examination at a later time is needed to formulate a diagnosis.

Rotary Stability

**Purpose:** The rotary stability test is a complex movement requiring proper neuromuscular coordination and energy transfer from one segment of the body to another through the torso. The rotary stability test assesses multi-planar trunk stability during a combined upper and lower extremity motion.

**Description:** The individual assumes the starting position in quadruped, their shoulders and hips at 90-degree angles, relative to the torso, with the 2 x 6 board between their hands and knees. The knees are positioned at 90 degrees and the ankles should be dorsiflexed. The individual then flexes the shoulder and extends the same side hip and knee. The leg and hand are only raised enough to clear the floor by approximately 6 inches. The same shoulder is then extended and the knee flexed enough for the elbow and knee to touch. This is performed bilaterally, for up to three attempts each side. If the individual cannot complete this maneuver (score a “3”), they are then instructed perform a diagonal pattern using the opposite shoulder and hip in the same manner as described for the previous test. They are also allowed three attempts at this test. (Figures 10 a, b; 11 a, b; 12 a,b)

**Tips for Testing:**

- The upper extremity that moves indicates the side being tested. Even if the individual receives a “3”, the test must be performed bilaterally and results recorded on the score sheet.
- The moving limbs must remain over the 2 x 6 board to achieve a score of “3”
- The elbow and knee must touch during the flexion part of the movement
- Make sure that the spine is flat, and the hips and shoulders are at right angles to begin the test

![Figure 9: Spinal extension clearing test. The subject performs a press-up in from the pushup position. If there is pain associated with this motion, give a score of “0” and conduct a more thorough examination.](image)

![Figure 10: Performance of the rotary stability test, scored as a “3”. The subject performs a correct unilateral repetition. A. Extended position (does not have to be > 6-8” off the ground). B. Flexed position, elbow and knee must meet. Note: must maintain narrow upper and lower extremity weight bearing over the 2 x 6 board without major weight shift away from the board.](image)
• Provide cueing to let the individual know that he/she does not need to raise the arm and leg more than 6 inches off of the floor
• When in doubt score low
• Do not try to interpret the score when screening

Clearing Exam: A clearing exam is performed at the end of the rotary stability test. This movement is not scored; it is performed to observe a pain response. If pain is produced, a positive is recorded on the score sheet and a score of zero is given for the test. This screening test is necessary because back pain can sometimes go undetected by movement screening.

Spinal flexion is cleared by assuming a quadruped position, and then rocking back and touching the buttocks to the heels and the chest to the thighs (Figure 13). The hands should remain in front of the body, reaching out as far as possible.

Clinical Implications for Rotary Stability: The ability to perform the rotary stability test requires asymmetric trunk stability in both the sagittal and transverse planes during asymmetric upper and lower extremity movement. Many functional activities in sport require the trunk stabilizers to transfer force asymmetrically from the lower extremities to the upper extremities and vice versa. Running and exploding out of a down stance in track and football are common examples of this type of energy transfer. If the trunk does not have adequate stability during these activities, kinetic energy will be dispersed (lost), leading to poor performance and increased potential for injury.

Poor performance during this test movement can be attributed to poor stability of the trunk (core) stabilizers. When an athlete achieves a score less than “3”, the limiting factor must be identified. Clinical documentation of these limitations can be obtained similarly to those limitations found in the trunk stability push
up, by using Kendall’s manual muscle tests for upper and lower abdominals,9 Sahrmann’s grading system for the lower abdominals, or bridging tests.10,11

KEY CONCEPTS RELATED TO THE FMS™
The authors of this clinical commentary suggest that the FMS™ is an important way to consider human movement at a pattern and functional level, which can be used both at the end of the rehabilitation process and at the beginning of a new fitness or conditioning endeavor. It is simply an appraisal of fundamental human movement, designed to identify a movement baseline by using a series of basic movement patterns performed with an individual’s body weight alone (henceforth referred to as 1x BW).

Let’s review. Start with the title: The Functional Movement Screen, and note the three operational words: Function is placed at the beginning to represent the absence of dysfunction within movement patterns. Movement designates the physical quality that is being appraised. Finally, the last word Screen demonstrates clearly that this is not a test, evaluation, or assessment. This exact type of thinking is well received, and commonplace in almost every other system of the body, where screens or screening procedures are central to the consideration of a body system. Consider the analogy of the blood pressure (BP) cuff. The BP cuff is used to place people into a “normal”, “hypotensive”, or “hypertensive” category. In most screening situations, the attempt is made to discern whether hypertension is present. Once hypertension is identified, the BP cuff is no longer needed to identify why the condition is occurring. Other tests, measurements, and diagnostic tools are used for that process.

This analogy holds for the FMS™. The screen serves a directional role, not a diagnostic role. If in some area you screen below a cut point, you are sent for further assessment or evaluation. In healthcare, this means greater investigation into biomarkers that could infer a potential problem or issue. Whereas, if you screen above the cut, the screen demonstrates a level of competency that can and could be tested in a more aggressive or higher threshold manner in order to describe fitness or performance deficits.

Thus, the FMS™ was never intended to be an assessment or evaluation; it was simply put in place as a user-friendly tool to identify questionable movement that falls into a dysfunctional category. Describing dysfunction of the movement system had to start somewhere!

REVIEW OF RESEARCH RELATED TO THE FMS™
As mentioned in Part 1 of this series, the FMS™ appears to be a relatively reliable test both between different raters and between different rating sessions performed by the same rater.13,14 The mean FMS™ scores in healthy, young active individuals range from 14.14 ± 2.85 points to 15.7 ± 1.9 points. This suggests that most untrained people are slightly above the cut-off score of ≤14 points, which is thought to be indicative of compensation patterns, increased risk of injury, and reduced performance.14,15

Several researchers have examined the ability of the FMS™ to determine who is at risk for injury or predict injury in various populations,16-19 however, many question the validity of the FMS™ for predicting injury or risk, for several reasons. First, the FMS™ should not be considered a unitary construct, as the total score cannot be treated as a cluster variable that estimates something as general and difficult to predict as injury. Stated differently, the use of a total FMS™ score for predicting injury risk should be avoided, as the individual components of the test are not correlated with one another and are therefore not measuring the same underlying variable.14 A total score below 14 indicates greater relative risk, however the converse is not true, at total score greater than 14 does not mean lower relative risk. And finally, it appears the knowledge of the test criteria appears to affect the outcome of the test.20

The use of a total FMS™ score alone for predicting injury risk may not be sufficient, as performance assessments executed at sports-specific demands and speeds differ substantially from those performed during the fundamental movements that comprise the FMS™. For example, power, endurance, change of direction, and other functional constructs are not included in the FMS™ screening. This means that an athlete could perform a completely different compensation pattern on the field of play compared to when carrying out the 1x BW screens. The creators of the FMS™ are fully aware of this limitation, and
advocate for using additional tests (greater than 1x BW, power, and sport specific screens and tests) for a complete assessment of readiness to compete or return to competition.

MISCONCEPTIONS AND MYTHS OF THE FMS™

Misconception #1: The Functional Movement Screen is designed to be diagnostic. Reality: it is designed to be a SCREEN, to determine movement competency, with 1x BW during fundamental movements that incorporate mobility, stability, and motor control. It was never intended to be a test or an assessment, which would be diagnostic, as compared to screening.

Misconception #2: The Functional Movement Screen results relate to how the person will perform under load or in competition. Reality: the goal of the Functional Movement Screen is not to measure sport performance. So the research studies that are trying to see if it relates to sport performance really miss the mark. Recall, the FMS™ is screen of 1x BW fundamental movement competency, and additional assessment is necessary to determine sport performance capabilities.

Misconception #3: All athletes should strive to get a “perfect” score. Reality: A higher score is not necessarily better! This is a screen used to describe or characterize an individuals' movement competency, thus attempting to reach a score of 21 is not the goal. Looking at raw numbers is not enough. Rather, it is important to identify asymmetries and 0's. Several sport specific exceptions to this rule exist, e.g. the overhead throwing athletes' lack of symmetry in glenohumeral joint rotation. The authors acknowledge that asymmetries exist in the athletic population, and many are sport specific. Performance asymmetries tend to occur more distally, whereas asymmetries in motor control tend to occur more proximally. Thus, proximal symmetry (e.g. of the core) is of greater importance and is more addressable than distal symmetry and should be addressed with corrective exercises.

The authors believe if someone scores well (within the norms) on the FMS™ that he/she can still be at risk of injury because of several factors, including but not limited to, poor landing mechanics, strength, endurance, agility, or power deficits. But if he/she has scored within the established norms (demonstrated movement competency), it is likely that he/she possesses the fundamental movement capability to improve those higher-level performance measures (Figure 14).

SUMMARY AND IMPLICATIONS FOR PRACTICE: “THE SO WHAT”

If movement is characterized into three categories, movement health, movement competency, and movement capacity, it is apparent that a movement screen is beneficial to the sports physical therapist. If all movement into "lumped" into a single category, a screen is of little use, however these three different descriptive categories of movement are what began the authors’ investigation into screening.

Movement Health: If movement health is defined as ability, then the opposite of that would be disability. When an athlete has structural changes, neurological insult, significant injuries involving inflammation, and acute, chronic, or permanent limitations to movement, then these should be investigated with a more sensitive movement tool than a screen. The FMS™ does not try to do this! Simply stated, it is not designed to be performed with people who demonstrate pain or other health-related concerns.

Figure 14: Functional Movement Systems. This diamond-shaped representation of related functional movement tools demonstrates where the FMS™ fits into the bigger picture of functional assessment. Note that it resides above the horizontal line indicating pain, and below specific performance tests and skill testing, indicating it’s role as a screen for movement competency. Of note, below the line indicating pain is the SFMA and impairment-based examination and assessment.
Movement Competency: Movement competency is something that must be established and investigated because at this time risk factors for movement dysfunction are incompletely described. In contrast, assessable risk factors have been described for almost every other system of the body, and signs of dysfunction (risk factors) emerge before the symptoms of dysfunction and/or disease or disability present. Even though people are out of health risk or pain with regard to movement, it does not mean that they are necessarily optimally “functional”. This simple fact may explain why movement dysfunction is so prevalent. Consider an important example related to movement: the segment of the population that is at high risk for falls has been identified, however, fall risk assessment is typically not performed until the first fall occurs. This is missing an important opportunity for primary prevention. Health providers are more proactive with risk assessment in almost every other body system (cardiovascular, pulmonary, endocrine) than the movement system. The take home message: fundamental movement screening is intended to identify and describe movement competency (or lack thereof) and determine whether it needs to be further investigated (Figure 15).

The last level of movement screening is that of movement capacity, which is greater than competency. Competency simply means that the movement system is working proficiently, and a solid foundation exists upon which to build performance. In the presence of movement competency, positive adaptations related to training should occur. Whereas, in cases of movement dysfunction (limitations in mobility, stability, and motor control) the same stress might cause unnecessary risk or at a bare minimum, wasted exercise time without the associated benefits of that investment. Movement capacity or physical capacity is where deficiencies are common. For example, an athlete displays movement competency but has extremely low endurance (capacity), which can be explained by the lack of training. The same illustration works for decreased strength. It should be noted that with regard to strength, it is most relevant to compare an individual to an age relative, gender specific norm or expectation. Age and gender specific comparisons are the best way to examine specific deficiencies in power, work capacity, speed, agility, and quickness.

When movement is examined relative to these three categories, the thinking regarding utility of screening becomes apparent: a screen creates direction. The screen can alert a practitioner to movement health issues, movement competency issues, and also can clear the individual for greater investigation into movement capacity. A screen such as the FMS™ sits in a unique, central place, not as a diagnostic tool, or as a stand-alone test, but as an appraisal of movement in both loaded and unloaded conditions, that represents some of the basic patterns of human movement. Screens exist in many other health and body systems but health providers lack clarity when it comes to screening of the movement system.

The authors of this clinical commentary are completely aware that screens, tests, evaluations, and assessments are simply methods that will grow, change, and become more refined toward specific goals. If the definitions of movement health, movement competency, and movement capacity are utilized, then the best screens, tests, and assessments will emerge. To initiate action and be a part of the process, the authors introduced the FMS™ and the SFMA as attempts to address movement patterns instead of isolated joint measurements.

The authors of this commentary have understood for quite some time that movement is a vital component of the human experience, because in human movement, the whole is greater than the sum of its parts. The recently adopted vision statement of the American Physical Therapy Association, state-
ment for the profession of Physical Therapy in 2013: “Transforming society by optimizing movement to improve the human experience”\textsuperscript{21,p.18} illustrates the commitment of the profession of physical therapy to placing movement at the center of physical therapist practice. In fact, discussion began some time ago regarding the definition of the movement system, developed with the help of Florence Kendall:

The movement system is a physiological system that functions to produce motion of the body as a whole or of its component parts. The functional interaction of structures that contribute to the act of moving.\textsuperscript{22}

Recently, Dr. Shirley Sahrmann has begun a profession-wide discourse on promotion of movement as a physiologic system, promoting an emphasis on pathokinesiology versus pathoanatomy. She advocates for making the human movement system be the cornerstone for physical therapist practice, education, and research across the practice spectrum and lifespan.\textsuperscript{23} The authors of this commentary agree wholeheartedly with Dr. Sahrmann, when she states: “We should incorporate more detailed observation and analysis of movement while patients perform functional activities into standardized physical therapist examinations”.\textsuperscript{23,p.1041} The authors believe that it is important for all PT’s to assess fundamental movement competency, as a starting point, regardless of the screening system you use.

As other systems are developed they may add to the practice of movement assessment, and may be utilized in addition to or instead of the FMS\textsuperscript{™}. After the “starting point” of fundamental movement competency is determined and deemed appropriate, this paves the way for use of higher-level functional assessments that include > 1x BW strength and performance/skill assessments.

The Functional Movement Screen\textsuperscript{™} is the registered trademark of FunctionalMovement.com. Gray Cook and Lee Burton have disclosed a financial interest in Functional Movement Systems. The Editors of IJSPT emphasize (and the authors concur) that the use of fundamental movements as an assessment of function is the important concept to be taken from Part 1 and Part 2 of this series and can be performed without the use of trademarked equipment.

REFERENCES


APPENDIX A

THE FUNCTIONAL MOVEMENT SCREEN

SCORING SHEET

<table>
<thead>
<tr>
<th>NAME</th>
<th>DATE</th>
<th>DOB</th>
</tr>
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<tbody>
<tr>
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<td></td>
</tr>
<tr>
<td>CITY, STATE, ZIP</td>
<td>PHONE</td>
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<tr>
<td>SCHOOL/AFFILIATION</td>
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<tr>
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<td>HEIGHT</td>
<td>WEIGHT</td>
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<td>PRIMARY POSITION</td>
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<tr>
<td>HAND/LEG DOMINANCE</td>
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<table>
<thead>
<tr>
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<th>FINAL SCORE</th>
<th>COMMENTS</th>
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<tr>
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<td></td>
</tr>
<tr>
<td>HURDLE STEP</td>
<td>L</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>INLINE LUNGE</td>
<td>L</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>SHOULDER MOBILITY</td>
<td>L</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>IMPINGEMENT CLEARING TEST</td>
<td>L</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>ACTIVE STRAIGHT-LEG RAISE</td>
<td>L</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>TRUNK STABILITY PUSHUP</td>
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<td>PRESS-UP CLEARING TEST</td>
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<td>ROTARY STABILITY</td>
<td>L</td>
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<td>POSTERIOR ROCKING CLEARING TEST</td>
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<tr>
<td>TOTAL</td>
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</table>

**Raw Score**: This score is used to denote right and left side scoring. The right and left sides are scored in five of the seven tests and both are documented in this space.

**Final Score**: This score is used to denote the overall score for the test. The lowest score for the raw score (each side) is carried over to give a final score for the test. A person who scores a three on the right and a two on the left would receive a final score of two. The final score is then summarized and used as a total score.
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