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# TABLE OF CONTENTS

## VOLUME 12, NUMBER 2

<table>
<thead>
<tr>
<th>Page Number</th>
<th>Article Title</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ORIGINAL RESEARCH</strong></td>
<td></td>
</tr>
</tbody>
</table>
| 163 | Two-Dimensional Video Analysis is Comparable to 3D Motion Capture in Lower Extremity Movement Assessment.  
*Authors: Schuur SA, Marshall AN, Resch JE, Saliba SA* |
| 173 | Prediction of Functional Movement Screen Performance from Lower Extremity Range of Motion and Core Tests  
*Authors: Chimera NJ, Knwell S, Cooper R, Kothe N, Smith C, Warren M* |
| 182 | Determination of Clinically Relevant Differences in Frontal Plane Hop Tests in Women's Collegiate Basketball and Soccer Players  
*Authors: Hardesty K, Hegedus EF, Ford KR, Nguyen AD, Taylor JB* |
| 190 | Intra-Rater Reliability of the Multiple Single-Leg Hop-Stabilization Test and Relationships with Age, Leg Dominance and Training  
*Authors: Sawle L, Freeman J, Marsden J* |
| 199 | The Effect of Fatigue on Upper Quarter Y-Balance Test Scores in Recreational Weightlifters: A Randomized Controlled Trial.  
*Authors: Salo TD, Chaconas E* |
| 206 | Prospective Functional Performance Testing and Relationship to Lower Extremity Injury Incidence in Adolescent Sports Participants.  
*Authors: Smith J, DePhilippe N, Kimura I, Kocher M, Hetzler R* |
| 219 | The Acute Effects of Concentric Versus Eccentric Muscle Fatigue on Shoulder Active Repositioning Sense.  
*Authors: Spargoli G* |
| 227 | Establishing Normative Change Values in Visual Acuity Loss during the Dynamic Visual Acuity Test  
*Authors: Marquez C, Lunger M, Raab S* |
| 233 | Variation in Medial and Lateral Gastrocnemius Muscle Activity with Foot Position  
*Authors: Chibulka M, Wenthe A, Boyfe Z, Callher D, Schwerdt A, Jarman D, Strube MJ* |
| 242 | Comparison of Video-guided, Live Instructed, and Self-Guided Foam Roll Interventions on Knee Joint Range of Motion and Pressure Pain Threshold: A Randomized Controlled Trial.  
*Authors: Cheatham SW, Kolber MJ, Cain M* |
| 250 | Investigating the Effectiveness of Kinesio® Taping Space Correction Method in Healthy Adults on Patellofemoral Joint and Subcutaneous Space  
*Authors: Lyman KJ, Keister K, Gange K, Mellinger CD, Hanson TD* |
| **CASE STUDIES** | |
| 258 | A Six-Week Supervised Exercise and Educational Intervention After Total Hip Arthroplasty: A Case Series  
*Authors: Pozzi F, Maikara K, Zeni JA* |
| **CLINICAL COMMENTARY** | |
| 273 | Current Concepts on the Genetic Factors in Rotator Cuff Pathology and Future Implications for Sports Physical Therapists.  
*Authors: Orth T, Pare J, Froehlich JE* |
| 286 | A Conceptual Model for Physical Therapists Treating Athletes with Protracted Recovery following a Concussion  
*Authors: Lundblad M* |
| 297 | Improving the Reporting of Therapeutic Exercise Interventions in Rehabilitation Research  
*Authors: Page P, Hoogenboom B, Voight ML* |
ABSTRACT

Background: Although 3D motion capture is considered the "gold standard" for recording and analyzing kinematics, 2D video analysis may be a more reasonable, inexpensive, and portable option for kinematic assessment during pre-participation screenings. Few studies have compared quantitative measurements of lower extremity functional tasks between 2D and 3D.

Purpose: To compare kinematic measurements of the trunk and lower extremity in the frontal and sagittal planes between 2D video camera and 3D motion capture analyses obtained concurrently during a SLS.

Study Design: Descriptive laboratory study.

Methods: Twenty-six healthy, recreationally active adults volunteered to participate. Participants performed three trials of the single leg squat on each limb, which were recorded simultaneously by three 2D video cameras and a 3D motion capture system. Dependent variables analyzed were joint displacement at the trunk, hip, knee, and ankle in the frontal and sagittal planes during the task compared to single leg quiet standing.

Results: Dependent variables exhibited moderate to strong correlations between the two measures in the sagittal plane ($r = 0.51 - 0.93$), and a poor correlation at the knee in the frontal plane ($r = 0.308$) at ($p \leq 0.05$) All other dependent variables revealed non-significant results between the two measures. Bland-Altman plots revealed strong agreement in the average mean difference in the amount of joint displacement between 2D and 3D in the sagittal plane (trunk = 1.68º, hip = 2.60º, knee = 0.74º, and ankle = 3.12º). Agreement in the frontal plane was good (trunk = 7.92º, hip = -8.72º, knee = -6.62º, and ankle = 3.03º).

Conclusion: Moderate to strong relationships were observed between 2D video camera and 3D motion capture analyses at all joints in the sagittal plane, and the average mean difference was comparable to the standard error of measure with goniometry. The results suggest that despite the lack of precision and ability to capture rotations, 2D measurements may provide a pragmatic method of evaluating sagittal plane joint displacement for assessing gross movement displacement and therein risk of lower extremity injury.

Level of Evidence: 3

Key Words: Movement pattern, sagittal plane, screening, single leg squat

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INTRODUCTION

Many athletic movement patterns, including decelerating, cutting, pivoting, and landing from a jump, have been linked to an increased risk of lower extremity injury.1-4 Dynamic knee valgus (DKV) is often described in the literature as a biomechanical risk factor for lower extremity injury, and it has been reported to prospectively contribute to anterior cruciate ligament (ACL) injury as well as to the development of patellofemoral pain (PFP).5,7 Furthermore, deficits in dynamic stability of the trunk8 and lower extremity asymmetries7,9 have been purported as mechanisms that initiate this faulty position and contribute to injury risk.

Functional assessments such as the Functional Movement Screen™,10 Selective Functional Movement Assessment,10 Star Excursion Balance Test,11 and the Landing Error Scoring System12 all have the ability to identify discrepancies in movement quality. Common clinical limitations among these assessments are the lack of measurable kinematic output, the training required for testing, and the time involved with test administration. While some observational screenings have been shown to be valid and reliable,12-14 others have exhibited poor reliability,15 and inadequate sensitivity.16 Previous literature has identified that rater experience,15 perception,17 and visual acuity17 may play a significant role in the standardization of observational screenings. The ability to easily identify quantifiable kinematic risk factors for lower extremity injury may allow sports medicine professionals to intervene more effectively and enable them to educate athletes about sport-specific, at-risk positions. The single leg squat (SLS) has been used as a qualitative measure to evaluate lower extremity injury risk.18,19 While this task is simple, and can identify unilateral dysfunction,20 kinematic evaluation is not commonly included in the SLS assessment.

Laboratory-based 3-Dimensional (3D) motion capture systems are considered the “gold standard” in the evaluation of biomechanical risk factors.21 These systems are reliable22,23 during many functional tasks and can accurately determine multi-planar and dimensional kinematics, including rotational forces across joints. However, 3D motion capture systems have limited application in the clinical setting due to the high-priced equipment and time consuming set-up, application of multiple electromagnetic sensors that do not always relate well to the performance of functional tasks, and difficulty to incorporate into pre-season screenings. Video screenings are a potential solution to the current limitations (e.g. portability, time and cost effectiveness, and standardization) in the aforementioned clinical movement assessments. Video assessments can take place in a physical therapy clinic or physician’s office and results can be readily discussed using phone or tablet applications. Additionally, these 2-dimensional (2D) video systems are portable, time and cost effective, and require little training.21 Since the majority of knee injury risk factors occur in the cardinal planes of movement, it was hypothesized that video analysis in the sagittal and frontal planes would be comparable to the same kinematic measures using 3D motion capture. Currently, limited research has addressed the relationship between 2D and 3D methods of kinematic analysis during functional tasks. Gwynne et al reported moderate to strong correlations between 2D and 3D analyses at the knee in frontal plane during the SLS ($r = 0.64-0.78$).24 The study, however, did not compare data from the two systems collected during the same session. Similarly, Ayala et al found a strong relationship between 2D and 3D analyses at the knee in the frontal plane during the drop vertical jump ($r = 0.82-0.97$).25 A limitation of both of these studies was the absence of a sagittal plane evaluation during the functional task. Therefore, the purpose of this study was to compare kinematic measurements of the trunk and lower extremity in the frontal and sagittal planes between 2D video camera and 3D motion capture analyses obtained concurrently during a SLS.

METHODS

This was a descriptive laboratory study with a single session of data collection. The independent variable was observation method at two levels: 2D video camera analysis and 3D motion capture. The dependent variables included joint displacement at the trunk, hip, knee, and ankle in the frontal and sagittal planes. These variables were calculated as the displacement between the kinematic value at quiet standing and the corresponding kinematic value at peak knee flexion, for each joint.
Participants
Twenty-six healthy and recreationally active adults (age: 22.26 ± 2.99 years, height: 1.70 ± 0.12 meters, mass: 67.43 ± 12.24 kilograms) were recruited as a volunteer sample of convenience from a University setting and the surrounding community. An a priori sample size estimate was performed based on previously published data exhibiting a correlation coefficient of 0.36 and effect size of 0.60 between 2D and 3D measurements of knee valgus during a side jump task. It was estimated that 26 total subjects would be sufficient to find statistically significant differences at an α level of 0.05, and power (1-β) of 0.80. Participants were excluded from the study if they reported a history of lower extremity surgery, history of lower extremity injury within the last year, or any lower extremity or balance condition that may have affected the participant’s ability to complete the task. The study was approved by the University of Virginia’s Institutional Review Board and each participant provided written informed consent prior to the start of data collection.

Three-Dimensional Motion Capture
Lower extremity joint kinematics were recorded with the Flock of Birds 6 degrees-of-freedom electromagnetic tracking system (Ascension Technology Inc., Burlington, VT, USA) and integrated with the Motion Monitor Software (version 8.85, Innovative Sports Training, Inc., Chicago, IL, USA). Ten electromagnetic sensors were secured with double-sided adhesive tape and non-adhesive elastic wrap to the subject’s skin: one on each calcaneus, one on the dorsal aspect of each foot, one on the middle third of each lateral shank, one on the middle third of each lateral thigh, one over the sacrum, and one at T1 (Figure 1). Height, mass, and joint centers were subsequently calibrated using the stylus. Sensors were secured and digitized by the same clinician for each participant. Kinematic data were collected at a sampling rate of 144 Hz.

Figure 1. 2D retroreflective marker (black circles) and 3D electromagnetic sensor (gray squares) locations.
Two-Dimensional Video Camera
Fifteen anatomical landmarks were identified with retroreflective markers and secured with double-sided adhesive tape to the subject's skin: one at the sternoclavicular notch, one on each acromioclavicular joint, one on each anterior superior iliac spine, one on each medial joint line of the knee, one on each lateral joint line of the knee, one on each medial malleolus, one on each lateral malleolus, and one on each base of the fifth metatarsal (Figure 1). Retroreflective markers were affixed by the same clinician for each participant, with a level of accuracy of less than 8mm. Two-dimensional videos of the SLS were captured using three Canon Vixia HF R42 digital cameras (Canon USA, Inc., Melville, NY, USA). Each camera was placed on a tripod at a height of 1.2 meters from the floor, and at a distance of 2.4 meters from the participant. One camera was placed in the sagittal plane, and two were placed in the frontal plane (one anterior, one posterior). Each camera was leveled using the Bubble Level application (version 2.1, Lemondo Entertainment, www.lemondo.com) on the clinician's smartphone. Two-dimensional data were collected at a sampling rate of 60 frames per second.

Data Collection Procedures
The participants performed three trials of a SLS on each leg (order randomized), for a total of six trials. Participants received verbal standardized instructions on the performance of the SLS maneuver from the researcher and were permitted up to three practice trials per leg. Each participant was instructed to look straight ahead, stand on the test limb with the opposite knee flexed to approximately 90°, and fold his or her arms across their chest. They were then asked to squat down as far as comfortably possible without losing balance, and to return to the starting position. Each SLS task was recorded individually, capturing the quiet single leg stance through the self-selected peak knee flexion, and back to the starting position. A trial was discarded if: the participant lost balance during the movement; the clinician determined that the movement was uncontrolled; a reflective marker or sensor fell off; or the trial was interrupted. The participant was permitted as much rest as they felt necessary between repetitions, and after three successful trials the participant repeated the process on the opposite limb.

3D Data Processing
Kinematic data was collected at 144 Hz for the ankle, knee, hip, and trunk during the six total trials of the SLS task for each participant. Lower extremity joint rotations were calculated using the Euler rotation method in the following order: Y (flexion-extension axis) X (abduction-adduction axis), Z (internal-external rotation axis). The hip joint center of rotation was determined using the Bell method. Data was filtered using a 4th order low-pass Butterworth filter at 6 Hz. For each trial, one virtual event marker was placed at quiet standing, and one virtual event marker was placed at peak knee flexion. Kinematic values at each joint that corresponded with peak knee flexion were extracted and compared with quiet standing to determine joint displacement.

2D Data Processing
Two-dimensional videos were processed using Kinovea Software (version 0.8.15, Kinovea Open Source Project, www.kinovea.org). For each trial, two still images were created in the frontal and sagittal planes (one at quiet standing, one at peak knee flexion). On each still image, the clinician measured joint angles at the trunk, hip, knee, and ankle using the retroreflective markers, and calculated the joint displacement between quiet standing and peak knee flexion. All angles were measured by the same clinician.

In the sagittal plane, trunk flexion was measured as the angle between a vertical line (perpendicular to the ground) bisecting the sacrum and a line bisecting the thoracic spine. Hip flexion was measured as the angle between the AC joint and lateral knee joint with the greater trochanter serving as the fulcrum. Knee flexion was measured as the angle between the greater trochanter and lateral malleolus with lateral knee joint serving as the fulcrum. Ankle dorsiflexion was measured as the angle between a line from the lateral knee joint through the lateral malleolus and a line parallel with the fifth metatarsal.

In the frontal plane, lateral trunk flexion was measured as the angle between a vertical line bisecting the contralateral ASIS (perpendicular to the ground) and a line from the ASIS to the AC joint marker. Hip abduction was measured as the angle between a vertical line bisecting the ipsilateral ASIS (perpendicular to the ground) and a line from the ASIS to the
point half the distance between the two knee joint markers. Knee abduction was measured as the angle connecting three points: one bisecting the malleoli of the ankle, one bisecting the femoral condyles, and one on the proximal thigh parallel to the ASIS. Ankle abduction was measured as the angle between a line bisecting the calcaneus and a line bisecting the distal 1/3 of the lower leg, using a rear foot view.

**STATISTICAL ANALYSIS**

The mean of the three trials on each limb and for each system were used for statistical analysis. Pearson product moment correlation coefficients were utilized to assess linear relationships between mean 2D and 3D displacement measures at the trunk, hip, knee, and ankle in the frontal and sagittal planes. The strength of the correlation (r) was interpreted as poor (0 to 0.49), moderate (0.50 to 0.75), and strong (> 0.75). Bland-Altman plots with average mean difference (AMD) and 95% limits of agreement (LOA) were used to evaluate agreement between 2D and 3D measurements for each dependent variable. Left and right average mean differences were combined for an overall analysis. The presentation of the LOA allows for the visual judgment of how well the two techniques agree. The smaller the range between the upper and lower limits, the stronger the agreement is. Statistical analyses were performed using SPSS software Version 23.0 (IBM Corporation, Chicago, IL, USA). Bland Altman plots were generated using the Microsoft Excel® software (Version 14.4.0, Microsoft Corporation, Redmond WA, USA). Alpha was set a priori at p ≤ 0.05

**RESULTS**

Dependent variables were all significantly correlated between the two measures in the sagittal plane at the trunk (r = 0.53, 95% CI: 0.30–0.70, moderate), hip (r = 0.93, 95% CI: 0.88–0.96, strong), knee (r = 0.86, 95% CI: 0.77–0.92, strong), and ankle (r = 0.51, 95% CI: 0.28–0.69, moderate), and in the frontal plane at the knee (r = 0.31, 95% CI: 0.04–0.54, poor). Correlations between 2D and 3D analyses were not significant in the frontal plane at the trunk, hip, or ankle (Table 1).

Bland-Altman plots revealed agreement in the AMD between 2D and 3D measurement techniques in the sagittal plane at the trunk (1.68°; LOA -54.45 to 57.81; Figure 2a), hip (2.60°; LOA -15.48 to 20.68; Figure 2b), knee (0.74°; LOA -3.71 to 4.19; Figure 2c), and ankle (3.12°; LOA -8.89 to 15.14; Figure 2d). Agreement in the frontal plane at the trunk (7.92°; LOA -6.65 to 22.50; Figure 3a), hip (-8.72°; LOA -21.90 to 4.45; Figure 3b), knee (-6.62°; LOA -29.83 to 16.59; Figure 3c), and ankle (3.03°; LOA -7.96 to 14.02; Figure 3d) was not as strong. A positive value indicates that the 2D analysis measured larger displacement than 3D analysis, whereas a negative value indicates that the 3D analysis measured larger displacement than the 2D analysis.

**DISCUSSION**

The relationship and agreement between two methods of commonly used biomechanical analyses: 2D video camera and 3D motion capture were evaluated. Utilizing both Pearson’s correlation coefficients and Bland Altman plots when comparing two measurement techniques allows for a more robust evaluation of consistency between measures by providing both linear association and agreement. The strongest relationships between the two measurement systems in the sagittal plane were observed at the hip and at the knee. This is consistent with previous literature, where Norris et al evaluated the relationship between a similar 2D measurement technique and goniometry in the sagittal plane during mechanical lifting. During this bilateral and foundational task, the researchers were able to observe near perfect reliability at both the hip (r = 0.99, 95% CI: 0.98–0.99) and at the knee (r = 0.98, 95% CI: 0.96–0.99), with a standard error of measurement...
Figure 2. Bland Altman plots comparing 2D and 3D analyses of the SLS in the sagittal plane with 95% limits of agreement (dashed lines). The difference between the 2D and 3D measurement score plotted against the mean of the two measurements for each dependent variable.

Figure 3. Bland Altman plots comparing 2D and 3D analyses of the SLS in the frontal plane with 95% limits of agreement (dashed lines). The difference between the 2D and 3D measurement score plotted against the mean of the two measurements for each dependent variable.
of 0.75° and 1.4°, respectively. The SLS task that this study utilized requires a greater degree of postural control and proprioception than double-legged foundational tasks, which could account for this slight decrease in reliability. In support of this theory, Gribble et al evaluated sagittal plane joint angle measurements between a 2D video method and standard goniometry during a SLS. The authors reported a difference of < 4° for the knee and < 11° for the hip, with strong reliability ($r = 0.76-0.89$).33

While significant relationships between 2D and 3D techniques were observed at all four joints in the sagittal plane, the only significant correlation observed in the frontal plane was at the knee, which was considered poor. Although previous studies have evaluated the reliability between 2D and 3D analyses, the systems are frequently just compared at the knee in the frontal plane. Similar to these findings, the side-step ($r = 0.40$), and the side-jump ($r = 0.32$) also exhibited poor reliability between the two techniques when evaluating knee varus/valgus motion.26 In contrast, moderate to strong reliability has been observed during the SLS ($r = 0.64-0.78$), and drop vertical jump ($r = 0.82-0.97$).25 A potential explanation for the lack of clinically relevant findings in the frontal plane could be related to the decision to self-select their SLS depth. Eltoukhy et al found similar results at the knee in the frontal plane when utilizing a self-selected SLS depth in their comparison between the Kinect camera and 3D motion capture ($r = 0.144$).34 As a result, this variation could allow individuals to utilize multiple movement strategies to complete the task—particularly the incorporation of transverse plane motion both proximal and distal to the knee at the hip and ankle.

Bland Altman plots allowed for the quantification of the agreement between these two clinical measurement techniques. The AMD between the two measures was less than 4° at each joint in the sagittal plane and less than 7° in the frontal plane. Previous literature reports interrater standard error of measurement of goniometry for the lower extremity ranging between 0.62° and 7.8°.35-39 While the 2D and 3D measurements had stronger agreement in the sagittal plane, it is important to note that both planes of motion exhibited an AMD that is clinically acceptable. Additionally, although there were no patterns in regards to which system consistently measured greater joint angles, and wide LOA were observed (particularly at the trunk). This finding could be the result of transverse plane motion that could not be accounted for in the 2D video assessment.40

It has been suggested that sagittal plane body positions affect lower extremity biomechanics and the risk of knee injuries.41 Landing with the body in a more erect position increases vertical ground reaction forces attenuated through the entire kinetic chain, which is believed to increase both acute and chronic knee injury risk.42,43 At the deepest landing position, hip flexion has been significantly related to knee flexion moment in a drop vertical jump as well as a single leg drop vertical jump.42 Subjects who used less hip flexion in the sagittal plane upon landing relied more heavily on frontal plane knee moments to decelerate their center of mass.42 Similarly, it has been demonstrated that females perform the SLS with less trunk flexion, greater knee abduction, and greater hip adduction when compared to males.40 While it is known that increased moments in the frontal plane lead to a significant increased risk for injury,5 an erect position coupled with the medial collapse at the knee has been suggested as a faulty movement pattern that predisposes an individual to non-contact ACL injury.44 The ability for clinicians to effectively measure sagittal plane kinematics during functional tasks adds a valuable component to functional assessments and risk factor screenings.

**Clinical Relevance**

Although poor movement quality exhibited during functional tasks may be attributed to deficits in lower extremity neuromuscular control, specific kinematic variables have been highlighted as primary risk factors for knee injury.7,20,21 There is evidence that peak knee flexion is the strongest predictor of SLS performance,20 and that males perform the task with greater knee flexion than females.20,45 While SLS depth was not standardized in this study in an effort to maintain clinical applicability, we may consider this modification in the future if comparing kinematics between sexes. The ability to detect these faulty movements during the SLS task
in 2D provides clinicians with a valuable kinematic measurement tool to utilize in screenings and during rehabilitation.

Limitations
It is anticipated that the method of 2D measurement utilized may have contributed to the results of this study. The points utilized to construct the joint angles were each explicitly identified by a retroreflective marker in the sagittal plane, whereas sets of anatomical landmarks were bisected to identify several points in the frontal plane. Although these methods are consistent with the literature,\textsuperscript{28-30} they could also potentially explain more variation in the identification of the frontal plane angles, as the clinician visually identified several points that comprised the joint angles (i.e. at the knee and at the ankle).

One factor that must be considered is that 2D methods are unable to measure rotation. Rotation of the trunk, hip, and tibia are included in the definition of DKV,\textsuperscript{46} and contribute to other biomechanical abnormalities that were unable to be analyzed. Previous authors have indicated that frontal plane movements during 2D video analysis may not be a true representation of 3D kinematics, as rotation cannot be measured.\textsuperscript{30,47} Indeed this presented a problem in this study, as those who had greater discrepancies between the two methods of measurement visually appeared to show more trunk rotation. This finding is supported by previous authors,\textsuperscript{26,48} who suggest that joint rotations at the hip and knee contribute to the appearance of 2D frontal plane kinematics. Another limitation to this study is that the maximal values for the calculation of joint displacement were taken at peak knee flexion. Recent data has shown that the deepest part of a squat or landing is a comparable position to an athletic task,\textsuperscript{7,49} however, discrepancies in movement and visible weaknesses may occur throughout the task.

CONCLUSION
The results of this study indicate that 2D video analysis is comparable to 3D motion capture when evaluating sagittal plane joint displacement during a SLS. Clinically, a valid 2D analysis may help health care professionals identify at-risk athletes and apply targeted interventions to these athletes, especially when they do not have access to a 3D motion analysis system, or the financial means to acquire one.\textsuperscript{29} Future studies should evaluate the use of mobile technology in the quantification of lower extremity kinematics during functional tasks, in an effort to move towards an even more expedient and efficient method of assessment.

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ABSTRACT

Background: There are varied reports in the literature regarding the association of the Functional Movement Screen™ (FMS™) with injury. The FMS™ has been correlated with hamstring range of motion and plank hold times; however, limited research is available on the predictability of lower extremity range of motion (ROM) and core function on FMS™ performance.

Purpose/Hypotheses: The purpose of this study was to examine whether active lower extremity ROM measurements and core functional tests predict FMS™ performance. The authors hypothesized that lower extremity ROM and core functional tests would predict FMS™ composite score (CS) and performance on individual FMS™ fundamental movement patterns.

Study Design: Descriptive cohort study

Methods: Forty recreationally active participants had active lower extremity ROM measured, performed two core functional tests, the single leg wall sit hold (SLWS) and the repetitive single leg squat (RSLS), and performed the FMS™. Independent t tests were used to assess differences between right and left limb ROM measures and outcomes of core functional tests. Linear and ordinal logistic regressions were used to determine the best predictors of FMS™ CS and fundamental movement patterns, respectively.

Results: On the left side, reduced DF and SLWS significantly predicted lower FMS™ CS. On the right side only reduced DF significantly predicted lower FMS™ CS. Ordinal logistic regression models for the fundamental movement patterns demonstrated that reduced DF ROM was significantly associated with lower performance on deep squat. Reduced left knee extension was significantly associated with better performance in left straight leg raise; while reduced right hip flexion was significantly associated with reduced right straight leg raise. Lower SLWS was associated with reduced trunk stability performance.

Conclusions: FMS™ movement patterns were affected by lower extremity ROM and core function. Researchers should consider lower FMS™ performance as indicative of underlying issues in ROM and core function. Clinicians may consider ROM interventions and core training strategies to improve FMS™ CS.

Level of Evidence: Level 2B

Key Words: Dorsiflexion, FMS™, range of motion, Single leg wall sit
INTRODUCTION
The Functional Movement Screen™ (FMS™) is a clinical screening tool used to assess seven fundamental movement patterns. Summing the scores from each of the fundamental movement patterns creates the FMS™ composite score (CS). The FMS™ CS has been associated with injury risk in some studies, but not others. Additionally, researchers have suggested that injury history affects FMS™ movement pattern score and when injury history was combined with FMS™ CS of less than 14, Division I and club sport athletes participating in a variety of sports demonstrated a 15 times increased injury risk. Further, asymmetrical performance in fundamental movement patterns that are scored separately on the right and left limb have been predictive of injury risk; the combination of scoring below 14 on the FMS™ CS and asymmetrical performance in fundamental movement patterns was highly specific (87%) for injury occurrence in American football. Therefore, it is important to investigate the body mechanics that may affect the FMS™ as this area has not been studied extensively and may contribute to the discrepancy in injury risk.

The FMS™ purports to assess coordination of functional movements, which may be related to core function. Recent studies on firefighters and children suggested that core muscle endurance, measured via a plank test, was significantly correlated with FMS™ CS. However, McGill’s trunk muscle endurance tests were not associated with FMS™ CS in recreational athletes. The McGill trunk muscle endurance tests, with the exception of the extension position, have been significantly, positively correlated with the repetitive single leg squat; this finding may suggest that it is necessary to isometrically contract the trunk muscles to stabilize the upper body during the dynamic repetitive single leg squat. The single leg wall sit test has been suggested to identify athletes with rapid fatigue of lumbopelvic, hip and lower extremity muscles. Further, reduced neuromuscular control of core musculature is related to lower extremity injury. The single leg wall sit test has been used as a measure of lower extremity stability, and when combining the single leg wall sit test, a core endurance test, with a large number of football games played, high Oswestry Disability Index, and low trunk-flexion hold time as injury predictors, researchers suggest that core stability is important in injury prevention.

In Coast Guard cadets, the FMS™ CS demonstrated moderate accuracy in injury prediction (sensitivity: 60.3%, specificity: 61.4%) in females, but low accuracy in injury prediction in males (sensitivity: 55.2%, specificity: 48.8%). This difference in findings between males and females may be related to FMS™ performance differences due to documented differences in flexibility. Further, males and females perform differently on the FMS™. A six week yoga intervention improved trunk flexibility and FMS™ performance, suggesting that improved flexibility may improve FMS™ performance. Further, superior performance on the FMS™ has been associated with increased hamstring flexibility in a sample of, primarily male, military cadets; however, the role of flexibility in other lower extremity joint motions has not been established. Therefore, understanding the association between lower extremity active range of motion (ROM), in addition to core function, with FMS™ score may improve the interpretation of and intervention for specific scoring. The purpose of this study was to examine whether active lower extremity ROM measurements and core functional tests predict FMS™ performance. The first hypothesis was that lower extremity ROM and core function would predict FMS™ CS. The second hypothesis was that lower extremity ROM and core function would predict performance on the all FMS™ fundamental movement patterns except shoulder mobility.

METHODS
Study Design
This study was a cross sectional cohort design. The predictor variables included dorsiflexion, knee flexion and extension, hip flexion and extension active range of motion, single leg wall sit hold, and repetitive single leg squat test. The criterion variables were FMS™ CS and six of seven (shoulder mobility was not included in this part of the analysis) fundamental movement patterns of the FMS™.

Participants
A total of 40 participants (Table 1) volunteered to participate in this study. To be included in this study, all
participants had to be between the ages of 18 and 30 and recreationally active, which was defined as participating in physical activity of at least 30 minutes per day on at least two days per week. Participants were excluded if they reported any current injury that limited daily activity or if they answered “yes” to any question on the Physical Activities Readiness Questionnaire (PAR-Q). This study was approved by the Institutional Review Boards at Daemen College and Northern Arizona University. All participants reviewed and signed an informed consent form before any data collection was initiated.

**Procedures**

All participants began the data collection by warming up on a stationary bike at a self-selected pace for five minutes. Next, lower extremity range of motion was measured starting with ankle dorsiflexion, which was measured with the weight bearing lunge. The weight bearing lunge was used as it is a more functional position than a non-weight bearing measurement. To perform the weight bearing lunge, the participant stood 10 cm away from a wall with their great toe at the 10 cm mark of a tape measure affixed to the floor. The participant was asked to assume a lunge position and try to touch their knee to the wall. The participant was instructed to keep their heel in contact with the ground while performing this movement. If the participant was able to touch their knee to the wall they moved back one centimeter and repeated the same movement. This was repeated until the participant reached a distance at which they were unable to touch their knee to the wall without lifting their heel. In the event that the participant lifted their heel while touching their knee to the wall, the participant then slid forward one millimeter and continued this movement until a point was reached where the participant could touch their knee to the wall without their heel rising up off the ground. Once that point was established, an inclinometer (Fabrication Enterprises INC, White Plains, New York 10602 U.S.A.) was placed at a point 15 cm below the tibial tuberosity to measure the angle of the tibia in relation to the ground. This method has been shown to have good inter- (ICC = 0.97) and intra-rater (ICC = 0.97 to 0.98) reliability.26

Following the weight bearing lunge all participants had lower extremity active ROM measured in the following order using standard positioning and a goniometer: knee flexion (supine); knee extension (90/90 Active Knee Extension Test); hip flexion (supine); hip extension (prone). For knee flexion, the participant actively slid one heel toward as far as possible towards their buttock. For knee extension, the participant held onto the back of their thigh to maintain 90° hip flexion while actively extending the knee as far as possible. For hip flexion, the participant held onto the back of their thigh to maintain 90° hip flexion while actively extending the knee as far as possible in this position. For hip extension, the participant was supine on the table with both knees bent with feet flat on table and they actively flexed one hip as much as they could, bringing their knee as close to their chest as possible. For hip extension, the participant was instructed to keep their trunk stabilized while simultaneously lifting their leg up toward the ceiling, keeping their knee extended the entire time. Three ROM measurements were obtained for each joint motion and the average was used for analysis.

Participants then completed two single leg core functional tests bilaterally: single leg wall sit hold (SLWS) and repetitive single leg squat (RSLS). The SLWS was performed bi-laterally and required the participant to sit for as long as possible with their back against a wall in a position of 90° knee and hip flexion; the time began when one leg (the participant was free to choose which leg they started with first) was lifted from the ground (Figure 1). The RSLS required the participant to perform repetitive single leg squats using the Dynamic Trendelenburg Test, (one repetition every six seconds) reaching an estimated 60° knee flexion and 65° hip flexion, while maintaining less than 10° hip adduction/abduction and less than 10° knee varus/valgus, until they could no longer complete the task correctly; the number of squats was recorded (Figure 2). Both the SLWS and the RSLS were explained and demonstrated to the participants before performing these tests.

<table>
<thead>
<tr>
<th>N</th>
<th>Age (yr ± SD)</th>
<th>Weight (kg ± SD)</th>
<th>Height (m ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>24</td>
<td>23.2 ± 2.4</td>
<td>64.8 ± 9.7</td>
</tr>
<tr>
<td>Male</td>
<td>16</td>
<td>24.0 ± 2.7</td>
<td>82.4 ± 10.9</td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
<td>24.0 ± 2.5</td>
<td>71.8 ± 13.4</td>
</tr>
</tbody>
</table>

Table 1. The distribution and demographics of male and female recreational athletes
(3-0) with a 3 representing ideal movement without compensation, a 2 representing ability to perform the movement with compensation, and a 1 representing inability to perform the movement; while a 0 was reserved for pain with movement pattern or a positive clearing test. The FMSTM CS was calculated by summing scores from the seven movements, and in the case of a movement pattern that was scored on both the right and left side the lower of the two performances was used in the calculation of the FMSTM CS which has a maximum score of 21.

Statistical Analyses

Demographic data were calculated and are presented as means ± SD (Table 1). Predictor data were checked for outliers; a value that was 1.5 times less than the 25th percentile or 1.5 times greater than the 75th percentile was considered an outlier. Independent t-tests were used to assess differences between right and left limb in all ROM measures and the results of the core functional tests (Table 2). Linear and ordinal logistic regressions were used to determine the best predictors of FMSTM CS and six of the fundamental movement patterns (shoulder mobility was not predicted from the lower extremity range of motion or core tests), respectively. Data analysis

Figure 1. This is the test position for the Single Leg Wall Sit Hold. Participants were asked to hold this position for as long as possible.

The seven fundamental movement patterns of the FMSTM were performed in the standard order: deep squat, hurdle step, inline lunge, shoulder mobility, straight leg raise, trunk stability, and rotary stability; and clearing tests were performed as indicated. The movements were scored using an ordinal scale of

Figure 2. This is the lower test position for the Repetitive Single Leg Squat. Participants started in single leg stance then were asked to reach this lower test position repeatedly until failure.
The mean FMS™ CS score for all participants was 14.86 ± 2.43. The means and standard deviations for the SLWS and the RSLS and the active range of motion tests can be found in Table 2. There were significant differences between right and left limb in SLWS and hip extension (Table 2). Therefore, two separate regression models were developed; one for right predictors and one for left predictors for each criterion variable. After outliers were removed, 37 data points remained for analysis and indicated, on the left side, that reduced DF and SLWS significantly predicted lower FMSTM CS (R²=0.39; p < 0.001). On the right side only reduced DF significantly predicted lower FMSTM CS (R²=0.27; p = 0.001).

Ordinal logistic regression models for the movement patterns demonstrated that reduced left and right DF ROM was significantly associated with lower performance in deep squat (Table 3). Reduced left knee extension was significantly associated with better performance in left straight leg raise; while reduced right hip flexion was significantly associated with reduced right straight leg raise. Lower right and left SLWS was associated with reduced trunk stability performance.

### DISCUSSION
The purpose of this study was to predict FMS™ performance based on lower extremity ROM and core was completed in SPSS v.20 (IBM, Armonk, NY) and SAS 9.4 (SAS Institute, Inc. Cary, NC). The sample for this study included 40 participants; therefore, it was sufficient for estimation of regression coefficients as two participants per predictor has been found to provide adequate estimation in regression. For the FMS™ CS dependent variables, linear regression, with forward selection, was used with an initial alpha of 0.25, and all predictors were simultaneously entered into the model. Only those predictive of performance were entered into the final prediction equation; the alpha level was set at 0.05 to calculate the R² for the regression model. Similar methods were utilized for the six FMS™ fundamental movement patterns as the dependent variables. Because each fundamental movement pattern is measured on an ordinal scale, ordinal logistic regression with forward selection was used. Pseudo R² and odds ratios were used to assess prediction.

### RESULTS

**Table 2.** Means [Standard Deviations (SD)] between left and right limb core tests and ROM, and p-values for statistical analysis (n = 37)

<table>
<thead>
<tr>
<th></th>
<th>SLWS (sec)</th>
<th>RSLS (reps)</th>
<th>DF (°)</th>
<th>KE (°)</th>
<th>KF (°)</th>
<th>HE (°)</th>
<th>HF (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MeanL</td>
<td>23.38</td>
<td>22.22</td>
<td>47.78</td>
<td>20.06</td>
<td>135.61</td>
<td>15.48</td>
<td>120.07</td>
</tr>
<tr>
<td>(SD)</td>
<td>(14.78)</td>
<td>(12.03)</td>
<td>(9.10)</td>
<td>(12.07)</td>
<td>(11.97)</td>
<td>(6.16)</td>
<td>(13.70)</td>
</tr>
<tr>
<td>MeanR</td>
<td>26.44</td>
<td>25.76</td>
<td>47.57</td>
<td>20.24</td>
<td>135.83</td>
<td>17.19</td>
<td>119.08</td>
</tr>
<tr>
<td>(SD)</td>
<td>(17.22)</td>
<td>(17.96)</td>
<td>(8.65)</td>
<td>(11.17)</td>
<td>(12.25)</td>
<td>(6.61)</td>
<td>(13.37)</td>
</tr>
<tr>
<td>p-value</td>
<td>0.04</td>
<td>0.12</td>
<td>0.76</td>
<td>0.82</td>
<td>0.65</td>
<td>0.02</td>
<td>0.33</td>
</tr>
</tbody>
</table>

MeanL = mean for left limb; MeanR = mean for right limb; SLWS = single leg wall sit; RSLS = repetitive single leg squat; DF = dorsiflexion; KE = knee extension; KF = knee flexion; HE = hip extension; HF = hip flexion

**Table 3.** Significant ordinal logistic regression predictors for individual FMS™ fundamental movement patterns

<table>
<thead>
<tr>
<th></th>
<th>Left SLWS</th>
<th>Right SLWS</th>
<th>Left DF</th>
<th>Right DF</th>
<th>Left KE</th>
<th>Right HF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR [95% CI]</td>
<td>OR [95% CI]</td>
<td>Pseudo R²</td>
<td>OR [95% CI]</td>
<td>OR [95% CI]</td>
<td>Pseudo R²</td>
</tr>
<tr>
<td>Deep Squat</td>
<td>-----</td>
<td>-----</td>
<td>0.92</td>
<td>OR=0.92</td>
<td>0.86</td>
<td>0.78</td>
</tr>
<tr>
<td>[0.85-0.98]</td>
<td>[0.85-0.99]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Straight Leg Raise</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>0.95</td>
<td>-----</td>
</tr>
<tr>
<td>[0.90-1.00]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Straight Leg Raise</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>1.11</td>
<td>-----</td>
</tr>
<tr>
<td>[1.04-1.18]</td>
<td>0.85</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunk</td>
<td>0.92</td>
<td>0.94</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>[0.88-0.98]</td>
<td>[0.90-0.98]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stability</td>
<td>0.91</td>
<td>0.91</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
</tbody>
</table>
| OR = Odds Ratio; 95% CI = 95% Confidence Interval
function. It appears that some lower extremity ROM and core function deficits lead to diminished performance in FMS™ CS and some FMS™ fundamental movement patterns. This may suggest that injury risk might be affected by lower extremity ROM and/or core function, which could be manifested as poor FMS™ performance.

The first hypothesis was that lower extremity ROM and core function would predict FMS™ CS. This was partially supported in that reduced ankle dorsiflexion ROM and SLWS resulted in lower FMS™ CS. This is an interesting finding as a previous report indicated that participants with worse deep squat performance also had lower FMS™ CS performance and the deep squat and the FMS™ CS were positively and significantly correlated with one another. Further, ankle dorsiflexion is one predictor of squat depth in males and females. The results of this current study, combined with previous results, suggest that dorsiflexion ROM affects FMS™ CS.

The SLWS also predicted FMS™ performance such that decreased SLWS hold time resulted in decreased FMS™ CS. This was only seen on the left side regression model, which may be a result of the significantly lower performance of the SLWS hold time on the left limb compared to the right limb. Wall squat training has been demonstrated to increase transverse abdominis and internal oblique muscle thickness suggesting that this exercise may impact core muscle function. The findings of this study may suggest that those with decreased SLWS hold times had inefficient performance of core muscles, which impacted FMS™ CS performance. Because the SLWS hold has been described as a predictor of lower extremity and core injury, it is possible that previous studies demonstrating the FMS™ CS can predict injury risk were really demonstrating that injury risk was associated with core muscle function rather than FMS™ CS. The findings of reduced dorsiflexion ROM and SLWS test performance predicting FMS™ performance may further support the questions in the literature surrounding the validity of using the FMS™ CS as a single construct for injury predictability.

The second hypothesis was that lower extremity ROM and core function would predict performance on the six FMS™ fundamental movement patterns assessed in this study. This was supported in the prediction of several movement patterns: deep squat, active straight leg raise (ASLR), and trunk stability. Reduced DF ROM and SLWS resulted in worse performance in the deep squat. This finding supports previous research that dorsiflexion ROM was significantly associated with anterior reach in the Star Excursion Balance Test (SEBT), which is very similar to motion required by the deep squat, where anterior tibial translation on a fixed foot is necessary to complete both movements. Dorsiflexion ROM was found to explain 28% of the variance in performance of the anterior reach of the SEBT. It would stand to reason that ankle dorsiflexion is a major contributor to deep squat performance as the compensation for inability to perform the deep squat with the feet flat on the floor (to score a “3”) is to place something under the heels, which shortens the gastrocnemius/soleus muscles and reduces stress on the Achilles tendon.

Reduced right hip flexion resulted in reduced ASLR on the right side; while reduced left knee extension was associated with improved ASLR on the left side. The former of the two may seem intuitive as hip flexion is an integral part of the active straight leg raise fundamental movement. The latter of reduced left knee extension being associated with improved ASLR is a bit more counterintuitive. It is important to note that the active knee extension ROM test used in this study was the 90/90 active straight leg test as the participant is first placed in 90 degrees of hip flexion and 90 degrees of knee flexion; the contralateral limb must remain flat against the ground in full extension without any internal or external hip rotation. This is different from the 90/90 active straight leg test as the participant is first placed in 90 degree of hip flexion and 90 degrees of knee flexion; the participant is then asked to extend their knee as far as possible. Therefore, it is likely
that these two tests were not measuring the same lower extremity ROM.

The addition of ankle dorsiflexion during the straight leg raise limits hip flexion by approximately 10°.36 Thus, the requirement of ankle dorsiflexion during the ASLR may affect performance by causing distal tensioning of the sciatic nerve;36 therefore, hamstring length may not be the sole contributor to successful performance of the ASLR. Further, there is a negative correlation between the ASLR and the active knee extension test, which is suggested to be related to an inability to keep the knee fully extended at the end range of hip flexion37 (or the final test position of the ASLR of the FMS™). Lastly, the ASLR is likely affected by lumbar spine stability in the transverse plane;38 while the 90/90 active knee extension test is affected by pelvic tilt.39 These findings suggest that, while the core is likely involved in successful performance of both the ASLR and the 90/90 active knee extension test, the function of core stability may be different between these two tests. Thus, it is possible, in the current study, that the reduced left knee extension association with improved ASLR on the left side and the reduced right hip flexion resulting in reduced active straight leg raise on the right side may have been related to differences in core function rather than range of motion.

In this study reduced SLWS hold time was associated with reduced trunk stability performance. The trunk stability fundamental movement was developed to test stabilization of the core in the sagittal plane during the closed chain activity of a symmetrical push up.40 Poor performance on the trunk stability fundamental movement is evidence for inefficient stabilization of the trunk or core muscles,40 while wall squats appear to be a means to train abdominal core muscles.31 Therefore, it seems reasonable that reduced SLWS hold time would predict lower performance during the trunk stability fundamental movement.

While this study is the first to simultaneously evaluate the impact of lower extremity ROM and core function on FMS™ performance there are a few limitations. We did not measure limb dominance; however, reduced left compared to right SLWS and hip extension ROM may indicate that these two variables are affected by dominance. Additionally, this study was performed on recreational athletes limiting external validity to other populations. It is worth noting that dorsiflexion range of motion did not predict inline lunge or hurdle step performance in this study. It is assumed that dorsiflexion range of motion is an important component of both of these fundamental movement patterns. Therefore, it is imperative that researchers continue to evaluate the biomechanical basis of the fundamental movement patterns so as to elucidate underlying mechanisms before implementing interventions to improve FMS™ performance. Finally, while there were significant regression models in this study, only 30-40% of the variance in FMS™ CS performance was able to be explained by individual factors. This suggests that the FMS™ CS, while influenced by dorsiflexion range of motion and/or SLWS hold, is certainly impacted by other factors.

CONCLUSIONS

The results of this study suggest that FMS™ movement patterns are affected by lower extremity ROM and core function. Thus, injury risk may be affected by lower extremity ROM and/or core function, as these appear to affect FMS™ CS and some of the fundamental movement patterns. Researchers should consider evaluating bilateral lower extremity ROM, additional measures of core function, and limb dominance in relation to the FMS™ in order to further examine implications for injury risk and targeted injury prevention intervention programs based on more comprehensive findings.

REFERENCES


ABSTRACT

Background: ACL injury prevention programs are less successful in female basketball players than in soccer players. Previous authors have identified anthropometric and biomechanical differences between the athletes and different sport-specific demands, including a higher frequency of frontal plane activities in basketball. Current injury risk screening and preventive training practices do not place a strong emphasis on frontal plane activities. The medial and lateral triple hop for distance tests may be beneficial for use in the basketball population.

Hypothesis/Purpose: To 1) establish normative values for the medial and lateral triple hop tests in healthy female collegiate athletes, and 2) analyze differences in test scores between female basketball and soccer players. It was hypothesized that due to the frequent frontal plane demands of their sport, basketball players would exhibit greater performance during these frontal plane performance tests.

Study Design: Cross-sectional.

Methods: Thirty-two NCAA Division-1 female athletes (20 soccer, 12 basketball) performed three trials each of a medial and lateral triple hop for distance test. Distances were normalized to height and mass in order to account for anthropometric differences. Repeated measures ANOVAs were performed to identify statistically significant main effects of sport (basketball vs. soccer), and side (right vs. left), and sport x side interactions.

Results: After accounting for anthropometric differences, soccer players exhibited significantly better performance than basketball players in the medial and lateral triple hop tests ($p < 0.05$). Significant side differences ($p = 0.02$) were identified in the entire population for the medial triple hop test, such that participants jumped farther on their left (400.3 ± 41.5 cm) than right (387.9 ± 43.4 cm) limbs, but no side differences were identified in the lateral triple hop. No significant side x sport interactions were identified.

Conclusions: Women’s basketball players exhibit decreased performance of frontal plane hop tests when compared to women’s soccer players. Additionally, the medial triple hop for distance test may be effective at identifying side-to-side asymmetries.

Level of Evidence: 3

Key words: Basketball, frontal plane, hop testing, performance tests, screening, soccer

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INTRODUCTION
Multidirectional women's sports, including basketball and soccer, have relatively high anterior cruciate ligament (ACL) injury incidence rates. With these elevated risks, ACL injury prevention programs have been designed to decrease the risk of injury and subsequent long-term ramifications (e.g., financial costs, increased risk of osteoarthritis) associated with an ACL rupture. Most prevention programs encompass some combination of strength, agility, and plyometric training to improve lower extremity biomechanics during high-risk sport related activities like jumping and cutting. However, the effectiveness of these programs is different between the sports, as women's soccer players have shown a higher reduction of injury risk compared to women's basketball players. The reason for the lack of effectiveness for injury prevention programs in women's basketball is unknown.

One reason for the decreased effectiveness of prevention programs in basketball may be because women's basketball and soccer players differ anthropometrically, and employ different biomechanical movement strategies during sport-specific tasks. Women's basketball players are taller, heavier, have greater lean body mass, and possess a higher body fat percentage compared to women's soccer players. Biomechanically, basketball players jump and land with larger ground reaction forces, while soccer players display higher ground reaction forces during cutting tasks. While jumping, landing, and cutting with higher ground reaction forces may increase explosiveness and performance, this strategy may also place these two different groups of female athletes at a relatively higher risk of injury during their respective tasks. Support for this contention is found in that 60% of ACL injuries in basketball occur during a jump landing, whereas the majority of soccer injuries are the result of a cutting mechanism.

Another reason that ACL injury prevention programs may have differing success in women's basketball and soccer players may be related to the distinctly different demands of the two sports. Basketball players jump vertically and move medially and laterally to a greater extent than soccer players while soccer players cover more ground horizontally while cutting and running in a straight line. Current prevention programs lack emphasis on medial and lateral demands, consequently making them more specific to the demands of soccer, and potentially more successful in soccer than basketball players.

Similarly, conventional physical performance tests, such as the drop vertical jump, triple hop for distance, broad jump, and timed 6M hop test are commonly used to help identify those that may be at risk for injury and a good candidate for preventative training by assessing landing biomechanics or side-to-side asymmetries, yet these standard tests are predominantly based in the sagittal plane and do not analyze an athlete's ability to move in other planes. Compared to sagittal plane movements, frontal plane movements elicit distinct lower extremity kinematics and kinetics. Frequent movement in the frontal plane may alter performance and/or injury risk and warrant screening tests that emphasize frontal plane demands to complement standard sagittal plane tests.

The frontal plane-focused medial and lateral triple hop for distance tests are relatively new tests that may help to identify deficits in frontal plane movements to help explain differences between basketball and soccer players; however, these modified single leg performance tests have only been assessed in dancers with hip pathology. Thus, the purpose of this paper was to 1) establish normative values for the medial and lateral triple hop for distance tests in healthy female collegiate athletes, and 2) analyze differences in test scores between female basketball and soccer players. It was hypothesized that due to the frequent frontal plane demands of their sport, basketball players would exhibit greater performance during these frontal plane performance tests.

METHODS
Subjects
Thirty-two NCAA Division-I female athletes (20 soccer, 12 basketball) participated in this study. All participants exclusively participated in either basketball or soccer at the collegiate level. Participants were excluded if they were not medically cleared for full sport participation. Informed written consent, approved by the High Point University Institutional Review Board was obtained prior to testing.
Procedures
Testing occurred as part of a larger pre-season injury risk factor screening session. The medial and lateral triple hop for distance tests were performed as previously described by Kivlan et al., by measuring the distance traveled over continuous, consecutive single-leg medial or lateral hops. A standard cloth tape measure was affixed to a rubber floor in a biomechanics laboratory setting. Participants started on a single limb, perpendicular to the start of the tape measure with their upper extremities and uninvolved lower limb in a self-selected position. For the lateral triple hop, participants were instructed to hop laterally (with respect to their weight-bearing limb), with measurements taken from the lateral surface of the shoe. The medial triple hop test was conducted in the same manner as the lateral hop test but in the medial direction of the stance leg. In accordance with previous studies and to ensure the most natural movement pattern, there was no standardization of upper extremity or uninvolved lower extremity position during the test. Participants were required to control their final landing, keeping their toes pointing straight forward, parallel to the starting line, throughout the duration of the hopping trial. Both direction and limb were randomized across all participants for each trial. Each participant was given one practice trial on each limb, in each direction prior to measurement. Three trials of each limb in each direction were then completed, with all three trials averaged and normalized to 1) height, 2) mass, and 3) height and mass, because of the considerable anthropometric differences between the two sets of athletes. Limb dominance was not assessed because of the varying definitions of dominance in the soccer (based on kicking limb) and basketball (based on jumping limb).

Data Analysis
SPSS (Version 23, IBM Corp, Armonk, New York, USA) was used for statistical analyses. Independent t-tests compared differences in anthropometrics (age, height, mass, BMI) between basketball and soccer players. Separate repeated measures ANOVAs were then performed to identify statistically significant main effects of sport (basketball vs. soccer), and side (right vs. left), and sport x side interactions for raw distances, and distances normalized to height and mass for medial and lateral triple hop scores. When necessary, post-hoc independent t-tests were used to further test pairwise comparisons. Statistical significance was set a priori at $\alpha<0.05$ for all analyses.

RESULTS
Anthropometric data are reported by sport in Table 1. Statistically significant differences were identified, where height ($p=0.02$), mass ($p=0.004$), and body mass index (BMI) ($p=0.02$) were greater in collegiate basketball compared to soccer players. Descriptive statistics of medial and lateral triple hop for distance measurements are reported in Table 2. There were no significant differences between sports when analyzing raw medial ($p=0.11$) or lateral ($p=0.20$) triple hop distances, yet after distances were normalized to height, soccer players jumped significantly further than basketball players in the medial ($p=0.01$) and lateral ($p=0.04$) directions. Similarly, when accounting for mass, soccer players jumped further than basketball players, with significant differences in the medial ($p=0.001$) and lateral ($p=0.003$) directions. Normalizing to both height and mass led to consistent significant differences in medial ($p=0.001$) and lateral ($p=0.001$) directions.

Additionally, statistically significant side differences ($p=0.02$) were identified in the entire population for the medial triple hop, such that participants jumped farther on their left (400.3±41.5 cm) than right (387.9±43.4 cm) limbs, but no side differences were identified in the lateral triple hop ($p=0.65$). Further, no significant side x sport interactions were identified.

DISCUSSION
Past research has indicated that ACL injury prevention programs are less successful in women's

<table>
<thead>
<tr>
<th>Table 1. Demographic and anthropometric measures of population</th>
<th>Basketball (n=12)</th>
<th>Soccer (n=20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>20.0 ± 1.4</td>
<td>19.2 ± 1.0</td>
</tr>
<tr>
<td>Height (m)*</td>
<td>1.73 ± 0.07</td>
<td>1.67 ± 0.06</td>
</tr>
<tr>
<td>Mass (kg)*</td>
<td>80.2 ± 13.6</td>
<td>65.9 ± 6.6</td>
</tr>
<tr>
<td>BMI (kg/m²)*</td>
<td>26.7 ± 3.6</td>
<td>23.6 ± 2.2</td>
</tr>
<tr>
<td>*significant difference between basketball and soccer players</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
target specific risk factors for each sport. Results of this study indicate that basketball and soccer players perform similarly in the medial and lateral triple hop for distance tests. However, after accounting for anthropometric differences between the two sets of basketball compared to soccer, yet the reason for this discrepancy is unclear. Identifying anatomical, neuromuscular, biomechanical and functional differences between athletes of the two sports may help clinicians design future prevention programs to

Table 2. Mean medial (MTH) and lateral (LTH) triple hop for distance scores in collegiate female basketball and soccer players

<table>
<thead>
<tr>
<th></th>
<th>Total (n=32)</th>
<th>Soccer (n=20)</th>
<th>Basketball (n=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>MTH Raw Distance (cm)</td>
<td>400.3 ± 41.6</td>
<td>387.9 ± 43.4</td>
<td>407.5 ± 44.3</td>
</tr>
<tr>
<td>MTH (normalized to height)*</td>
<td>2.36 ± 0.24</td>
<td>2.29 ± 0.26</td>
<td>2.44 ± 0.23</td>
</tr>
<tr>
<td>MTH (normalized to mass)*</td>
<td>5.77 ± 1.15</td>
<td>5.60 ± 1.16</td>
<td>6.24 ± 0.90</td>
</tr>
<tr>
<td>MTH (normalized to height and mass)*</td>
<td>0.034 ± 0.007</td>
<td>0.033 ± 0.007</td>
<td>0.037 ± 0.005</td>
</tr>
<tr>
<td>LTH Raw Distance (cm)</td>
<td>363.4 ± 41.5</td>
<td>361.0 ± 47.3</td>
<td>369.3 ± 42.1</td>
</tr>
<tr>
<td>LTH (normalized to height)*</td>
<td>2.15 ± 0.25</td>
<td>2.13 ± 0.28</td>
<td>2.21 ± 0.23</td>
</tr>
<tr>
<td>LTH (normalized to mass)*</td>
<td>5.24 ± 1.04</td>
<td>5.21 ± 1.10</td>
<td>5.63 ± 0.68</td>
</tr>
<tr>
<td>LTH (normalized to height and mass)*</td>
<td>0.031 ± 0.007</td>
<td>0.031 ± 0.007</td>
<td>0.034 ± 0.004</td>
</tr>
</tbody>
</table>

* significant differences between basketball and soccer players (p<0.05), † significant side to side differences in all cohorts (p<0.05)

* Figure 1. Participant performing the a) medial and b) lateral triple hop for distance tests.
athletes, basketball players are unable to jump as far in the frontal plane as soccer players. These weaknesses may translate to less lower extremity control during medial and lateral movements, potentially putting basketball players at higher risk for injury, considering the frequency of such movements in their sport.

Results from both the medial and lateral triple hop for distance tests indicate that relative to body size, soccer players are more powerful in the frontal plane than basketball players. These findings do not support the original hypothesis that basketball players would hop greater distances compared to soccer players. This was based on the specificity of training principle, where basketball players jump and move more often in the frontal plane than soccer players, and therefore, would have adapted to become more powerful in that plane. One possible explanation for the current findings may relate to anthropometric differences between the athletes. Basketball players possess larger BMIs than soccer players and show a significantly larger increase in total body and fat mass over their collegiate careers than soccer players. However, previous research has found no significant differences between female basketball and soccer players in raw forward triple hop distances and higher raw distances in male basketball than soccer players. This finding may be because the medial and lateral triple hop for distance tests measure different constructs than the forward triple hop for distance test. For example, the forward triple hop for distance test has been closely linked with both quadriceps and hamstrings strength, yet past evidence suggests that basketball and soccer players do not exhibit differences in sagittal plane thigh strength. Similar data linking the medial and lateral hop tests to the strength of certain muscles is limited. In fact, Kea et al found little correlation between single medial and lateral hop tests and isokinetic testing of the hip abductors and adductors. This finding can again be attributed to isokinetic strength and frontal plane hopping being different constructs or that hip abductor/adductor strength is not the sole factor influencing frontal plane movement performance. In other words, an athlete may simply be able to change the position of the stance leg to recruit the larger, more powerful gluteus maximus rather than the gluteus medius. This strategy would be controlled in the current study’s method of testing but may explain why it should not be assumed that basketball players would fare better on frontal plane hop tests. There is some support that simply lowering the center of gravity (i.e. greater hip and knee flexion) may be an even more important component of effective lateral movement. Further understanding of the specific constructs tested in medial and lateral triple hop for distance tests is needed.

The results that basketball players exhibit less powerful movement potential in the frontal plane may have direct clinical implications. While sport-specificity is generally a strong component of rehabilitation and return to play practices, it is less common in the injury prevention paradigm, despite different effectiveness of prevention programs in various sports. The results suggest that injury prevention programs, specifically in women’s basketball players, may need to place a stronger emphasis on frontal plane activities than current programs administer. In reviewing the three ACL injury prevention programs that have been studied in women’s basketball players, only 12% of plyometric activities are devoted to frontal plane movements. Though the specific prescription of plyometric exercises need more study, activities such as lateral bounding on flat or plyometric boxes, or perhaps even frontal plane triple hops with or without a vertical component should begin to be incorporated into prevention practices. Because most injury prevention programs emphasize sagittal plane movements, they may not be providing adequate stimulus to improve biomechanics and performance during frontal plane movements, which appear to be inherently weaker in basketball players.

Frontal plane hop tests may also have merit in more general rehabilitation or injury prevention settings.
The medial and lateral triple hop tests used in this study have been previously examined in dancers with hip pathology, with the medial triple hop test being able to identify side-to-side differences between the involved and uninvolved sides. Another frontal plane test gaining traction in the literature is the lateral leap and catch, which assesses power (speed of movement) in addition to movement quality. To date, none of the frontal plane hop tests have been validated for prediction of injury risk or successful return to play. Continuing to develop and assess frontal plane testing is necessary for athletes with high frontal plane demands inherent within their sport. This study provides normative values for the medial and lateral triple hop for distance tests in healthy collegiate athletes. These results can be used by clinicians as a complementary piece of information to other tests and measures to help gauge frontal plane performance during their assessment of high-level athletes. However, clinicians must make appropriate clinical decisions as to whether their patients/athletes are able to safely perform this high-level task.

The results of the current study indicate that the medial triple hop test elicited side-to-side differences, such that athletes performed better on their left limb than their right limb. The authors purposefully chose not to categorize limbs based on dominance in this study. While limb dominance may be intuitively easy to define in soccer by the preferred kicking limb, this definition is not applicable to basketball players. While jumping may be a more appropriate activity to define dominance in basketball players, a player's self-selected dominant jumping limb is not consistent with their vertical or horizontal jumping performance. However, the fact that participants in this study showed greater performance on their left than right limbs may be related to sport-specific demands, as a large majority of soccer players preferred to kick with their right limbs (making the left their preferred stance limb) and all basketball players were right-handed, generally making the left limb the preferred jumping and landing limb during single-leg activities. Further exploration of differences in limb dominance in these two sports may provide additional insight to the difference in effectiveness of ACL injury prevention programs.

Results of this study indicate that further research may be needed to 1) establish the clinical utility of frontal plane hop tests in an athletic or clinical setting and 2) further understand differences between basketball and soccer players. Future studies could identify whether frontal plane hop tests have the ability to complement other tests and measures as potential predictors of injury, rehabilitation progression or successful return to play in healthy or clinical populations, or whether these tests provide similar information previously established hop batteries.

Additionally, while this study identified significant differences in medial and lateral triple hop for distance tests between collegiate female basketball and soccer players, forward triple hop for distance tests were not performed in both groups. Confirming previous findings that there are no significant differences in this same population of women's basketball and soccer players in the sagittal plane would have provided even further confirmation that these differences identified in the frontal plane are clinically important, and may lead to further study regarding other biomechanical or neuromuscular differences that exist between athletes that participate in these sports.

**CONCLUSION**

Women's basketball players exhibit decreased performance of frontal plane hop tests as compared to women's soccer players. Considering the high rate of ACL injuries, the relatively poor efficacy of ACL injury prevention programs and the frequent frontal plane demands of the sport, basketball players may benefit from further emphasis on frontal plane screening measures, strength and neuromuscular control training.

**REFERENCES**


ABSTRACT

Background: Balance is a complex construct, affected by multiple components such as strength and co-ordination. However, whilst assessing an athlete's dynamic balance is an important part of clinical examination, there is no gold standard measure. The multiple single-leg hop-stabilization test is a functional test which may offer a method of evaluating the dynamic attributes of balance, but it needs to show adequate intra-tester reliability.

Purpose: The purpose of this study was to assess the intra-rater reliability of a dynamic balance test, the multiple single-leg hop-stabilization test on the dominant and non-dominant legs.

Design: Intra-rater reliability study

Methods: Fifteen active participants were tested twice with a 10-minute break between tests. The outcome measure was the multiple single-leg hop-stabilization test score, based on a clinically assessed numerical scoring system. Results were analysed using an Intraclass Correlations Coefficient (ICC_{2,1}) and Bland-Altman plots. Regression analyses explored relationships between test scores, leg dominance, age and training (an alpha level of p = 0.05 was selected).

Results: ICCs for intra-rater reliability were 0.85 for the dominant and non-dominant legs (confidence intervals = 0.62-0.95 and 0.61-0.95 respectively). Bland-Altman plots showed scores within two standard deviations. A significant correlation was observed between the dominant and non-dominant leg on balance scores ($R^2 = 0.49$, $p < 0.05$), and better balance was associated with younger participants in their non-dominant leg ($R^2 = 0.28$, $p < 0.05$) and their dominant leg ($R^2 = 0.39$, $p < 0.05$), and a higher number of hours spent training for the non-dominant leg ($R^2 = 0.37$, $p < 0.05$).

Conclusions: The multiple single-leg hop-stabilisation test demonstrated strong intra-tester reliability with active participants. Younger participants who trained more, have better balance scores. This test may be a useful measure for evaluating the dynamic attributes of balance.

Level of Evidence: 3

Key words: Assessment, balance, reliability, hop testing

ORIGINAL RESEARCH

INTRA-RATER RELIABILITY OF THE MULTIPLE SINGLE-LEG HOP-STABILIZATION TEST AND RELATIONSHIPS WITH AGE, LEG DOMINANCE AND TRAINING

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INTRODUCTION
Normal balance requires the interaction between multisensory organ systems (proprioceptive, visual and vestibular) and the brain and spinal cord, which ultimately control the multi-joint musculoskeletal system. These systems can be affected by factors such as nutrition, age, injury and disease. At an optimal level they work to maintain the center of gravity within a defined base of support, as well as the task specific orientation of body parts.

Within sports medicine, assessing an athlete's balance is an important part of a clinical examination. It is within this domain that an emphasis is placed upon proprioceptive / balance exercises as both a tool for injury prevention and as a rehabilitation strategy. However, the physical demands of sport are extremely diverse, and balance and postural control appear to be influenced by other performance attributes. For example, strength training programs lead to significant improvements in both static (Romberg) and dynamic (Star Excursion Balance Test) measures of balance.

Despite the implementation of balance training for both injury prevention and rehabilitation, no gold standard outcome measure exists with which to quantify balance within the athletic population. While it is acknowledged that balance can be measured statically or dynamically, the population being examined should direct the nature of the test selected. Furthermore it should not be assumed that static balance ability is positively correlated with dynamic balance performance. Therefore it appears appropriate to use a dynamic measure of balance when examining the athletic population, as all sports require a "dynamic" attribute of balance in some way.

The purpose of looking at athletic balance stems from the results of a series of single case studies evaluating the use of clinically targeted compression in athletes, whereby compression was delivered to the pelvic girdle via a customised orthosis in the form of shorts. Questionnaire responses from the participating athletes suggested that this type of external pelvic compression may have had a positive effect upon balance. In order to investigate whether this is the case, the intention was to incorporate a functional measure of athletic balance in future clinical trials. On the basis of the current literature and discussion with clinical colleagues, it is anticipated that a functional single leg test may be an appropriate measure of dynamic balance.

Previous researchers have found that knee instability is positively correlated with one-legged tests, and that a single leg hopping test can demonstrate good test re-test reliability. The multiple single-leg hop-stabilization test (MSLHST) is a single leg dynamic measure, involving forwards, and diagonal movements in a unipedal stance, that incorporates periods of statically maintaining this stance. Athletes are scored on both a balance and landing scale, according to the errors that they commit in each period of the test; these scores are summed to give the total error score. It has been argued that this type of functional test is important because it challenges athletes in a way which reflects the forces and directions of movement that are integral to sport.

Although this test has been reported to have very good inter-tester reliability (ICC values 0.70-0.92), intra-rater reliability was shown to be lacking. Closer inspection of the intra-rater reliability reveals that this lack of reliability only refers to the balance scores which significantly differed between tests; no significant difference was observed with the landing scores. Further, this study assessed three test sessions, each 48 hours apart; a different scenario to the current intra-rater reliability study in which the testing was completed in one session.

A further consideration for any balance study involving athletes with a lower limb injury is the influence of lower limb dominance. In football, a players' dominant (preferred kicking leg) has been shown to be significantly stronger than their non-dominant leg in terms of hip adductor strength, and hip flexor strength, but not in all muscle groups. It has been suggested that any rehabilitation of injury needs to take leg dominance into consideration. As a strength deficit may potentially contribute to poor balance, it is important that a study considers the role of limb dominance, and examines how this may influence the reliability of the balance measure used.

The purpose of this study was to assess the intra-rater reliability of a dynamic balance test, the MSLHST on the dominant and non-dominant legs. A secondary purpose was to explore whether...
relationships exist between the MSLHST scores and leg dominance, age, and time spent engaging in exercise (training).

**METHODS**

**Design**
An intra-rater reliability study was undertaken. All of the testing was undertaken by a single investigator, using portable equipment; the test was scored in “real time” while the balance measure was being performed.

**Participants**
A convenience sample of volunteers was recruited from Plymouth University staff and students, and from local sports clubs. To maximise recruitment the study was conducted at the University (Human Movement Laboratory) to accommodate the staff and student participants. Ethical approval was gained from a local University Ethics Committee (Plymouth University).

**Eligibility Criteria**
To be included, participants had to be over the age of 18, and able to give informed consent, be self-declared as healthy, and have sustained no lower limb musculoskeletal injuries in the prior three months. Participants were excluded if they were pregnant, had a current illness / unresolved condition, or had any neurological, musculoskeletal or cardiorespiratory impairment.

**Sample Size**
Reliability coefficients greater than 0.7 are deemed to be acceptable for most clinical trials. A power calculation indicated that 15 people were needed to be recruited in order to demonstrate an ICC of >0.7 (power = 0.88; \( \alpha = 0.05 \)). This is in keeping with the work of Fleiss and their discussion of the numbers required for a reliability study involving quantitative measures.

**Participant Characteristics**
Participant demographics (age, gender, height, weight), their leg dominance (as defined by which side they would kick a ball), and the average number of hours spent training / performing sports in a week were recorded.

**Measurement of the MSLHST**
Testing was undertaken in standard sports attire (shorts, t-shirt and athletic shoes) and conducted in the same environment, in order to minimise external influences and allow for standardization. Standardized written instructions were given to all participants prior to testing; this included photographs of stances. Participants also received verbal instructions from the researcher while viewing the MSLHST set up, and before completing their practice attempts.

The distances between each of the boxes (Table 1) were standardized according to the participants' height. Diagonal distances represented 45% of the participants' height (wearing athletic shoes), and Pythagoras Theorem used to calculate the distances in the frontal plane, for the adjacent boxes. The mat was labelled according to the height related distances prior to testing to ensure that during testing, there was minimal delay in setting up the mat. This was achieved using hook and loop combinations of numbered Velcro® squares.

One practice attempt on each leg was undertaken for familiarization of the procedure while avoiding fatigue. Both the dominant leg (as defined as the leg that people would prefer to kick a ball with) and the non-dominant leg were tested in a randomized order (randomization was undertaken using the Microsoft Excel Random Number Generator). The mat was labelled according to the height related distances prior to testing to ensure that during testing, there was minimal delay in setting up the mat. This was achieved using hook and loop combinations of numbered Velcro® squares.

<table>
<thead>
<tr>
<th>Height in Centimetres (cm)</th>
<th>Diagonal Distance (cm)</th>
<th>Adjacent Distance (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150-159.9</td>
<td>70</td>
<td>49</td>
</tr>
<tr>
<td>160-169.9</td>
<td>74</td>
<td>53</td>
</tr>
<tr>
<td>170-179.9</td>
<td>79</td>
<td>58</td>
</tr>
<tr>
<td>180-189.9</td>
<td>83</td>
<td>59</td>
</tr>
<tr>
<td>190-199.9</td>
<td>88</td>
<td>62</td>
</tr>
<tr>
<td>200-209.9</td>
<td>92</td>
<td>66</td>
</tr>
</tbody>
</table>
The balance and landing error scores. The MSL-HST scoring was defined as:

**Balance score.** Up to three error marks were given for participants committing the following in any balance period:

- Touching the floor with the non-weight bearing limb;
- Removing hands from iliac crests;
- Non-weight bearing limb touching the weight bearing limb;
- Non-weight bearing limb moving into excessive flexion, extension or abduction (this was defined as movement beyond the predetermined stance (>30 degrees of movement); displayed to the participants in a photographic format).

**Landing score.** Up to 10 error marks were given for participants committing the following in any landing period:

- Removing hands from iliac crests;
- Foot not covering the numbered square;
- Stumbling on landing;
- Landing foot not facing forwards with 10 degrees of inversion or eversion.

Therefore potential test scores could range from 0-130 (0-100 for the landing component, and, 0-30 for the balance element).

**Statistical Analyses**

Statistical analyses were performed using SPSS 20 for Windows (IBM). Two-way random absolute agreement intra-class correlation ($\text{ICC}_{2,1}$) and 95% confidence intervals were used to assess the intra-rater reliability.\(^2^4\) Bland Altman plots were presented to show a visual representation of intra-rater reliability. Using more than one measure of reliability has been advised as no one measure is suitable for all reliability studies.\(^2^5\) ICCs give a relative view of reliability, therefore it has been advised not to draw conclusions before using methods of examining the absolute reliability.\(^2^6\)

A paired t-test was used to ascertain if there was a significant difference between the balance ability of the dominant and non-dominant leg ($p = <0.05$). Regression analyses were undertaken to explore possible relationships between balance ability on the dominant leg.

Excel 2010 randomization function). After a 10 minute rest, participants were asked to complete the MSLHST again on both legs, in the same order.

The starting position was standardised with the participants standing on one leg with both hands on their iliac crests and eyes facing forwards. Participants were asked to hop to a series of numbered boxes; each with an area of 2.5cm$^2$ (Figures 1a, 1b). Arm position was standardized throughout the test, with participants asked to keep their hands on their iliac crests. The task was paced by a metronome (with an auditory cue every one second). On landing on each box, participants were asked to maintain their position for five seconds (counted aloud by the investigator). The balance period was defined as the period prior to undertaking each jump and the period one to five seconds after landing and stabilizing the position. The landing period was defined as the one second period immediately after landing, when the participant attempted to stabilize their position.

Previous work has described how any error in either a landing or balance phase was counted as a failure.\(^1^8\) Errors were scored according to the period in the test in which they were committed i.e. 3 points for an error in a balance period, and 10 points for a landing period error. Testing did not stop following an error; participants continued with the test and all errors were scored. The final test score was the sum of the balance and landing error scores.

![Figure 1a. A representation of the boxes marked out for the multiple single-leg hop-stabilisation test. 1b. A photograph of the testing mat being prepared for variable distances.](image-url)
The time spent training each week was further explored using t-tests to determine the possibility of predicting test performance according to the amount of training undertaken (< or > five hours per week). Such a relationship has been observed in previous work, showing that lifelong football trained men demonstrated significantly superior balance to age matched untrained men.28

**RESULTS**

Fifteen participants (males = 8), aged 22-57 participated in the study. The demographics of the tested population are presented in Table 2.

Table 3 presents the MSLHST score intra-rater reliability ICCs for the dominant and non-dominant leg, along with the 95% CIs. ICCs for both legs = 0.85.

Tables 4 and 5 present the ICCs for the balance and landing scores on each leg. For the non-dominant leg, balance and landing score ICCs were 0.87 and 0.78 respectively. For the dominant leg, ICCs were 0.88 for the balance score, and 0.72 for the landing score.

Figures 2 and 3 present visual representations of the intra-rater differences in scores for the dominant and non-dominant legs. Offer a summary statement here too.
Paired t-tests revealed no significant differences between performance of the dominant and non-dominant legs in the first or second performance of the test (p = >0.05), therefore the scores for the dominant and non-dominant legs were averaged across the two tests (Figure 4).

There was a significant positive and strong relationship between the scores obtained on the dominant and non-dominant legs; higher scores on one leg were associated with higher scores on the other leg (R² = 0.49 p<0.05; Figure 5).

There was a significant positive and moderate relationship between the scores obtained on both the dominant / non-dominant legs and the age of the participant. Higher scores (indicating more errors) were associated with advancing age The relationship was stronger on the dominant leg (non-dominant leg R² = 0.28, p<0.05, Figure 6; dominant leg R² = 0.39, p<0.05, Figure 7).
Greater number of training hours per week were associated with lower scores on the MSLHST. This relationship, which was of moderate strength, was significant for the non-dominant leg only ($R^2 = 0.37$, $p < 0.05$).

Further analysis using t-tests showed a significant difference ($p = <0.05$) in overall scores between those training more and those training less than five hours per week. This was seen for the average scores for both dominant and non-dominant legs.

**DISCUSSION**

ICC values can be interpreted as follows; 0.75 and above indicates excellent reliability, 0.4-0.75 is fair to good reliability and <0.4 is seen as poor reliability. The ICC results for both the dominant and non-dominant leg both demonstrate a mean value of 0.85. Whereas this may be considered as demonstrating excellent intra-rater reliability, examination of the 95% CI urges more caution. The intervals ranging from 0.62-0.95 for the dominant leg, and, 0.61-0.95 for the non-dominant leg, should be interpreted as showing that the MSLHST demonstrates good to excellent intra-rater reliability in a healthy, exercising population.

The varying degrees of reliability shown in Tables 4 and 5 allows a comparison with previous findings on the differences in the landing and balance score reliability. The current findings show that ICCs range from 0.72-0.88; indicating good to excellent reliability. The finding that reliability is greater with the balance scores than landing is in contrast to prior work. While this may reflect the difference in the prescribed scores given for landing and balance errors, for the purpose of this work the focus upon intra-rater reliability is with the overall MSLHST score which is derived by totalling the balance and landing scores.

While ICCs were examined to provide a quantitative assessment of reliability in terms of consistency of agreement; Bland Altman plots were examined as a qualitative method of assessing reliability and determining degree of absolute agreement. Inspection of these plots (Figures 2 and 3) show that the MSLHST intra-rater scores all lay within the two standard deviation limits. Considering these findings together with those of previous research, it appears that the MSLHST could be a reliable functional outcome measure, and may be considered for inclusion in future clinical trials in a similar population.

Thorborg et al suggested that one may expect to see a difference in balance ability between the dominant/ non-dominant legs. However, paired t-tests used to examine the current data demonstrated that...
there was no significant difference between the dominant and non-dominant limbs in this sample ($p > 0.05$). Furthermore a significant strong, positive correlation was observed between the MSLHST scores of the dominant and non-dominant leg. Those making less errors completing the test on their dominant leg, tend to perform similarly on their non-dominant leg. This finding has also been observed in the sedentary population, although future work is warranted to explore this in athletes.

A moderate and significant positive relationship was demonstrated between balance scores and age; higher error scores (indicative of worsening balance) occurred with increasing age when both the dominant and non-dominant legs were assessed. A deterioration of balance with age has been reported previously. Changes include an increased amplitude and speed of postural sway, reduced dynamic balance and greater instability when sensory inputs controlling balance are perturbed or reduced. Many of these studies compared balance ability in younger (<30 years) and older (>60 years) age groups. It is of note that this measure of dynamic balance appeared able to detect variations in performance with age even within the relatively narrow age band of the current sample (22-57 years).

People who trained for greater time periods each week had lower scores on the MSLHST (indicating better balance ability). This was only significant on the non-dominant leg. Interestingly, the task used to define the dominant leg was kicking a ball in which the opposite non-dominant leg is balancing, supporting the body weight. The moderate relationship seen between the hours spent training and better performance on the non-dominant leg balance scores might be because this leg is used more frequently for balancing activities; especially during asymmetric activities like football that involve phasic movements of the dominant leg.

Predicting performance scores through other variables can be useful in forecasting future performance outcomes. Led by the findings of earlier research the number of training hours undertaken each week was explored as a predictor of subjects MSLHST scores; a significant difference ($p < 0.05$) was shown between participants when grouped in terms of the time spent engaged in exercise activities each week. More specifically the results show that it is possible to predict how well a participant will do on the MSLHST by looking at the number of hours that they spend training each week; more than five hours of training per week is a strong indicator that a participant will have a lower error score (indicative of better balance). This is supported by literature in other populations where engagement in sport and physical activities has been shown to be associated with better balance and postural control.

**CONCLUSION**

The results of the current study demonstrate that the MSLHST demonstrates good to excellent intra-rater reliability in a healthy, active population. Furthermore simple regression analyses suggest that predictions may be made as to participants’ MSLHST error scores, based on known factors such as their age and training hours. The latter showing a significant difference ($<0.05$) in performance between those training more and less than five hours per week. However further work is required to confirm these findings. Similar to the findings of previous work, it appears that this test could be an appropriate functional measure of athletic balance for use in future studies.

**REFERENCES**


ABSTRACT

**Background:** A paucity of research currently exists for upper extremity return to sport testing. The Upper Quarter Y-Balance Test (YBT-UQ) is a clinical test of closed kinetic chain performance with demonstrated reliability. Prior investigations of the YBT-UQ were conducted with individuals in a resting state and no comparison to performance in a fatigued state has been conducted.

**Purpose:** To examine the effect of upper extremity fatigue on the performance of the YBT-UQ in recreational weightlifters.

**Study Design:** Randomized controlled trial

**Methods:** 24 participants who participated in recreational weight training three days per week were randomly allocated to a control or experimental group. Individuals in the control group were tested using the YBT-UQ and re-tested after a 20-minute rest period. Participants in the experimental group were tested with the YBT-UQ, performed an upper extremity exercise fatigue protocol, and immediately re-tested. Examiners were blinded to participant allocation.

**Results:** Differences from pre- to post-fatigue YBT-UQ testing revealed score reductions between 2.04cm – 12.16cm for both composite scores and individual reach directions. The repeated measures ANOVA revealed significant differences when comparing the pre- and post-testing results between the fatigue and non-fatigue groups for all individual directions (p<.006) and composite scores both limbs (p<.035).

**Conclusion:** The performance of an upper body fatigue protocol significantly reduces YBT-UQ scores in recreational weightlifters.

**Level of Evidence:** 1b

**Keywords:** Fatigue, functional testing, upper extremity, Upper Quarter Y-Balance Test

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INTRODUCTION
Resistance training is a popular form of exercise for both athletic and recreational purposes. Injury resulting in medical attention as a result of resistance training, has been reported at a prevalence between 25-30%.1 The shoulder complex is a common region for exercise related injury, comprising 36% of all incidents.1 Shoulder injury often results in reduced strength, proprioception, and balance which can be assessed with both open or closed chain testing.

Two common tests used to evaluate the upper extremity include the closed kinetic chain upper extremity stability test (CKC-UEST) and the one-arm hop test.2-4 The CKC-UEST requires participants to assume an upright push-up position with their feet 36 inches apart. The test then scores how many times an individual can reach across midline to the contralateral hand while maintaining the push-up position. The CKC-UEST has been shown to be reliable and predictive of injury, but only assesses the upper extremity in a single plane and does not differentiate performance for a single limb.2,3 The one-arm hop test, has also been shown to be reliable, but only measures single arm power.4 More recently, the Upper Quarter Y-Balance Test (YBT-UQ), a clinical test of closed kinetic chain performance, has demonstrated high reliability for assessment of unilateral upper extremity function.5 The YBT-UQ has also demonstrated the ability to serve as a measure for normal function when testing an injured upper extremity with reported similarity between dominant and non-dominant limbs.6

The clinical tests described previously are commonly used by physical therapists to assess upper extremity performance, but individuals are typically tested in a non-fatigued state. Fatigue is defined as a transient decrease in the capacity to perform physical actions7 and can result in a reduction in muscle force, impaired coordination, delayed neuromuscular activation, and impaired joint stability.8-13 These fatigue induced impairments could result in greater injury risk in both athletic and recreational activities. To date, a paucity of research exists investigating the performance of the YBT-UQ under fatigue. The purpose of this investigation was to examine the effect of muscular fatigue on YBT-UQ scores in recreational weightlifters. The hypothesis was that YBT-UQ performance would decline in participants tested in a fatigued state.11-13

METHODS
Study Design
This study was a prospective randomized controlled trial. The study flow diagram is outlined in Figure 1. Twenty-four healthy, college-aged subjects were recruited from a local university community with publicly displayed flyers. Participants were provided explanation of testing procedures and gave written informed consent prior to testing. Participants were included in the study if they performed upper-extremity resistance weight training on average three days per week (range 2-5), possessed sufficient ability to read English as required for completing questionnaires, and were over 18 years of age. Exclusion criteria consisted of any single red flag item noted in the patient's medical screening questionnaire, answered yes to any question on the physical activity readiness questionnaire (PAR-Q), prior surgical history on either left or right upper extremity and currently experiencing pain in either the left or right upper extremity. The Institutional Review Board approved the study protocol.

Participants
Twenty-four participants (mean age 25.75 years ± 2.67) met the inclusion criteria and were randomized to either the fatigue or non-fatigue groups. The fatigue group included 11 individuals (4 females and 7 males) while 13 participants were allocated to the non-fatigue group (3 females and 10 males). The sample size of 24 participants was powered based on prior lower extremity research demonstrating significant between group differences when comparing fatigue to non-fatigued testing of the Lower Quarter Y-Balance Test (YBT-LQ).14

Procedures
The protocol described by Gorman et al.5 was utilized for YBT-UQ testing procedures with the Y-Balance Test kit (Functional Movement Systems, Chatham, VA). Prior to conducting the initial testing procedures all participants viewed a video on proper performance of the test, received a demonstration by the primary investigator and practiced two trials in all
rest provided at the conclusion of all four exercises. Three sets of each exercise were performed in total prior to immediately re-testing the YBT-UQ.

Participants who were assigned to the control group were asked to rest in a seated position for 20 minutes in a separate room. Examiners were blinded to participant allocation for the fatigue protocol or resting protocol. Following the completion of the resistance training protocol or rest protocol, participants were re-tested on the YBT-UQ using the same procedures as previously described. Examiners were blinded to group allocation for each individual participating in this study.

Data Analysis

The statistical package for social sciences (SPSS version 22.0, Chicago, Ill.) was used for analysis. Baseline between group differences for demographic data including height, weight, body mass index, arm dominance and age were compared with the independent samples t test. The two-way factorial Analysis of variance (ANOVA) was used to compare the interaction between group and time to analyze both between and within group differences for YBT-UQ.
The reduction in scores for the fatigue group ranged from 2.04 cm – 12.16 cm for both limbs, individual reach distances and composite scores, indicating that fatigue significantly impairs testing scores on the YBT-UQ.

**DISCUSSION**

Upper extremity injuries are common in both sport and recreational activities. However, few closed
To the authors’ knowledge, no other studies have examined the impact of a rested and fatigued state on UQ-YBT scores, nor on other tests of closed kinetic chain upper quarter function (CKCUEST, one-arm hop test). Therefore, it would be challenging to directly compare these results against other studies of upper quarter functional testing under fatigue. The results of this study can be compared to other studies that have examined the role of fatigue on movement and performance.

Kinetic chain tests have been identified to assess those with upper extremity performance deficits prior to returning to sport. Moreover, even fewer studies have examined the effect of fatigue on the performance of these upper quarter closed kinetic chain tests. The YBT-UQ has previously been identified as a reliable assessment of unilateral upper extremity closed kinetic chain excursion ability in healthy college-aged subjects. The purpose of the current study was to identify if upper body fatigue affected the performance on the YBT-UQ. The results of the current study suggest there is a significant decrease in YBT-UQ performance when performed in a fatigued state.

Previous researchers have found similar reach distances normalized to limb length in a variety of populations when performing the YBT-UQ in a non-fatigued state. Taylor et al reported YBT-UQ reach distances in Division 1 collegiate athletes, which in comparison to the current study reach distances, were in excess of 10cm greater in each direction. This difference in excursion is likely a result of the different populations tested; Division 1 athletes vs. recreational weightlifters.

To the authors’ knowledge, no other studies have examined the impact of a rested and fatigued state on UQ-YBT scores, nor on other tests of closed kinetic chain upper quarter function (CKCUEST, one-arm hop test). Therefore, it would be challenging to directly compare these results against other studies of upper quarter functional testing under fatigue. The results of this study can be compared to other studies that have examined the role of fatigue on movement and performance.

<table>
<thead>
<tr>
<th>Subject characteristics</th>
<th>Non-fatigue (n=13, 3 males, 10 females)</th>
<th>Fatigue (n=11, 4 females, 7 males)</th>
<th>p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>26 (1.41)</td>
<td>25.43 (3.72)</td>
<td>.061</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>80.18 (14.33)</td>
<td>78.59 (13.45)</td>
<td>.651</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>175.94 (9.22)</td>
<td>178.03 (10.98)</td>
<td>.437</td>
</tr>
<tr>
<td>Right limb length (cm)</td>
<td>89 (4.84)</td>
<td>87.18 (6.00)</td>
<td>.567</td>
</tr>
</tbody>
</table>

*Independent samples *t* test

Table 1. Descriptive characteristics for both the fatigue and non-fatigue groups.
Fatigue has been demonstrated to result in a reduction of muscle force, impaired coordination, delayed neuromuscular activation, and impaired joint stability.⁸⁻¹³ It has also been shown previously that a significant portion of injuries occur in the latter stages of games/competition, which indicate a potential effect of fatigue on risk of injury.¹⁸⁻²⁰ Sarshin et al¹² demonstrated a reduction in dynamic postural control, measured by YBT-LQ excursions, after fatigue was induced via running at different intensities. Similarly, Wassinger et al²¹ found that distant fatigue, or fatigue induced at a different area of the body being tested, can also impact performance as subjects in their study performed an upper body fatigue protocol resulting in a decrease for dynamic standing balance measured via the YBT-LQ. In a systematic review, Santamaria and Webster⁹ found fatigue appears to affect lower-limb biomechanics during single-limb landings.

Study limitations include limited generalizability outside of the recreational weight training population and use of an exercise protocol that may create a level of fatigue excessively specific to the upper quarter. An effort was made to utilize a fatigue protocol specific to recreational weight lifters but this may not be applicable to athletes engaging in other sports or recreational activities. A comparison for both local muscular and aerobic fatigue should also be considered, as this investigation did not monitor energy expenditure or correlate levels of fatigue to YBT-UQ scores.

Future research involving the use of YBT-UQ should be performed in specific athletic populations and utilize a fatigue protocol that closely simulates the demand of the sport for the population being studied. Performing a fatigue protocol that closely resembles the physiological demand of the sport or activity allows for the potential of combined local

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**Table 2.** Comparison of pre- and post-testing scores examining the interaction between group and time with the factorial ANOVA for the right and left limbs. Reported as mean ± (standard deviation).

<table>
<thead>
<tr>
<th>YBT-UQ direction</th>
<th>Non-fatigue group pre-test (n=13)</th>
<th>Non-fatigue group post-test (n=13)</th>
<th>Fatigue group pre-test (n=11)</th>
<th>Fatigue group post-test (n=11)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right</td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>Medial</td>
<td>97.05(8.22)</td>
<td>99.76(8.04)</td>
<td>98.10(8.84)</td>
<td>101.51(8.65)</td>
</tr>
<tr>
<td>Superior/lateral</td>
<td>68.33(10.78)</td>
<td>69.60(11.39)</td>
<td>68.36(9.97)</td>
<td>70.89(10.93)</td>
</tr>
<tr>
<td>Inferior/lateral</td>
<td>92.37(11.20)</td>
<td>85.84(10.80)</td>
<td>94.72(11.40)</td>
<td>87.05(9.54)</td>
</tr>
</tbody>
</table>

*Significant at p<.016

**Table 3.** Comparison of pre- and post-testing composite scores examining the interaction between group and time with the factorial ANOVA for right and left limbs. Reported as mean ± (standard deviation).

<table>
<thead>
<tr>
<th>YBT-UQ</th>
<th>Non-fatigue group pre-test (n=13)</th>
<th>Non-fatigue group post-test (n=13)</th>
<th>Fatigue group pre-test (n=11)</th>
<th>Fatigue group post-test (n=11)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right</td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>Composite Score</td>
<td>85.92(9.06)</td>
<td>85.07(9.45)</td>
<td>87.06(8.78)</td>
<td>86.48(9.09)</td>
</tr>
</tbody>
</table>

*Significant at p<.035

**Figure 7.** Fatigue group and control group comparison of post testing composite YBT-UQ scores for both right and left limbs.
and central responses specific to that sport. Future research should also examine a fatigue protocol targeting the trunk and lower extremity musculature due to the YBT-UQ not specifically being an isolated upper extremity test. There is also a need to expand normative data using the YBT-UQ on varied populations. Additionally, there is a need to expand data of YBT-UQ performance both in a rested and fatigued state to determine if differences exist among populations other than the recreational weightlifter population used in this current study.

CONCLUSION
The performance of an upper body fatigue protocol significantly reduces YBT-UQ scores in recreational weightlifters for all three individual reach directions and composite scores. Clinicians using the YBT-UQ for return to activity decisions should be aware of the individuals’ state of fatigue during testing. Additionally, clinicians should consider testing in both a non-fatigued and fatigued state to allow for a more thorough evaluation of performance prior to return to activity.

REFERENCES
ABSTRACT

**Background:** Due to the high number of adolescent athletes and subsequent lower extremity injuries, improvements of injury prevention strategies with emphasis on clinic-based and practical assessments are warranted.

**Purpose:** The purpose of this study was to prospectively investigate if a battery of functional performance tests (FPT) could be used as a preseason-screening tool to identify adolescent athletes at risk for sports-related acute lower extremity injury via comparison of injured and uninjured subjects.

**Methods:** One hundred adolescent volleyball, basketball and soccer athletes (female, n=62; male, n=38; mean age = 14.4±1.6) participated. The FPT assessment included: triple hop for distance, star excursion balance test, double leg lowering maneuver, drop jump video test, and multi-stage fitness test. Composite scores were calculated using a derived equation. Subjects were monitored throughout their designated sport season(s), which consisted of a six-month surveillance period. The schools certified athletic trainer (ATC) recorded all injuries. Subjects were categorized into groups according to sex and injury incidence (acute lower extremity injury vs. uninjured) for analysis.

**Results:** Mean FPT composite scores were significantly lower for the injured compared to the uninjured groups in both sexes (males: 19.06±3.59 vs. 21.90±2.44; females: 19.48±3.35 vs. 22.10±3.06 injured and uninjured, respectively) ($p<.05$). The receiver-operator characteristic analysis determined the cut-off score at ≤20 for both genders (sensitivity = .71, specificity = .81, for males; sensitivity = .67, specificity = .69, for females) ($p<.05$) for acute noncontact lower extremity injuries. Significant positive correlations were found between the FPT composite score and the multi-stage fitness test in male subjects ($r=.474$, $p=.003$), suggesting a relationship between functional performance, aerobic capacity, and potential injury risk.

**Conclusion:** A comprehensive assessment of functional performance tests may be beneficial to identify high-injury risk adolescents prior to athletic participation.

**Keywords:** Adolescent, injury risk, pre-participation, screening

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INTRODUCTION
In the United States of America, more than half of all high school students participate in some form of athletics each year, making up a population of over 7 million adolescent student-athletes. High school athletes sustain an estimated 1.5 million injuries each year with the ankle and knee being the most common sites of injury. Severe injuries negatively affect the injured athlete's health, result in the athlete missing a large part of his or her season, and often burden the health care system, as they are more likely to require advanced medical treatment such as surgery. Due to the sheer number of injury occurrences and detrimental consequences, previous authors have suggested a need for implementation of specific injury prevention strategies for the ankle and knee joints via identifying modifiable injury risk factors.

Prior studies have commented on the importance of longitudinal research when evaluating injury risk factors (i.e., demographics, biomechanics, fitness level, etc.) through prospective injury surveillance. A relationship between intrinsic static and dynamic factors that may contribute to increased risk of suffering acute lower extremity injuries in sports has been previously reported. Intrinsic risk factors include demographics (previous history of injury), anthropometric variables (BMI, age, gender), postural stability (balance), fatigue, and physical performance measures (jump-landing, single leg hopping, core stability, cardiorespiratory fitness). Functional performance tests (such as the drop-jump video test, star excursion balance test, double leg lowering maneuver, triple hop for distance test, and multi-stage fitness test) have been presented in the literature as reliable and valid assessments for jump-landing mechanics, dynamic balance, core stability, lower limb strength and power, and cardiorespiratory fitness, respectively.

Functional performance tests have been used to assess components of sport performance (strength, power, agility), determine readiness for return to sport, evaluate effectiveness of neuromuscular training interventions, and predict injury of the lower extremity. An advantage of functional tests are that they require minimal personnel, are quick to administer, and require only minimal equipment.

Due to the high number of adolescent athletes and subsequent lower extremity injuries, improvements of injury prevention strategies with emphasis on clinic-based and practical assessments (time, equipment, finances, etc.) are warranted. Furthermore, assessments should be objective and include scores from validated clinical tests. Other screening programs have been proposed; however, many require subjective rating systems or singular variables. The purpose of this study was to prospectively investigate if a battery of functional performance tests (FPT) could be used as a preseason-screening tool to identify adolescent athletes at risk for sports-related acute lower extremity injury via comparison of injured and uninjured subjects. This investigation included comparisons of composite scores between injured and non-injured matched subjects and calculation of likelihood ratios to describe probabilities and assess risk. A second purpose was to investigate the relationship between aerobic capacity, functional performance, and potential injury risk. Hence, performance on the multi-stage fitness test (MSFT) was correlated with the FPT composite score.

METHODS
Subjects
One hundred male and female athletes between the ages of 12 and 17 years (14.44 ± 1.65 years) were recruited from a private school and were chosen as a sample of convenience. Sample size was determined by performing a priori power analysis using G*Power statistical software (Version 3.1.9.2) with power set at 0.8. As participants in middle and high school athletics, all subjects played at least one of three sports: soccer (n = 22), volleyball (n = 14), or basketball (n = 64). These specific sports were selected based upon the common occurrence of noncontact acute lower extremity injuries involved with sport participation and high-risk maneuvers. Since soccer, volleyball, and basketball all share common athletic maneuvers and injury mechanisms, all three sports were grouped together for statistical analysis. All subjects completed pre-participation health history questionnaires to rule out pathological conditions that were present at the time of the initiation of the study (any condition that would prohibit clearance to participate in athletics) and contrain-
dications to study participation, which were evaluated by a physician. Exclusionary criteria included: incomplete pre-participation physical exam, and/or inability to physically perform any of the five required assessments. Prior to study participation all procedures were explained to each subject. Subjects and their parents/guardians read and signed assent and consent forms and video assent and consent forms that were approved by the university institutional review board for human subjects.

Injury Surveillance Protocol
Subjects were monitored throughout their designated sport season(s), which consisted of a surveillance period, which extended through the entire sporting season. The school's certified athletic trainer and principal investigator were responsible for documenting and recording all injuries that occurred throughout the sports seasons. Sports injury was defined as an acute injury during athletic practice or game that caused restricted participation or athletic time loss (inability to participate in the current or next scheduled practice or game) as described by Hagglund.44 The present study was particularly concerned with reporting acute noncontact injuries to the lower extremity (e.g. ACL tear, ankle sprain) since research has shown potential in risk reduction through neuromuscular training for these types of injuries.29,30,34 This study did not include chronic or over-use type injuries for analysis.

Following the injury surveillance, subjects were categorized into groups according to sex and injury incidence for analysis. Those who sustained an acute lower extremity injury were placed in the injured group and those who did not sustain an acute lower extremity injury were pooled in the uninjured group. Those who sustained an overuse-type injury were excluded from statistical analysis. Data were then analyzed for differences between groups. Additionally, the injured subjects were then matched with an equal number of uninjured subjects based on sex, age, height, and body mass for further analysis.

Procedures
Data were collected by the same four examiners at all testing sessions. All examiners were graduate-level NATABOC certified athletic trainers. Anthropometric data were recorded before all testing procedures and included height, body mass, BMI (body mass index), age, date of birth, grade, sport, and level of sport participation by the principal investigator. All testing was performed in the school's gymnasium. Before testing, subjects conducted a dynamic warm-up led by the principal investigator. The dynamic warm up included jogging, backpedaling, side-stepping, and walking stretches. Subjects were then divided into four different groups, two for each gender. Each group started at a different test station. The starting (test) position was randomly assigned and included synchronous clockwise rotation of all groups. Standardized oral instructions for each test were rehearsed and read by the examiners to all test groups. Standardized instructions were designed to maintain consistency of testing procedures, decrease instructional time, and allow concise and precise data collection. Incorrect test performance required that the test be restarted after a minimum 30-second rest period. No corrective feedback was given to subjects.

Functional Performance Tests
The Triple Hop for Distance Test (THD) evaluated maximal hopping distance on a single limb and was assessed in centimeters (cm) with a standard tape measure fixed to the ground, perpendicular to the starting line.27 Subjects stood on the designated testing leg with the great toe on the starting line and performed three consecutive maximal hops forward on the same limb. Arm swing was allowed, and the investigator measured the distance hopped from the starting line to the point where the heel struck the ground upon completing the third hop with stability. The test was then repeated on the contralateral limb. Previous authors have offered no normalization of this test, since height or leg length may not necessarily affect hop distance. The maximum distance (MaxD) achieved during three trials was recorded in centimeters and used for analysis.27

The Star Excursion Balance Test (SEBT) was used to record single-leg reach distance in cm(s) on each leg, in three directions, assessed with a standard vinyl tape measure according to Gribble et al.35 Subjects stood on the center of the testing grid with one limb and reached with their ipsilateral limb in the anterior, posterior, and lateral directions. Average and maximum reach distances (MaxD) in each di-
rection were recorded in centimeters and normalized according to leg length of the stance leg in order to adjust for variances of different anthropometrical variables. The sum of the SEBT scores were expressed as a percentage of leg length.36

**The Double Leg Lowering Maneuver** (DLLM) was assessed with a hand-held inclinometer (Johnson Tool 700 Magnetic Angle Locator) placed along the extended legs over the estimated middle of thigh as described by Kendall.37 to assess slope of inclination of the lower extremities in degrees. The subject, beginning with the knees extended and the hips flexed to 90° was then asked to lower both legs while maintaining the lumbar spine parallel (neutral spinal position) to the test surface (performing an abdominal bracing procedure) to prevent anterior pelvic motion. The tester palpated at the anterior superior iliac spine (ASIS) and at the point when anterior pelvic rotation was observed, the test trial was concluded and the hip angle was measured with the inclinometer. The DLLM score was calculated by subtracting the average angle (in degrees) from 90º (starting position). The same examiner then measured and recorded leg length on one leg with a Gulick tape measure (cm) from ASIS to the distal edge of the medial malleolus; leg length was used for post-testing normalization procedures of the SEBT scores.

**The Drop Jump Video Test** (DJV) was performed according to Noyes et al.19 A Sony Mini DV camcorder (Sony Corp of America, New York, NY) was used to record jump landing mechanics, placed on a 102 cm high stand, positioned approximately 366 cm in front of a box that was 30 cm in height and 38 cm in width. Jump landing mechanics were analyzed post-testing session via Dartfish Motion Analysis Software (ProSuite version 4.0.9.0) where lower limb separation distances at the hip and knee were calculated. Immediately before each subject performed the DJV test, the same examiner placed two sets of 4 x 4 cm florescent pink reference markers over the ASIS and center of patella for each limb. Hip separation distance (HSD) was measured while standing erect on top of the box and defined as the distance between the most prominent points of each anterior superior iliac spine. Knee separation distance was measured at the lowest point of each jump landing prior to transition to takeoff into the vertical jump and was defined as the distance between the centers of the patellae. The average absolute knee separation distance during three successful trials was recorded in centimeters and then normalized relative to HSD to yield a percentage for each subject.19,38

After completion of the four-abovementioned functional performance tests, a five minute rest period was provided before all subjects completed the Multi-Stage Fitness Test (MSFT) to evaluate maximal oxygen consumption (VO₂ max)38 and provide field-based data regarding aerobic fitness and fatigue. The subjects were required to perform a shuttle run back and forth along 20 meters, keeping in time with a series of auditory signals (provided by an mp3 player) by touching the appropriate end line in time with each audio signal. The frequency of the auditory signals (and hence running speed) was progressively increased until the subjects reached volitional exhaustion and could no longer maintain pace with the signals. VO₂ max was estimated using correlation regression data described by Ramsbottom et al.39

The FPT composite score was calculated using the following equation (see full description below):

\[
FPT \text{ Composite} = (\text{DLLM scaled}) + \\
(\text{SEBT mean of scaled right and left anterior reach}) + \\
(\text{THD mean of scaled right and left MaxD}) + \\
(\text{DJV absolute KSD scaled})
\]

**STATISTICAL METHODS**

All data were analyzed using SPSS Statistics Version 22.0.0.0 (IBM, Armonk, New York, USA), with an alpha level set at .05 to determine statistical significance. Descriptive statistics were generated and Pearson product-moment correlation coefficients were established between variables of interest (FPT composite scores). Subjects were divided into groups according to gender and injury (acute lower extremity injury, non-injured). Subjects with chronic or overuse lower extremity injuries were excluded from statistical analysis. Univariate general linear model (GLM) was used to assess differences in each functional performance test variable using composite score data between injured and uninjured groups.

Results of all functional performance tests were then each scaled individually using linear regres-
sion, which allowed for the normalization of data for each test with scores ranging on a scale from 0 to 10. Scaling data involved computing the mean ± 3 standard deviations (SDs) for each test variable according to absolute scores for males and females. The data were then entered into regression equation models with the fixed notations: the mean equaling a score of ‘5 out of 10’, – 3 SDs equaling a score of ‘1 out of 10’, and + 3 SDs equaling a score of ‘10 out of 10’. Utilizing the scaled measurements, the scores for the four performance functional performance tests were added and the sum was characterized as the FPT composite score, as described above.

Receiver-operator characteristic (ROC) curves were used to determine cut-off scores for both males and females in the FPT composite score that maximized sensitivity and specificity. The area under the curve (AUC) was calculated using the ROC analysis to measure the accuracy of the FPT composite test as a predictor of injury. Positive predictive values (PPV) were defined in the present study as the probability that subjects with a positive screening test will truly sustain an acute lower extremity injury and were calculated using the following equation:

$$PPV = \frac{True \ Positive}{True \ Positive + False \ Positive}.$$

Positive likelihood ratios (LR+) were calculated for both males and females to utilize established ranges to interpret the results.

Simple regression was used to correlate composite scores and MSFT shuttle level.

RESULTS

Demographic characteristics of injured and uninjured groups according to gender are provided in Table 1. There were no statistically significant differences in demographic variables between groups ($p > .05$). A total of 95 subjects (57 females, 38 males) were included in the statistical analyses at the end of the six-month injury surveillance period. Fifteen females and seven males sustained an acute lower extremity injury with no previous history of injury. Of the injured females, two suffered noncontact anterior cruciate ligament (ACL) tears confirmed by MRI and 13 suffered acute ankle sprains confirmed by physical examination using anterior drawer and talar tilt test. All seven males suffered acute ankle sprains. Forty-two females and thirty-one males were categorized as the uninjured group (no reported and no previous history of acute lower extremity injury). A total of five subjects were excluded from statistical analyses as a result of incurring other non-acute lower extremity injuries (overuse knee injuries) during the prospective injury surveillance period.

Regression equations used for scaling data for all subjects and according to gender are presented in Table 2.

| Table 1. Injured and uninjured subject demographic characteristics (mean ± SD). |
|-------------------------|-------------------------------|-------------------------------|-------------------------|
| **Females**             | Overall, n = 57               | Injured, n = 15               | Uninjured, n = 42       |
| Age (years)             | 14.2 ± 1.6                    | 14.7 ± 1.7                    | 14.0 ± 1.5              |
| Height (cm)             | 161.6 ± 6.6                   | 164.1 ± 6.5                   | 161.0 ± 6.4             |
| Body Mass (kg)          | 55.9±13.4                     | 57.1 ± 9.2                    | 55.5±14.6               |
| Body Mass Index (kg/m²) | 21.2±4.2                      | 21.2 ± 2.5                    | 21.2 ± 4.6              |
| Leg Length Right (cm)   | 86.6±4.4                      | 88.2 ± 4.8                    | 86.1 ± 4.1              |
| Leg Length Left (cm)    | 86.5±4.4                      | 88.1 ± 4.7                    | 86.1 ± 4.1              |
| Hip Separation Distance (cm) | 22.9±2.4                     | 23.2 ± 1.8                    | 22.8 ± 2.6              |
| Sport Experience (years)| 4.8±2.7                       | 5.2 ± 2.2                     | 4.6 ± 2.9               |
| **Males**               | Overall, n = 38               | Injured, n = 7                | Uninjured, n = 31       |
| Age (years)             | 14.8±1.6                      | 14.6 ± 1.7                    | 14.9 ± 1.6              |
| Height (cm)             | 168.1±9.8                     | 171.3 ± 6.6                   | 167.3±10.4             |
| Body Mass (kg)          | 62.9±14.9                     | 70.8±14.4                     | 61.1±14.6               |
| Body Mass Index (kg/m²) | 22.0±3.8                      | 24.1 ± 4.8                    | 21.5 ± 3.5              |
| Leg Length Right (cm)   | 89.4±5.5                      | 92.2 ± 4.9                    | 88.8 ± 5.5              |
| Leg Length Left (cm)    | 89.4±5.5                      | 92.0 ± 5.4                    | 88.9 ± 5.4              |
| Hip Separation Distance (cm) | 24.7±2.6                     | 26.6 ± 3.1                    | 24.3 ± 2.3              |
| Sport Experience (years)| 5.8±2.7                       | 5.4 ± 2.9                     | 5.8 ± 2.8               |
Statistical means, standard deviations (SD), and ranges of the functional performance tests results for injured and uninjured subjects are presented in Table 3. Univariate GLM indicated significant differences between groups for the DLLM and the DJV tests in females and only with the DJV test in males are presented in Table 4. Results of the multi-stage fitness test (MSFT) are presented in Table 5. Univariate GLM failed to identify any significant differences on performance of the MSFT between the injured and uninjured groups (p > .05).

Means, SDs and ranges of the FPT composite scores are presented in Table 6. Mean FPT composite scores were significantly different for injured versus uninjured males and females (19.0 ± 3.5 vs. 21.9 ± 2.4 and 19.4 ± 3.3 vs. 22.1 ± 3.0, respectively) (p < .05). These scores are presented in Table 7. The ROC analysis determined the cut-off score of 20 (total scoring range: 1–40) for the FPT composite score in both males and females. Area under the curve (AUC) was statistically significant for both males and females (AUC = .765, p = .030 and AUC = .694, p = .029, respectively). The ROC analysis revealed that the sensitivity and specificity were 71% and 81% for males and 67% and 69% for females, respectively (Figure 1).

DISCUSSION
The main finding of the present study was that the prospectively measured FPT composite scores were significantly different between the injured and uninjured groups for males and females (p = .016, p = .008 respectively). Significant differences were found between the injured and the uninjured groups (p < .05) during the drop jump video test and the double leg-lowering maneuver, identifying jump-landing mechanics and core strength as potential injury risk factors.

When the injured males were matched with similar uninjured males (n = 7 injured, n = 7 uninjured), significant differences were found during the SEBT anterior reach direction between groups (p = .019). This finding is consistent with prior reports that poor balance and reach distance deficits found during the SEBT predicted lower extremity injury in high school athletes.16,40 Additionally, the FPT composite score correlated positively with the MSFT (r = .474, p = .003), identifying a relationship between functional performance testing and aerobic fitness in male adolescent athletes.

The advantage of utilizing the functional performance tests described in the present study is the determination of a composite score that crosses categories of performance, and that can potentially measure function and give insight to injury-prone athletes. This proposed assessment consists of scaling data using gender based linear regression

| Table 2. Regression equations used for scaling data for all subjects (y = mx + b). |
|-----------------|-----------------|
| Functional Test Variable | Females (n = 47) | Males (n = 38) |
| DLLM | y = 0.1482(DLLM) + 0.8734 | y = 0.1604(DLLM) + 1.0563 |
| SEBT Right Anterior | y = 0.253(SEBTR) – 12.988 | y = 0.2423(SEBTR) – 12.376 |
| SEBT Left Anterior | y = 0.214(SEBTL) – 10.57 | y = 0.2762(SEBTL) – 14.658 |
| THD Right MaxD† | y = 0.0293(THDR) – 7.2108 | y = 0.0144(THDR) – 3.2046 |
| THD Left MaxD† | y = 0.0258(THDL) – 5.5665 | y = 0.0134(THDL) – 2.4636 |
| DJV Absolute KSD | y = 0.2841(KSD) + 0.5038 | y = 0.173(KSD) + 0.3887 |
| DJV NKSD | y = 0.0659(NKSD) + 0.4358 | y = 0.0439(NKSD) + 0.249 |
| MSFT | y = 1.0176(MSFT) – 0.7243 | y = 0.6929(MSFT) – 1.0091 |

DLLM=Double leg lowering maneuver = (average of 3 trials) – 90; degrees
SEBT=Star excursion balance test = (average of 3 trials in cm) x (Leg length) x 100; anterior direction for right/left legs reported as percentage of leg length
THD=Triple hop for distance
MaxD = maximum distance of 3 trials on right/left leg; centimeters
DJV=Drop jump video test
KSD=Absolute knee separation distance, average of 3 trials, defined as the distance between the patella measured via Dartfish in centimeters
NKSD = Normalized KSD (Avg Absolute KSD + Hip separation distance) x100; reported as percentage of hip width
MSFT=Multi Stage Fitness Test, shuttle level reached during 20 meter volitional maximal exhaustion running test
equations and computing the sum for the following variables: 1) DLLM average, 2) SEBT average anterior reach distance of right and left legs, 3) DJV absolute knee separation distance, and 4) THD average max distance of right and left legs. The criteria for selection of the functional performance tests used in the assessment were repeated-measures reliability, validity in assessing desired measures of function, clinical applicability of testing procedures and instrumentation, and theorized relationship between injury risk factor and neuromuscular association.19,24-28

Table 3. Functional performance test scores, including absolute and normalized, categorized by injured and uninjured for both males and females.

<table>
<thead>
<tr>
<th></th>
<th>DLLM</th>
<th>SEBT Anterior</th>
<th>SEBT Posterior</th>
<th>SEBT Medial</th>
<th>THD R MaxD</th>
<th>THD L MaxD</th>
<th>DJV Absolute KSD</th>
<th>DJV NKSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females Uninjured</td>
<td>n=42</td>
<td>32.22</td>
<td>76.44</td>
<td>83.09</td>
<td>93.85</td>
<td>435.18</td>
<td>423.15</td>
<td>17.93</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>9.80</td>
<td>6.11</td>
<td>7.32</td>
<td>6.39</td>
<td>50.37</td>
<td>59.39</td>
<td>5.56</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>18–58</td>
<td>64–91</td>
<td>67–99</td>
<td>83–106</td>
<td>353-561</td>
<td>297-569</td>
<td>9–33</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>23.55</td>
<td>76.34</td>
<td>87.86</td>
<td>96.50</td>
<td>419.26</td>
<td>420.21</td>
<td>14.35</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>9.69</td>
<td>9.50</td>
<td>10.10</td>
<td>8.91</td>
<td>50.89</td>
<td>55.72</td>
<td>3.47</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>5–43</td>
<td>57–91</td>
<td>68–107</td>
<td>76–111</td>
<td>345-498</td>
<td>335-516</td>
<td>9–21</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>27.25</td>
<td>76.44</td>
<td>93.01</td>
<td>101.04</td>
<td>596.49</td>
<td>587.14</td>
<td>29.61</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>9.72</td>
<td>5.20</td>
<td>7.60</td>
<td>7.24</td>
<td>100.45</td>
<td>108.05</td>
<td>9.05</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>8–50</td>
<td>68–87</td>
<td>75–108</td>
<td>90–117</td>
<td>269-754</td>
<td>264-752</td>
<td>15–44</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>24.04</td>
<td>72.23</td>
<td>92.90</td>
<td>98.92</td>
<td>584.92</td>
<td>545.37</td>
<td>22.92</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>8.43</td>
<td>4.73</td>
<td>13.03</td>
<td>8.73</td>
<td>134.39</td>
<td>136.89</td>
<td>3.71</td>
</tr>
</tbody>
</table>

Table 4. Univariate General Linear Model results for significant functional test variables between injured and uninjured males and females (mean ± SD; η%).

<table>
<thead>
<tr>
<th>Functional Test</th>
<th>Injured</th>
<th>Control</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females (n=57)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DLLM n=15 (26%)</td>
<td>n=42(74%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DLLM</td>
<td>22.10± 9.69</td>
<td>32.63± 9.54</td>
<td>9.93</td>
<td>.003</td>
</tr>
<tr>
<td>DJV Absolute KSD</td>
<td>14.35± 3.47</td>
<td>17.93± 5.56</td>
<td>5.47</td>
<td>.023</td>
</tr>
<tr>
<td>DJV NKSD</td>
<td>61.73±13.70</td>
<td>78.88±24.45</td>
<td>6.58</td>
<td>.013</td>
</tr>
<tr>
<td>Males (n=38)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DLLM</td>
<td>86.68±14.57</td>
<td>121.59±34.44</td>
<td>6.79</td>
<td>.013</td>
</tr>
</tbody>
</table>

DLLM= Double leg lowering maneuver = (average of 3 trials) – 90; degrees
SEBT= Star excursion balance test = (max distance of 3 trials in cm) – (leg length of stance leg) x 100; reach directions were averaged between right/leg legs and reported as a single mean score; expressed as a percentage of leg length
THD= Triple hop for distance MaxD = maximum distance of 3 trials on right/left leg; centimeters
DJV= Drop jump video test absolute knee separation distance (KSD) = average of 3 trials; KSD defined as the distance between the patellae measured via Dartfish in centimeters
NKSD= normalized DJV= (Avg Absolute KSD ÷ Hip separation distance) x100; reported as percentage of hip width
Table 5. Multi-stage fitness test (MSFT) variables according to gender and categorized by injured and uninjured.

<table>
<thead>
<tr>
<th></th>
<th>MSFT Shuttle Level*</th>
<th>MSFT VO₂ Max**</th>
<th>Time to Fatigue†</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Female</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>n=42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>6.00</td>
<td>33.14</td>
<td>5:16</td>
</tr>
<tr>
<td>SD</td>
<td>1.49</td>
<td>4.68</td>
<td>1:51</td>
</tr>
<tr>
<td>Range</td>
<td>2.9</td>
<td>22.43</td>
<td>1–8</td>
</tr>
<tr>
<td><strong>Injured</strong></td>
<td>n=15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>5.83</td>
<td>32.65</td>
<td>4:54</td>
</tr>
<tr>
<td>SD</td>
<td>1.47</td>
<td>4.64</td>
<td>1:58</td>
</tr>
<tr>
<td>Range</td>
<td>3–8</td>
<td>26–41</td>
<td>2–8</td>
</tr>
<tr>
<td><strong>Male</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>n=31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>9.20</td>
<td>43.65</td>
<td>8:47</td>
</tr>
<tr>
<td>SD</td>
<td>2.12</td>
<td>7.10</td>
<td>2:05</td>
</tr>
<tr>
<td>Range</td>
<td>5–13</td>
<td>32–56</td>
<td>5–12</td>
</tr>
<tr>
<td><strong>Injured</strong></td>
<td>n=7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>8.98</td>
<td>42.94</td>
<td>8:39</td>
</tr>
<tr>
<td>SD</td>
<td>2.52</td>
<td>8.31</td>
<td>2:57</td>
</tr>
<tr>
<td>Range</td>
<td>4–12</td>
<td>27–51</td>
<td>3–11</td>
</tr>
</tbody>
</table>

*MSFT = shuttle level reached during 20 meter volitional maximal exhaustion running test  
**MSFT VO₂ Max: estimated using shuttle level and linear regression reported by Ramsbottom[39]; mL/kg/min  
†Time to fatigue: overall time to completion of test (volitional exhaustion); reported in minutes and seconds

Table 6. Functional Performance Test (FPT) composite scores with scaled values of combined functional tests according to gender and categorized by injured and uninjured.

<table>
<thead>
<tr>
<th></th>
<th>FPT Composite*</th>
<th>FPT Composite Aerobic†</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Female</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>n=42</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>22.10</td>
<td>27.45</td>
</tr>
<tr>
<td>SD</td>
<td>3.06</td>
<td>3.40</td>
</tr>
<tr>
<td>Range</td>
<td>16–29</td>
<td>20–34</td>
</tr>
<tr>
<td><strong>Injured</strong></td>
<td>n=15</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>19.48</td>
<td>24.70</td>
</tr>
<tr>
<td>SD</td>
<td>3.35</td>
<td>4.42</td>
</tr>
<tr>
<td>Range</td>
<td>12–24</td>
<td>16–31</td>
</tr>
<tr>
<td><strong>Male</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>n=31</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>21.90</td>
<td>27.25</td>
</tr>
<tr>
<td>SD</td>
<td>2.44</td>
<td>3.37</td>
</tr>
<tr>
<td>Range</td>
<td>16–26</td>
<td>19–33</td>
</tr>
<tr>
<td><strong>Injured</strong></td>
<td>n=7</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>19.06</td>
<td>24.28</td>
</tr>
<tr>
<td>SD</td>
<td>3.59</td>
<td>4.92</td>
</tr>
<tr>
<td>Range</td>
<td>12–23</td>
<td>13–29</td>
</tr>
</tbody>
</table>

*FPT Composite = (DLLM scaled) + (SEBT mean of scaled right and left anterior reach) + (THD mean of scaled right and left MaxD) + (DJV absolute KSD scaled); scale 1–40  
†FPT Composite Aerobic = (DLLM scaled) + (SEBT mean of scaled right and left anterior reach) + (THD mean of scaled right and left MaxD) + (DJV absolute KSD scaled) + (MSFT shuttle level); scale 1–50
The creation of a FPT composite score and its ability to differentiate between the injured and uninjured groups are of clinical importance, as the value in assessing injury risk via a composite score has been described in literature examining the utility of the Functional Movement Screen™ (FMS™) which has been shown to be able to identify injury risk in athletic and military populations. The FMS™ has been described as an injury predictor with a composite score less than or equal to 14 (out of 21) associated with an increased risk of serious injury in professional football players (12 times more likely). In previous studies, the ROC curve was used to determine the validity of functional performance tests as predictors of injury risk. The ROC analysis in the present study revealed that the FPT composite score at the cut-off of ≤ 20 demonstrated sensitivities and specificities of 71% and 81% for males and 67% and 69% for females, respectively. When examining frequency counts of injured and uninjured groups by the ROC cut-off score, results indicated that 71% of the injured and 29% of the uninjured males had prospective composite scores of ≤ 20; similarly, 67% of the injured and 31% of the uninjured females had prospective FPT composite scores of ≤ 20 (Figure 4).

<table>
<thead>
<tr>
<th>Functional Test</th>
<th>Injured (n=57)</th>
<th>Uninjured (n=42)</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FPT Composite</td>
<td>19.48 ± 3.35</td>
<td>22.10 ± 3.06</td>
<td>7.53</td>
<td>.008</td>
</tr>
<tr>
<td>FPT Composite Aerobic</td>
<td>24.70 ± 4.42</td>
<td>27.45 ± 3.40</td>
<td>6.23</td>
<td>.016</td>
</tr>
<tr>
<td>Males (n=38)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FPT Composite Aerobic</td>
<td>24.28 ± 4.92</td>
<td>27.25 ± 3.37</td>
<td>3.73</td>
<td>.061</td>
</tr>
</tbody>
</table>

FPT Composite = (DLLM scaled) + (SEBT mean of scaled right and left anterior scaled) + (THD mean of scaled right and left MaxD) + (DJV absolute KSD); scale 1–40
FPT Composite Aerobic = (DLLM scaled) + (SEBT mean of scaled right and left anterior scaled) + (THD mean of scaled right and left MaxD) + (DJV absolute KSD) + (MSFT shuttle level); scale 1–50

**Table 7.** Univariate General Linear Model results for Functional Performance Test (FPT) composite scores between injured and uninjured males and females (mean ± SD; n(%)).

**Figure 1.** Receiver-operator characteristic (ROC) curves for FPT composite scores in males and females. The green line represents the line of no-discrimination. The diagonal divides the ROC space. Points above the diagonal represent good classification results (better than random), points below the line represent poor results (worse than random). Blue dots represent points that maximize sensitivity and specificity on the ROC curve (FPT composite score ≤20).
Among those who had a positive FPT composite score (≤ 20), the probability of sustaining an acute lower extremity injury was 45% for males and 48% for females. Therefore, these results suggest that the FPT composite score of ≤ 20 has moderate predictability for acute lower extremity injuries in adolescent males and females. The positive likelihood ratios of 3.74 and 2.16 for males and females, respectively, describe a slight to moderate increase effect on post-test probability of acute lower extremity injury, and a >15% approximate change in probability for acute lower extremity injury.

Performance on the multi-stage fitness test (MSFT) was correlated with the FPT composite score in male subjects (r = .47, p = .003). Subjects who performed poorly overall on the functional performance tests tended to score low on the MSFT, thus reaching volitional maximal exhaustion earlier than subjects who scored higher on the functional performance tests (Figures 2 and 3).

Fatigue has been shown to adversely alter lower extremity landing biomechanics, decrease lower limb strength, and decrease dynamic balance. Furthermore, it has been reported that a high percentage (60%) of injuries

![Figure 2. Correlation of Functional Performance Test (FPT) composite score and MSFT shuttle level in male subjects (n = 38, r = .474, p = .003).](image)

Among those who had a positive FPT composite score (≤ 20), the probability of sustaining an acute lower extremity injury was 45% for males and 48% for females. Therefore, these results suggest that the FPT composite score of ≤ 20 has moderate predictability for acute lower extremity injuries in adolescent males and females. The positive likelihood ratios of 3.74 and 2.16 for males and females, respectively, describe a slight to moderate increase effect on post-test probability of acute lower extremity injury, and a >15% approximate change in probability for acute lower extremity injury.

Performance on the multi-stage fitness test (MSFT) was correlated with the FPT composite score in male subjects (r = .47, p = .003). Subjects who performed poorly overall on the functional performance tests tended to score low on the MSFT, thus reaching volitional maximal exhaustion earlier than subjects who scored higher on the functional performance tests (Figures 2 and 3).

Fatigue has been shown to adversely alter lower extremity landing biomechanics, decrease lower limb strength, and decrease dynamic balance. Furthermore, it has been reported that a high percentage (60%) of injuries

![Figure 3. Relationship of functional performance test (FPT) composite score* and Multi Stage Fitness Test (MSFT) estimated VO2 max† in male subjects (n = 38, r = .468, p = .003).](image)

*FPT Composite = (Double Leg Lowering Maneuver (DLLM) scaled) + (Star Excursion Balance Test (SEBT) mean of scaled right and left anterior scaled) + (Triple Hop for Distance (THD) mean of scaled right and left Maximum Reach Distance (MaxD)) + (Drop Jump Video Test (DJV) absolute Knee Separation Distance (KSD)); scale 1–40  
MSFT = Multi Stage Fitness Test shuttle level (shuttle level reached during 20 meter volitional maximal exhaustion running test)

†MSFT VO2 Max: estimated using shuttle level and linear regression reported by Ramsbottom[39]

![Figure 4. Frequency distribution for the FPT composite cut-off score of ≤20 (out of 40) between injured and uninjured females (n = 42).](image)

![Figure 4. Frequency distribution for the FPT composite cut-off score of ≤20 (out of 40) between injured and uninjured males (n = 31).](image)
occur during the latter stages of a game or practice and the risk of suffering moderate to severe injuries increases compared to minor injuries. Therefore, subjects who performed low on the FPT composite score may benefit from improving aerobic endurance and VO₂ max and thus decreasing potential injury risk associated with fatigue.

The main limitations of the present study include: not controlling for activities that subjects may have been involved in before and/or after the functional testing, lack of reporting athletic exposures during the injury surveillance period, and subsequent calculation of hazard ratio’s and relative risk between functional performance testing and acute lower extremity injury occurrence. Additionally, external devices (e.g. ankle braces, knee supports, etc.) and leg dominance/handedness were not recorded.

The limitations of the individual functional tests include the following: subjects kept their shoes on for the SEBT which may have affected their balance and overall scores; ankle separation distance was not measured during the DJV; and VO₂ max was evaluated with a 20 meter shuttle run performance (MSFT) to volitional exhaustion (scores may not be representative of true maximal aerobic capacity in the subjects tested).

Other general limitations include: relatively small sample size, short injury surveillance period, and a homogenous subject population (adolescent athletes in a single school in a particular geographic area). Also, the provided scaled data may not be used as norms for other populations (i.e. collegiate or professional athletes) as theoretically older and more elite athletes would perform better overall on the assessment thus requiring new regression equations for normative measures. Finally, only sports participants from soccer, basketball, and volleyball were included in this study.

**CONCLUSION**

The FPT composite utilized in the current study is an objective, quantifiable athletic assessment that combines reliable and valid functional performance tests and utilizes a normalization procedure to combine results into a single composite score. This composite score has demonstrated potential in identifying adolescent athletes at risk for acute lower extremity injuries, as significant differences were noted in the FPT composite scores between the injured and the uninjured groups in both females ($p = .008$) and males ($p = .016$).

Therefore, if the FPT composite score can identify at risk athletes prior to competition, prevention strategies could be employed based on an adolescent soccer, basketball and volleyball athletes specific scores. However, further research is needed to further explore the FPT composite utilizing larger sample sizes via a multi-institution approach with mass testing.

**REFERENCES**


ABSTRACT

Purpose/Background: Shoulder proprioception is essential in the activities of daily living as well as in sports. Acute muscle fatigue is believed to cause a deterioration of proprioception, increasing the risk of injury. The purpose of this study was to evaluate if fatigue of the shoulder external rotators during eccentric versus concentric activity affects shoulder joint proprioception as determined by active reproduction of position.

Study design: Quasi-experimental trial.

Methods: Twenty-two healthy subjects with no recent history of shoulder pathology were randomly allocated to either a concentric or an eccentric exercise group for fatiguing the shoulder external rotators. Proprioception was assessed before and after the fatiguing protocol using an isokinetic dynamometer, by measuring active reproduction of position at 30° of shoulder external rotation, reported as absolute angular error. The fatiguing protocol consisted of sets of fifteen consecutive external rotator muscle contractions in either the concentric or eccentric action. The subjects were exercised until there was a 30% decline from the peak torque of the subjects’ maximal voluntary contraction over three consecutive muscle contractions.

Results: A one-way analysis of variance test revealed no statistical difference in absolute angular error ($p > 0.05$) between concentric and eccentric groups. Moreover, no statistical difference ($p > 0.05$) was found in absolute angular error between pre- and post-fatigue in either group.

Conclusions: Eccentric exercise does not seem to acutely affect shoulder proprioception to a larger extent than concentric exercise.

Level of evidence: 2b

Key words: Exercise, joint position sense, neuromuscular control

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INTRODUCTION

Shoulder proprioception has been acknowledged in physical therapy practice as a sensory component that needs to be addressed in rehabilitation of various disorders. Proprioception is defined as the specialized variation of sensory modality of touch, and encompasses the sensation of joint movement (kinesthesia) and joint position sense. It is commonly believed that joint proprioceptive feedback occurs due to the simultaneous activity of several different types of mechanoreceptors located in the skin, muscles, joints, capsular, and ligamentous structures. Such mechanoreceptors include: Ruffini receptors, Golgi tendon receptors, Pancinian corpuscles, free nerve endings, and muscle spindles.

Because mechanoreceptors located in muscles around a joint are believed to contribute to joint proprioception, it is possible that fatiguing the muscles surrounding a joint will affect the proprioception of that joint. Muscle fatigue is defined as impairment of physical performance that increases the perception of effort necessary to exert a specific force. The effects of muscle fatigue on joint proprioception are very important as proprioceptive afferent feedback has a key role in motor control, posture, and also in sport activities where optimal movement patterns are required. Impairment of joint proprioception may influence joint stability and has been associated with the occurrence of injuries that occur during sports and exercise.

To date, while it seems clear that muscle fatigue affects joint proprioception, no study has investigated if there is an immediate difference on shoulder joint proprioception following muscle fatigue induced by either concentric or eccentric exercise of the shoulder rotators. Therefore, the purpose of this study was to evaluate if fatigue of the shoulder external rotators during eccentric versus concentric activity affects shoulder joint proprioception as determined by active reproduction of position. As eccentric exercise is reported to be more stressful and damaging than concentric exercise, the hypothesis for this investigation was that shoulder muscle fatigue induced by eccentric exercise would deteriorate shoulder joint proprioception to a larger extent than shoulder muscle fatigue induced by concentric exercise. The results of this study may help clinician better understand the physiology of proprioception of the shoulder joint.

METHODS

Subjects and experimental groups

Between June and August 2012, twenty-two healthy people from the general student population at the University of Central Lancashire (UCLan), Preston, United Kingdom, responded to recruitment. Exclusion criteria for participation included a history of shoulder surgery, shoulder pain or any major event involving the shoulder complex (trauma or dislocation) within the previous two years, or any serious medical condition. All twenty-two subjects (14 males, 8 females, age 20-32 years; mean age 25.04) were included for the study and informed consent was obtained. Ethical approval was obtained from the UCLan Ethics Committee. All subjects had shoulder range of motion (ROM) within normal limits and no difficulty or discomfort in moving the shoulder in internal and external rotation in the ROM utilized for the testing protocol.

Allocation to either concentric exercise group (CEG) or eccentric exercise group (EEG) was achieved by a computer generated table of random numbers. The CEG included 10 subjects (6 males, 4 females, mean age of 23.9 years, with a range from 20 and 32 years) while the EEG included 12 subjects (8 males, 4 females, mean age of 26 years, with a range from 23 and 28 years). TABLE 1 displays the characteristics of the two groups.

Instrumentation and proprioception assessment

Proprioception assessment was conducted using an isokinetic dynamometer (CSMI, Cybex Humac Norm, USA) at the UCLan Movement Analysis Laboratory. Proprioception was assessed as in a previous study by active reproduction of position (ARP). Each subject reported their arm dominance as the proprioception assessment and the fatigue protocol was performed on the dominant shoulder only. The shoulder was positioned at 30° of abduction, 0° of external rotation, in the plane of the scapula (30° anterior to the frontal plane), with the elbow flexed at 90°, in mid-pronation and was strapped to the arm device. For comfort reasons the height of
position and notify the assessor when they thought they were at the reference position for three trials, each beginning from 0° of external rotation. The three absolute angular differences between the reference angle and the angle reproduced by the subjects were recorded and the average was calculated, which was called the absolute angular error (AAE), the dependent variable for this study.

**PROCEDURES**

Following the initial proprioception assessment, three maximal voluntary contractions (MVCs) of the shoulder external rotators consistent with the same contraction type of the fatiguing protocol were executed. For this task the subjects remained in the same position as in the shoulder proprioception assessment. The subjects in the CEG were instructed to move their shoulder into external rotation; from 40° of internal rotation to 80° of external rotation as intensely as they could. The subjects in the EEG were instead instructed to try to oppose a forced internal rotation induced by the dynamometer; from 80° of external rotation to 40° of internal rotation as intensely as they could. For both types of action, the speed of the dynamometer was set at 180°/second.

To familiarize the subjects with the testing device, the type of contraction requested, and as a warm-up, before each MVC the subjects performed five low-intensity contractions consistent with their group allocation. To do so, the subjects were instructed to apply a force of approximately 20% of their maximal capability. There was one-minute rest between the three MVCs. As in a previous study, the cut point for shoulder muscle fatigue was considered the highest MVC's peak torque minus 30%.17

According to the group allocation, shoulder external rotators were then fatigued using either concentric or eccentric muscle action. The subjects in the CEG performed external contractions from 40° of inter-

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**Table 1.**

<table>
<thead>
<tr>
<th>SUBJECTS (22)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ECCENTRIC GROUP (12)</strong></td>
<td><strong>CONCENTRIC GROUP (10)</strong></td>
</tr>
<tr>
<td>Age (years ± Standard deviation)</td>
<td>26±1.95</td>
</tr>
<tr>
<td>Males/Females</td>
<td>8/4</td>
</tr>
<tr>
<td>Right handed/Left handed</td>
<td>11/1</td>
</tr>
</tbody>
</table>

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**Figure 1.** Initial position for shoulder joint proprioception assessment.
The aim of this study was to investigate whether shoulder muscle fatigue induced by eccentric exercise affected shoulder joint proprioception to a larger extent than concentric exercise. In this study, shoulder proprioception was measured using ARP and quantified by AAE. For this study, it was hypothesized that eccentric exercise would have had greater effects on shoulder proprioception than concentric exercise. However, the results showed that eccentric exercise did not immediately affect shoulder joint proprioception to a larger extent than concentric exercise. Moreover, the results indicate that shoulder muscle fatigue as induced in the current study did not affect shoulder joint proprioception regardless the type of muscle action.

Proprioceptive feedback regarding joint position and joint movement is believed to depend on mechanical stimulation of mechanoreceptors present in the articular structures, within muscles, and in tendons. It is known that mechanoreceptors demonstrate adaptive properties depending upon the type of the stimulus. Slow adapting mechanoreceptors such as joint receptors are thought to mediate the sensation of joint position while quick adapting mechanoreceptors as muscle spindles, and Golgi tendon organs tend to mediate the sensation of joint motion. Since the subjects in the current investigation exercised their shoulder external rotator muscles to fatigue, it was expected that reproduction of a reference angle in external rotation would have become worse.

The results of the current study are in conflict with many other studies that support the idea that shoulder joint proprioception deteriorates significantly after shoulder muscle fatigue.
Voight et al. utilized both active and passive repositioning at 75° of shoulder external rotation to assess shoulder proprioception. The authors found that shoulder proprioception was negatively altered in presence of shoulder muscle fatigue ($p<0.05$) in both methods. The explanation given by the researchers regarding the decrease in shoulder proprioception was known as the “dysfunctional mechanoreceptors” theory. According to the authors, the fatiguing protocol directly affected the contractile elements of the shoulder such as the muscles and the receptors imbedded in them. Therefore, the receptors may have been inefficient, leading to reduction of shoulder joint proprioception as measured by active and passive repositioning.

Carpenter et al. found that shoulder joint proprioception worsened by 73% after shoulder muscle fatigue in both dominant, and non-dominant shoulders. However, it is difficult to directly compare the results as in the current study proprioception was assessed by ARP and not by threshold to detection to motion as utilized by Carpenter et al. There is some evidence indicating that threshold to detection to motion is a more sensitive method of proprioception assessment and that methods requiring matching of joint angles using active motions require additional sensorimotor process. Therefore it may be possible that if Carpenter et al. had utilized a different method of proprioception assessment, they would not have noticed changes in shoulder proprioception acuity.

Myers et al. found a significant difference between pre- and post-test value for AAE for the subjects who demonstrated shoulder muscle fatigue. The investigators utilized active reproduction of reference angles as the proprioception assessment. After the fatiguing protocol which was the same utilized by other two studies, proprioception deteriorated significantly ($p<0.05$). The authors also suggested that this was a result of the “dysfunctional mechanoreceptors” theory whereby muscle fatigue desensitises muscle spindles, decreasing afferent feedback to the central nervous system that leads to deterioration of proprioception.

The findings of the current study contradict those of Pedersen et al. who found that shoulder exercise to fatigue negatively influenced shoulder joint proprioception. However, contrarily to studies above, the researchers utilized a different proprioception assessment and a different muscle fatiguing protocol. Shoulder joint proprioception was assessed by recognizability of the speed at which shoulder rotation was performed. The subjects underwent either light-exercise (10% of their maximal exertion) or hard-exercise (maximal exertion) fatiguing protocols until the peak torque fell by 30% of their MVC. Because the current investigation utilized the same level of peak torque decrement utilized by Pedersen et al. as indicator of shoulder muscle fatigue, reduction in proprioception acuity should have been noticed. However, the difference in findings between the two studies might be due to the different method of shoulder proprioception assessment employed. Speed of movement measurements may be more sensitive to detect proprioceptive changes, although there is no evidence to suggest that is the case.

Lee et al. utilized active and passive reproduction of positions (45° of shoulder internal rotation and 75° of shoulder external rotation) to assess shoulder joint proprioception before, and after shoulder muscle fatigue. The researchers found a statistically significant difference only in the ARP of 75° of shoulder external rotation, and they suggested that shoulder muscle fatigue reduced the sensitization of the mechanoreceptors in the external rotator muscles alone as they have a lower resistance to fatigue compared to the shoulder internal rotator muscles. However, as in the current study it was no possible to demonstrate similar results, it may be possible that disturbance in proprioception may be attributed also to alterations in central commands rather than to abnormal function of the muscle receptors only.

Finally, Sterner et al. demonstrated similar results as in the current investigation, using a randomized controlled design that adopted a peak torque by 50%. The researchers assessed shoulder joint proprioception pre- and post-fatigue through four different methods: active reproduction of passive positioning, active reproduction of active positioning, reproduction of passive positioning and threshold to detection to motion. No statistically significant differences were found between pre- and post-fatigue in any of the proprioception assessment methods.
There are some reasons that may explain why eccentric exercise did not cause a larger proprioception detriment than concentric exercise and why there was not difference between pre- and post-fatiguing protocols in either group.

First of all, in this study the researcher utilized a less intense fatiguing protocol than those utilized in the majority of previous similar studies. The fatiguing protocol in the current study was terminated when the subjects' peak torque fell by 30% from the MVC over three consecutive contractions, while other investigators continued their fatiguing protocol until a higher drop was observed. A 50%-fall in the peak torque (as utilized by the other authors) is believed to be a significant indication of fatigue level, indicating that a higher peak torque drop may severely affect shoulder proprioception. However, in a different study utilizing the same value of peak torque drop of the current study (30%), the authors did identify deterioration of shoulder joint proprioception. Another important reason may be in the type of shoulder muscle action utilized during the fatiguing protocols. While other studies reported only concentric action to achieve shoulder muscle fatigue, the current study utilized either concentric or eccentric muscle action for the shoulder external rotators. As eccentric exercise is reported to have more deleterious effects on muscle fiber conduction than concentric exercise, the authors hypothesized that the subjects in the eccentric group would have had larger decline in shoulder joint proprioception than the subjects in the concentric group. The results of two studies have in fact already demonstrated that immediately after eccentric exercise the size of errors observed during position- and force-matching tasks increases significantly more after eccentric than after concentric exercise. Moreover, in the same studies it was reported that the degree of matching errors is associated with the degree of force loss. This suggests that if a more intense fatiguing protocol had been employed, shoulder proprioception deterioration might have been noticed.

In the current study a reference angle of 30° of external rotation was utilized for angle reproduction. As the author of the current investigation was more interested in the muscle receptors rather than articular mechanoreceptors and since muscle receptors are best activated in the mid range of motion, it was thought that 30° of external rotation best suited the author's aim of biasing the muscle receptors. Moreover, since a recent review indicates that reposition acuity of the glenohumeral joint in the outer range of external rotation is impaired by muscle fatigue, it was expected that a clear decline of shoulder proprioception would be noticed. This supports the possibility that a more intense fatiguing protocol should have been used.

In terms of shoulder joint proprioception assessment, elevation angle appears to play a key role. It seems that active joint position sense of the gleno-humeral joint correlates to the elevation in the scapular plane, improving as the shoulder approaches 90° of elevation. In the current study proprioception was assessed with the glenohumeral joint at 30° of abduction in the scapular plane, thus, a position closer to 90° of elevation may have resulted in a lower AAE.

While the author of the current study chose to assess proprioception in standing, other authors have utilized lying or sitting positions, which may have affected results. Standing testing position was chosen to maximally reduce afferent stimuli coming from structures other than the shoulder joint, for example the receptors located in the skin in contact with the bed or the chair. There is, in fact, some evidence suggesting that nociceptors located in the skin may contribute to proprioception. This may explain why in the current investigation there were larger pre- and post-fatigue AAEs when compared to subjects of other studies where shoulder joint proprioception was assessed in sitting or lying down on a treatment table. This may indicate that for an accurate assessment of the shoulder joint proprioception, a standing position should be adopted so that only the mechanoreceptors in the shoulder joint are activated.

There are some limitations that affect the current study. A major flaw is in the cut point utilized to determine muscle fatigue. Because it is agreed upon in the literature that a fatiguing protocol that has a cut point of 50% decrease in the peak torque causes...
shoulder proprioception detriment, 1, 16, 18, 19, 23 the researcher of the current study decided to utilize a less intense fatiguing protocol (30%) that had only been utilized in one previous study. 19 The use of a higher cut point for muscle fatigue may have elicited a clear decrease of shoulder active reposition acuity.

In terms of fatiguing protocol, it is important to acknowledge that it was not possible to completely isolate eccentric and concentric action for the external rotators. In order to go back to the starting position and start a new muscle contraction, the subjects in the eccentric group had to perform a light eccentric contraction of their shoulder internal rotators while the subjects in the concentric group had to perform a light concentric contraction of their shoulder internal rotators. Therefore, it was not possible to fatigue only the shoulder external rotators, even though the focus was on that muscle group.

Finally, all of the subjects in the study were young and did not have any history of shoulder injury on their tested side; thereby the results found in this study may not be applied to older populations or populations with subjects with shoulder injuries. Research studies that investigate the effects of muscle fatigue on shoulder proprioception among elderly people, and people with shoulder injuries are needed.

CONCLUSIONS.
The results of this study indicate that shoulder muscle fatigue induced by eccentric exercise does not affect shoulder joint proprioception to a larger extent than fatigue induced by concentric exercise. Moreover, the results indicate that regardless the type of muscular action, shoulder proprioception does not deteriorate after shoulder muscle fatigue of 30%. The results of this study contradict with some of the recent research that suggests that muscle fatigue negatively influences proprioception, and research should be continued to fully understand the effects of varied levels of muscle fatigue on shoulder joint position sense.

REFERENCES


ABSTRACT

Background: Baseline visual acuity (VA) loss from static to dynamic head conditions assessed using the Dynamic Visual Acuity Testing (DVAT) have not been established in NCAA football players. DVAT assesses the Vestibulo-Ocular Reflex (VOR) which is measured in Logarithm of the Minimum Angle of Resolution (logMAR). Decreased VA beyond baseline measures may detect VOR impairment and impact treatment protocols and assist in return to play decisions post-concussion.

Hypothesis/Purpose: To establish normative VA mean scores during a static head posture as well as dynamically during the DVAT with a head speed of 150 deg/s in the pitch (vertical) and yaw (horizontal) planes rotating 20 degrees in each direction.

Study Design: Descriptive study, Diagnostic Tests.

Methods: Sixty-seven, NCAA Division I College football players (age = 19.68 ± 1.53) completed static VA and DVAT assessment in the pitch and yaw planes during baseline concussion testing at the beginning of the 2014 regular football season. Comparison of VA was evaluated by calculating the difference in players’ static and dynamic VA values using the DVAT.

Results: Static VA for all participants (n=67) was -0.232 ± 0.109 logMAR. Dynamic VA for participants (n=67) was 0.0845 ± 0.159 in pitch and -0.007 ± 0.141 in yaw at 150 deg/sec. Mean losses in VA during pitch and yaw at 150 deg/sec were 0.317 ± 0.140 and 0.227 ± 0.133, respectively.

Conclusions: VA diminishes during head movement at 150 degrees/sec. Loss of acuity beyond established normative values from baseline may be indicative of VOR dysfunction, especially secondary to head trauma. The assessment of visual acuity function with head movements of 150 deg/sec can potentially identify concussion and subsequent sequelae. Further research is recommended.

Level of Evidence: 2b

Key words: Concussion, oculomotor measures, Vestibulo-ocular reflex

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INTRODUCTION
The methods to assess potential sequelae from concussion should include the higher brain centers that control eye reflexes. Football exposes participants to concussion risk secondary to violent high-speed impacts; it also has the highest incident of concussion compared to other collegiate sports.1 The occurrences of concussion may be higher than the documented rates due to under reporting by players because of a perceived need or desire to continuing play and the misinterpretation of the variety of symptoms that are associated with concussions.2 A plethora of symptoms are associated with concussions and fall in the general domains of cognitive, physical, or behavioral symptoms. This research focuses on the symptoms that are associated with the physical domain, specifically to vestibular related impairments. It is estimated that when assessing symptoms associated with the vestibular system and involvement, 78.8% of football players at the high school and college level reported dizziness and 55.8% reported balance problems secondary to concussion.3 The vestibular system is comprised of sensory organs in the ear, the ocular system, postural muscles of the body and areas of the brain responsible for balance and coordination. The vestibular system has two functions, visually tracking and focusing on objects during head movement, and managing posture. Visual tracking is specific to the vestibular-ocular system while maintenance of balance is specific to the vestibulospinal system. These distinctive functions of the system allow for individual assessment. Assessments used in Athletic Training settings such as the Balance Error Scoring System (BESS) or other stationary balance tests assess the vestibulospinal component, however such assessments fail to assess the vestibular-ocular component of the vestibular system.4,5

There are clinical screening techniques to assess the health and function of the vestibular-ocular system. These screenings include the King-Devick and the Vestibular Ocular Motor Screening (VOMS) assessment, that are meant to replicate concussion symptoms by challenging components of the vestibular ocular system.4,6 The King Devick requires an athlete to read a series of numbers from left to right and top to bottom on a series of three cards without errors. On each subsequent card the numbers are more challenging to visually sequence into lines. A concussed individual will find it more challenging to discern the lines and will make errors in the number sequencing. The King Devick requires rapid saccadic eye movement but zero head movement.4,6 One component that is tested during the VOMS assessment is the vestibulo-ocular reflex (VOR). The VOR is a mechanism of the vestibular ocular system that allows the eyes to remain stabilized on an object during high-speed head movements.7 The VOR is malleable through the continued actions of focusing on images of varying distances during head movements.8 These actions can be trained though activities that require high velocity head movements such as specialized tests that identify the changes and integrity of visual acuity. The two tests that are performed to isolate the integrity of the VOR are the gaze stabilization test (GST) and the dynamic visual acuity test (DVAT). The GST and DVAT both analyze changes in visual acuity during head movement but have very distinct testing protocols. The GST quantifies changes in visual acuity through varying the velocities of head movement while DVAT is done at a constant velocity. Both measures have acceptable sensitivity ranges (0.64-0.83) published in the literature, especially in individuals who have vestibular dysfunctions and a previous history of mild traumatic brain injury (mTBI).9-17 The GST and DVAT can differentiate between individuals that have vestibular dysfunctions and those with normal function.18 The utilization of GST and DVAT may also assist in determining quantifiable measurements of VA during sessions of vestibular rehabilitation.14,15 The ability to numerically identify changes in VA during rehabilitation is important because it could quantify improvements in vestibular function achieved after concussion using vestibular rehabilitation rather than rest.14,15 The relationship between concussions and vestibular dysfunction supports the need for more research on the function of the vestibular system post-concussion.

While the quantitative numbers from GST and DVAT have been suggested to be reliable in determining visual acuity changes during high-speed head movements, there are no normative values established for the differences in visual acuity compared to baseline static visual acuity during testing in NCAA Division I football players. The purpose of this study was to
establish normative VA mean scores during a static head posture as well as during the DVAT with a head speed of 150 deg/s in the pitch (vertical) and yaw (horizontal) planes rotating 20 degrees in each direction.

**METHODS**
This was a descriptive study using data from sixty-seven Division 1 football players (age = 19.68 ± 1.53) at two institutions that completed initial baseline concussion assessment prior to the 2014 regular football season. The data were collected during baseline testing by the universities sports medicine staff. The research team retrospectively reviewed the de-identified data to answer the research objective. The data points were from each football player completing the screening in accordance with the guidelines for DVAT assessment. Furthermore, each player also self-reported a prior history of mTBI, head or neck injury, nystagmus, or any other diagnosed vestibular dysfunctions during pre-participation exams.

**Measures**
The InVision System developed by Neurocom (Neurocom, Clackamas, Oregon, USA) was used to assess both static visual acuity (SVA) and dynamic visual acuity (DVA). Measurements of SVA were collected as comparative values of visual acuity with a stationary head posture and during DVAT with head movement. All measurements of visual acuity, both in static and dynamic conditions were described using the Logarithm of the Minimum Angle of Resolution (logMAR). LogMAR is considered the gold standard during clinical trials and interventions that involve visual acuity. Lower values of logMAR indicate clearer visual acuity compared to higher values, for example, a logMAR of 0 is equal to 20/20 vision while a logMAR of -0.0187 is equal to 20/13 on a Snellen eye chart. Instruments used for the data collection included the InVision program that was installed on a 15 inch laptop combined with a head mounted accelerometer and gyroscope to accurately report head movement speed and amount of motion. (Figure 1)

**SVA and DVAT**
Measurements of SVA were taken at the beginning of the baseline testing protocol to determine visual acuity of the subject while their head was stationary. The SVA test required the subject to state the orientation of the optotype “E” on the center of the computer screen to the clinician. The optotype would appear on the computer screen for the duration of one second. The optotype would change its orientation (up, down, right, left) and would decrease in size until the subject could no longer correctly state the orientation of the optotype. The program provided a quantifiable measurement of SVA in the form of both a Snellen fraction and logMAR. The study used measurements of SVA in logMAR for all calculations. The measurements of visual acuity while the head was stationary established a value to compare to during the DVAT when the head was moving at 150 deg/sec.

The DVAT measures the difference between an established SVA and the dynamic visual acuity values determined by yaw (horizontal), pitch (vertical), and roll (ear to shoulder) motions of the head. During the yaw motions, subjects rotated their heads from left to right as if shaking their head ‘no’ to approximately 20° in each direction with a target head velocity of at least 150 degrees/second. Subjects were allowed to practice the motions before actual DVA testing began to familiarize themselves with the testing parameters. The InVision program provided visual cues to the subjects on both head velocities and how far they were turning their head. Once actual testing started, there would be visual cues given to the subject until they reached the target head position and speed. It was required that the subject would have to maintain both head speed and the targeted range of motion prior to the optotype briefly being shown on the computer.
screen. Once an optotype appeared on the screen, the subject was to state its orientation to the clinician. The size of the optotype would decrease in size until the subject could no longer correctly state its orientation. The same procedure was followed while testing head motion in the pitch axis. The pitch motion simulates a ‘yes’ head nod, and moves the head 20º up and down from neutral. Due to time constraints during baseline testing, assessments about the roll axis were not completed.

**Procedures**

Players underwent baseline concussion testing during the off-season when their workouts included weight training and skills practice without the use of any kind of pads or helmet. Zero contact was taking place and subjects were expected to have been free from previous head trauma for the preceding six months. All subjects participated in pre-participation exams in coordination with questions about their medical history, physical exams by team physicians, and screening for diseases. Clinicians included questions from the SCAT-3 to establish dominant handedness, self-reported prior history of concussion, current symptoms, and memory recall.

At the time of testing, all subjects were taken into a well-lit room and seated ten feet away from the testing computer screen that was adjusted to their individual eye-level. Subjects requiring corrective lenses were instructed to wear them during the assessment. Subjects then began the SVA test to establish a quantifiable number for their respective static acuity prior to starting the DVAT. Subjects were monitored for any signs of dizziness or nausea during the testing period. If the subjects did become either dizzy or nauseous as a result of testing protocol, they were allowed a small rest break until their symptoms subsided. There were no complications during testing and all the subjects were able to fully complete the protocol.

**Statistical Analysis**

All statistical data points were placed into an Excel spreadsheet (Office 2007, Microsoft Corp., Redmond, WA) by the clinicians at the respective universities prior to being de-identified and transferred to SPSS (version 19, SPSS Inc., Chicago, IL). The research team then analyzed the SPSS file. Descriptive data was calculated using SPSS to report all collected measures of visual acuity in static and dynamic conditions. All measurements of visual acuity were analyzed in logMAR. Ninety-Five Percent Confidence Intervals where calculated to estimate meaningful ranges of acuity values to be expected in similar populations.

**RESULTS**

The participants had an average perception time of 20.09 ± 3.363 ms. The overall mean SVA for all sixty-seven subjects were -0.232 ± 0.109 logMAR (Figure 2). The average departure head speed from the target of 150 deg/sec was 183.439 ± 17.309 deg/sec in pitch and 184.621 ± 20.609 in yaw. The average DVA in pitch (combined value of moving the head up and down) was 0.0845 ± 0.159 logMAR. The average DVA in the yaw plane (combined head movements of left and right) was –0.007 ± 0.141 logMAR. There was an average loss of 0.316 ± 0.140 logMAR in pitch and 0.227 ± 0.133 logMAR in yaw. The 95% CI for acuity lost in pitch and yaw was [0.269, 0.358] and [0.191, 0.261] respectively. (Table 1)

![Table 1. Variable Descriptives](image)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
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<tbody>
<tr>
<td>Age (years)</td>
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</tr>
<tr>
<td>Perception Time (ms)</td>
<td>20.09</td>
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</tr>
<tr>
<td>SVA (logMAR)</td>
<td>-0.232</td>
<td>±0.109</td>
</tr>
<tr>
<td>DVA in Pitch (logMAR)</td>
<td>0.085</td>
<td>±0.159</td>
</tr>
<tr>
<td>DVA in Yaw (logMAR)</td>
<td>-0.007</td>
<td>±0.141</td>
</tr>
</tbody>
</table>

logMAR = Logarithm of the Minimum Angle of Resolution.
DISCUSSION
The results from this study support the assertion that a lower value of VA is expected in individuals when they undergo DVAT compared to VA in static conditions. The testing speed was set at 150 deg/sec; however, the average actual speed was higher despite the visual cues provided to the participants by the InVision program. It is plausible that with greater practice, participants could more accurately maintain the goal head speed of 150 deg/sec. The subjects increased speed may overestimate the loss of VA. However, accuracy of the assessment at speeds between 150-200 deg/sec is supported.11,12 The ability of the DVAT to assess the function of the VOR could potentially aid clinicians in identifying vestibular dysfunction associated with head injuries missed by assessments not tailored to the vestibular-ocular system.2 It is supported in the literature that horizontal movements in yaw are more reliable in determining vestibular impairments than in pitch when assessing DVA.12 The values reported in this study found VA in the horizontal plane (yaw) did not drop as much as VA in the vertical plane (pitch). It is speculated that football players are more accustomed to scanning a field from left to right and not up and down. This supports the assertion that further research comparing head movements and post mTBI symptoms across sports and positions is warranted. It is possible that kickers or kick returners will perform better in pitch. The DVAT may also serve as an appropriate baseline tool to compare the integrity of the vestibular system in athletes when they suffer a concussion that can typically be completed as part of pre-participation examinations.11 It is also noteworthy to remember that future studies could include measurements of DVAT in the roll movement, which is not a typical movement in athletes but may be sensitive to vestibulo-ocular deficits. Comparison of baseline DVA results may also influence clinicians regarding decisions related to return to play status of athletes who have suffered from vestibular dysfunctions secondary to mTBI.

This study has several limitations. This study only assessed healthy football players and excluded the motion of ‘roll’. Future studies should include the ‘roll’ head movement, include other types of athletes, and measure the difference in VA from static and during dynamic head movements in athletes who are post-concussion.

CONCLUSION
The results of this study provide mean data regarding SVA and dynamic DVAT during head movements at 150 degrees/second. All conditions for DVAT demonstrated decreases in losses in VA as compared to SVA. Losses of VA during DVAT beyond an established norm or outside the currently reported confidence intervals may be indicative of VOR dysfunctions, potentially secondary to head trauma. There is a need for more research to be completed in order to establish definitive DVAT values and changes from SVA prior to its employment as a reliable tool to assess the vestibular function and return to play in multiple populations. With further research, the InVision system may become an important tool in assessing the VOR in athletes’ pre and post-concussion assisting clinicians in return to play and long-term treatment plans.

REFERENCES
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ABSTRACT

Background: The gastrocnemius has two heads, medial gastrocnemius (MG) and lateral gastrocnemius (LG); little is known how they contract with different foot positions. The MG is more frequently strained than the LG; and gastrocnemius activation pattern altered by foot position may play a role in injury. Leg exercises often use a toe-in versus toe-out foot position to isolate one gastrocnemius head over another.

Purpose: The purpose of this study was to determine the electromyographic gastrocnemius muscle activity in the toe-out and toe-in foot positions during weight bearing and non-weight bearing activities. The hypothesis was that a toe-out foot position would elicit greater MG than LG activity; while the toe-in position would elicit greater activity in LG than MG in both weight bearing and non-weight bearing (NWB) positions.

Study Design: A cross-sectional study of young adults.

Methods: Thirty-three participants were recruited. Surface electrodes were placed on the bellies of the MG and LG. The gastrocnemius muscle was tested in toe-in and toe-out foot positions using two different tests: a standing heel-rise and resisted knee flexion while prone. Electromyographic activity was normalized against a MVIC during a heel raise with a neutral foot position. A 2x2x2 (Foot Position x Test Position x Muscle) ANOVA was used to determine if differences exist in activity between the MG and LG for toe-in versus toe-out standing and prone test positions.

Results: Significant test position main effect (F[1,32] = 86.9; p < .01), significant muscle main effect (F[1,32]= 5.5; p < .01), and significant foot position x muscle interaction (F[1,32] = 14.58; p < .01) were found. Post hoc tests showed differences between MG and LG in toe-out position (t = 3.10; p < .01) but not in the toe-in for both test positions (t = 1.27; p = 0.21).

Conclusions: With toe-out, the MG was more active than LG in standing and prone; no difference was noted between MG and LG in toe-in for either position.

Level of Evidence: Level 2

Key words: Electromyography, gastrocnemius, toe-in, toe-out

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INTRODUCTION
Physical therapists often see patients who have injuries related to the gastrocnemius muscle such as achilles tendinopathy, achilles tendon ruptures, and muscle strains. All of these conditions are associated with weakness of the gastrocnemius muscle. Inexplicably gastrocnemius muscle strains occur almost exclusively in the MG muscle, a condition called “tennis leg.” That the MG is found injured much more often than the LG suggests that the MG might have differences in activation patterns that make it more susceptible to injury than the LG muscle.

One possible explanation is that the MG and the LG muscles may have different patterns of activation. This idea originated from weightlifters that vary their foot positions in an attempt to emphasize contraction of one gastrocnemius head over the other. This same concept encouraged a study by Reimann et al who showed that when altering the lower extremities foot positions; the MG and LG have different amounts of muscle activity when performing a standing heel-raise. Riemann et al showed that when pointing the toes-in, internally rotating the entire lower extremity, the LG was activated more than the MG during the concentric phase of a heel raise. While when the entire lower extremity was externally rotated by pointing the toes out, the MG was activated more than the LG during both the eccentric and concentric phases of a heel rise. So far no one has repeated this study, nor have they performed the same comparison during plantarflexion in a non-weight bearing position.

Different patterns of MG and LG activation with toeing-in versus toeing-out may have a neurological explanation for patterns of activity during gastrocnemius contraction. Toeing-in and toeing-out during gait influences the amount and direction of plantar pressure that develops on the plantar aspect of the foot. Toeing-in puts more pressure laterally while toeing-out places more pressure medially on the plantar aspect of the foot. Grimby has shown that plantar stimulation to the different parts of the sole of the foot creates different muscle activity in the leg. Nurse et al demonstrated that muscular patterns in the lower extremity are altered when reducing the plantar pressure on the foot. Thus, the activity of the MG and LG may be influenced by plantar pressure placed on the foot when weight bearing. Consequently, if plantar pressure variations were responsible for the pattern of activation, a non-weight bearing contraction would not likely create the same kind of pattern of MG and LG activation.

The impetus of this study came from clinical experience. We noted that performing gastrocnemius muscle strengthening exercises (plantarflexion with the knee extended) in a toe-out foot position led to faster rehabilitation times when treating those with medial gastrocnemius strains and medial insertional achilles tendonitis. The purpose of this study was to determine the electromyographic gastrocnemius muscle activity in the toe-out and toe-in foot positions during weight bearing and non-weight bearing activities. The hypothesis was that a toe-out foot position would elicit greater MG than LG activity; while the toe-in position would elicit greater activity in LG than MG in both weight bearing (WB) and non-weight bearing (NWB) positions.

METHODS
Recruitment of Participants
This study was a cross-sectional design where all data was acquired during one session. The Institutional Review Board at Maryville University approved this study. Participants included were a convenience sample from the surrounding St. Louis area. Recruitment was open to anyone from the ages of 18 to 65 years old. Participants were included if they were adults between 18-65 years old and could perform a 5/5 on a current MMT of the plantar flexors (tested by performing 25 heel raises on one leg of at least two inches in height), could follow simple instructions, and could perform all required positions (prone and standing) for at least fifteen minutes. The exclusion criterion included: a history of hip, knee, or ankle surgery in the prior year, history of lower extremity trauma in the prior year, lower extremity joint pain in the previous month, neuromuscular or musculoskeletal disorders that inhibit or impair movement, history of thrombophlebitis, and/or if the participant exhibited an adverse reaction to the electrode adhesive or gel. Prior to data collection all participants were informed of the experimental protocol and signed an informed consent. Participants then completed a questionnaire with demographic
information and reviewing the inclusion and exclusion criteria. Participants were given a randomized three-letter code to ensure participant confidentiality. All participants were unshod in this study. A simple coin toss was then used to determine which leg (to avoid “double dipping”; using both the left and right sides of a person as separate independent measures) the assessments would be performed on (a priori “heads” was designated the right leg, “tails” the left leg). All subsequent testing was performed on the designated leg. The participant was measured using the standing heel rise plantar flexor MMT, as described by Hislop et al. Each participant was assessed for lower extremity alignment including the Craig-Ryder test and external tibial torsion.

For the standing heel-raise MMT, participants performed the heel raises to the beat of a metronome. As used in previous research, the metronome was set at 60 beats/minute (one heel raise per two seconds). If the participant could complete 25-heel raises they were included in the study.

**EMG Setup**

To determine electrode placement for the MG and LG, a prone resisted plantar flexion contraction was elicited, the muscles were palpated, and the electrodes were placed over the most prominent section of each corresponding muscle belly. The electrode placement areas were shaved as needed and the skin was abraded with an alcohol swab. The recording electrodes were placed in parallel with the muscle fibers. Two additional ground electrodes were placed on the tibial tuberosity and the fibular head to decrease EMG artifact. The MG and LG were recorded using individual disposable, Ag/AgCl sEMG Norotrode 20 bi-polar surface electrodes (Myotronics Inc., Kent, WA) with 10 mm pickup diameter with 22mm interspacing between the bi-polar electrodes and the Motion Lab Systems MA420 bi-polar preamplifiers. Electrode placement was confirmed by assessing EMG that were tested prior to data collection using unilateral standing plantar flexion contractions. Electrodes were firmly secured with 2 cm wide tape. The gain was adjusted as needed before formal data collection.

All EMG signals were recorded for the MG and LG using an MA-300 EMG system connected to a laptop computer via a DI-720 USB Data Acquisition System (Motion Lab Systems Inc., Baton Rouge, LA). The EMG system signal bandwidth was 10 Hz – 2 kHz, –3 dB limited to 10–350 Hz, using the low-pass Bessel filter in the MA300. All EMG data were sampled at 1,876 samples per second per channel, using WinDaq Data Acquisition Software (DATAQ Instruments Inc., Akron, OH).

**Determination of Maximal Voluntary Contraction**

To determine the maximum voluntary isometric contraction (MVIC) from each participant’s MG and LG a stationary barbell was used for the participant to push up into during isometric plantarflexion when standing using a set up similar to Hebert-Losier et al. EMG values were collected during the performance of two MVICs heel rises in a unipedal standing position. A previous study showed that the standing weight bearing position is just as effective as the NWB position when attempting to elicit a maximal contraction from the gastrocnemius muscle. Two trials of MVIC testing were conducted with a two-minute rest period between tests. The length of each test was approximately five seconds with two seconds of a ramped increasing effort and three seconds of a sustained maximum isometric contraction. The two MVIC trials were then averaged to establish the MVIC score. Testing for MVIC was performed in a modified squat rack so that the barbell was firmly secured so that it would remain stationary. Participants stood comfortably and the height of the barbell was adjusted so as to rest on the posterior deltoids and upper thoracic spine region (e.g. as in performing a normal squat) of the standing participant with the knees extended at 0°. Padding was added as needed to the bar to maximize patient comfort while pushing up maximally. Participants positioned themselves under the stationary barbell standing unilaterally on the test leg in a comfortable weight bearing foot position and when instructed plantar flexed isometrically with maximal effort. The ankle was positioned midway between their neutral and full plantarflexion. The previously described position with the knee at 0° and in weight bearing has been found to most frequently elicit a MVIC of the gastrocnemius muscle. Participants were allowed to familiarize themselves with the set up and were given two minutes to recover prior to
formal testing. For all weight-bearing tests participants were instructed to isometrically “try to push upwards on the bar as hard as you can” and “keep your knee straight.” To obtain the MVIC data for each participant, the data was filtered (to remove DC values) and mathematically squared creating data values that were only positive. The square root of these mean values were taken from the data window of the last three seconds of the five-second reading of the unilateral isometric maximum plantar flexion contractions and were used in the normalization process.

DESCRIPTION OF TEST POSITIONS

WB Test Position
The standing WB position was identical to the method used to determine MVIC with the only difference being the performance of the test using two positional variations: a position of maximal in-toeing and one of maximal out-toeing of the foot. The toe-in (Figure 1) and toe-out positions were accomplished by having the participant fully rotate the entire lower extremity in or out. The instructions during testing were identical to testing for MVIC as described previously, and each contraction was held for five seconds. Three contractions per each test variation were used to gather EMG data from the MG and LG muscles.

NWB Test Position
A NWB position was used to test the gastrocnemius muscle to determine if the same pattern of activity resulted with the toe-in and toe-out positions using a resisted test of knee flexion due to the role of the gastrocnemius as a secondary flexor of the knee. Although the gastrocnemius is not a strong knee flexor this action was chosen to see if the same pattern of muscle activity in the MG and LG occurred during knee flexion and without applying pressure to the plantar aspect of the foot. Results of a previous study have already shown that the MG and LG muscles have less muscle activity in the NWB position compared to WB therefore the authors chose to investigate gastrocnemius activity during a different action (knee flexion). For the NWB (prone) position, participants were instructed to “bend the knee,” “pull as hard as possible,” or “keep pulling,” while the examiner applied a “break” force approximately 8 cm proximal to the malleoli in the direction of knee extension (Figure 2) for five seconds. Participants were allowed to hold onto the treatment table as needed for stabilization during the muscle tests. These verbal instructions were standardized for each participant in order to encourage maximum contraction. Three contractions per each test position were performed to gather EMG data from the MG and LG muscles.

EMG Capture and Normalization
Data were recorded during all positions and rotational variations (as described above) with Motion Lab Electromyography (MA 300) using a Gateway Laptop (Model QA1) and stored on a password protected USB device in Motion Lab Systems C3D files using EMG Analysis and Graphing software (Motion Lab Systems Inc., Baton Rouge, LA). The root-mean-square (rms) amplitudes (expressed in μv) from the MG and LG during all test conditions were determined by taking the EMG signals from the last three seconds of the five-second isometric contractions for each participant. The data from each of the three
trials was averaged for all data collected from WB and NWB tests. The EMG rms amplitudes from test conditions were normalized using the previously established values for MVIC for each muscle group.

**Data Analysis**

The statistical package R (R: A Language and Environment for Statistical Computing, R Core Team, R Foundation for Statistical Computing, Vienna, Austria) was used for data analysis. The outcome data was the mean peak normalized muscle activity for the MG and LG in each of the positions and variations. Data are presented as percentages of MVIC with means and standard deviations (±SD). The normalized EMG data was also analyzed using the intraclass correlation coefficient statistic (ICCs 3,1) to determine test-retest reliability for the prone testing position.

A 2x2x2 (Foot Position x Test Position x Muscle) repeated measures of analysis of variance (ANOVA) was used to analyze the data to determine if differences exist in Muscle activity between the MG and LG when comparing toe-in versus toe-out foot positions while in the standing and prone test positions. A Bonferroni correction was applied on the post hoc tests to prevent family wise error inflation.

**RESULTS**

The group of participants (20 females, 13 males) had a mean age of 21.7 years (range: 19-25), weight: 72.6 kg (range: 52-113.4 kg.), height: 172.6 cm (range: 157.5-193.0 cm). All of the participants were right leg dominant except one, which was determined by asking them with which leg they would normally kick a ball. Also all participants were healthy students that were active either in sports or recreational activities. Lower extremity alignment measures for mean femoral anteversion was 10.4º (range: -1 to 19º) and the mean tibial torsion was 5.1º (range: -11 to 15º).

Intra-rater reliability was high for the NWB normalized EMG data in for the MG for toe-in (ICC = .91) for MG toe-out (ICC = .95), for LG toe-in (ICC = .87) and LG toe-out (ICC = .85). The standard error of the measure (SEM) for the normalized muscle activity for the LG = 6.7% while the MG = 4.7%. The reliability for standing normalized EMG was not assessed because of concerns over fatigue of the gastrocnemius muscle.

The MG achieved 41.3% MVIC in the prone (NWB) test position with toe-in while the LG achieved 37.8%, the MG had 43.5% MVIC while the LG had 32.6% in the toe-out position. In the (WB) standing position toe-in the MG had 75.8% MVIC while the LG had 70.7%, with toe-out the MG had 79.2% MVIC while the LG had 68.9%. Figure 3 and 4 show all of the means and standard errors for each test position. EMG activation was always greater for the MG than the LG during all positions and rotational variations, but the differences were not statistically significant.

No differences were found between the normalized MG and LG outputs (mean: MG = 4.93 μv; LG = 5.02 μv; t = -1.60; p = .94) when performing a heel rise while standing with the foot in a neutral position (toes pointed straight forward) during the MVIC testing. However, a significant test position main effect (F [1,32] = 86.9; p < .01), a significant muscle main
effect (F [1,32] = 5.50; p < .01), and a foot position x muscle interaction (F [1,32] = 14.58; p < .01) were found. Post hoc tests showed a significant difference between MG and LG activation in the toe-out position (t = 3.10; p < .002), with greater MG activation, but not in the toe-in positions for both prone and standing test positions (t = 1.27; p = 0.21).

**DISCUSSION**

The results of this study shows that differences in EMG activation between the MG and LG exist when altering foot position during a weight bearing (standing heel rise) and non-weight bearing (resisting knee flexion while lying prone) activities. The MG was significantly more active than the LG in the toe-out positions in both the weight bearing and non-weight bearing positions, which did not support the hypothesis that plantar pressure, during weight bearing, would have an effect on the pattern of MG-LG activity. The results from this study support the hypothesis that the toe-out position elicited more MG than LG activity. These results also agree with previous research by Riemann et al who showed that that during WB the MG was more active than the LG during both the concentric and eccentric phase of plantarflexion in a toe-out position.12 No differences were noted between the MG and LG when in the toe-in position for either weight bearing (standing) or non-weight bearing (prone) test positions thus the current results did not support the hypothesis that the toe-in position would elicit more LG than MG.

Riemann et al reported results that were similar to this study in that they did not find a difference between MG and LG during toe-in during the eccentric phase of a heel raise, however they did show that the LG was activated more than the MG during a concentric heel raise.12 In the current study only isometric contractions were performed. Also in the current study the MG always produced greater EMG activation than the LG during both weight bearing and non-weight bearing test positions and with toe-in and with toe-out foot positions (Table 1). Fiebert et al found similar results with integrated muscle activity during maximal plantarflexion; the activity of the MG was always greater than the LG, but not significantly. Interestingly the muscle activity level of the MG changed very little when comparing toe-in to toe-out for both the non-weight bearing (prone) and weight bearing (standing) positions, however the LG was significantly different between toe-in and toe-out but only for the prone position. Perhaps this pattern of activation is an integrated ontogenic response pattern developed in our central nervous system.

Herbert-Losier et al found that the gastrocnemius muscles (MG and LG) displayed much less activity...
when the knee was flexed to 90° when compared to 0° degrees during NWB testing. This is consistent with Fiebert et al who found that when the gastrocnemius muscle was placed at different muscle lengths muscle activity was lower when the muscles were shortened and greater when they were lengthened. Fiebert et al found that as the knee flexes from full extension to 90° flexion the activation of the MG and LG significantly declines, the muscle shortening that is described by the properties of the length-tension curve. The results of the present study also demonstrated that the activity of the MG and LG while prone with the knee flexed 90° was considerably less than when standing where the knee is in full extension.

Rotating the lower extremity internally or externally by toe-in or out may alter the biomechanics of the MG and LG muscles. Riemann et al hypothesizes that rotating the hip may change the line of force projected through the ankle joint to shift laterally during IR and medially with ER. Riemann et al also suggests that IR and ER of the lower extremity may alter the architectural features of the MG and LG such as the line of action, angle of pennation, and fascicle lengths influencing the force-generating capabilities of the MG and LG. The MG moment arm is considered an external rotator of the tibia while the LG an internal rotator of the tibia on the femur. Thus an isometric contraction is needed to “hold” the tibia in external rotation (out-toeing) would likely produce more MG activity with an isometric contraction to “hold” the tibia in internally rotated (in-toeing) would produce more LG activity. Further studies are needed to confirm these patterns of activation.

Both static tibial torsion and hip anteversion were measured using the Craig-Ryder test to examine the ranges of toe-in and toe-out and to note any outliers that could have affected the results. A caveat is that toe-in or toe-out positions were not standardized. Participants were asked to maximally internally or externally rotate their legs during the toe-in and toe-out heel raises, without standardizing the degree of leg rotation. Thus we do not know if a particular amount of internal and external rotation would modify EMG activation. Also, we did not measure reliability and validity of the Craig-Ryder test or the Thigh-Foot Angle tests; this could be a source of error. Future research that looks at those who have significantly greater toe-in or toe-out would be interesting.

A number of other factors may have influenced the generalizability these results. First, the participants that volunteered to participate in this study consisted of young college-aged men and women (19-25 years old). This may limit the generalizability of the results to a broader population. Further studies are needed to confirm these patterns of activation.
years old). It is difficult to determine if comparable results would be found with other populations, such as older adults. When using surface electrodes to measure electrical activity of a muscle sources of possible error include skin impedance and cross talk between muscles. To decrease skin impedance, the skin was abraded with an alcohol swab. However, electrical resistance (ohms) was not assessed to measure the amount of impedance. Cross talk is always a limitation with surface electrodes. Ekstrom et al suggest that surface EMG is appropriate for superficial muscles,24 the gastrocnemius muscles are superficial and easily located. Perhaps a future study with indwelling needle electrodes could be performed.

CONCLUSIONS
A toed-out foot position creates greater muscle activity in the MG than the LG when standing and performing a heel raise and when resisting knee flexion while lying prone. No differences were noted between MG and LG in the toe-in foot position between the two test positions (WB and NWB). However, the EMG activation was always greater for the MG than the LG during all positions and rotational variations, but the differences were not statistically significant. The muscle activity of the MG and the LG during contraction of the gastrocnemius muscle were also consistent for both weight bearing versus non-weight bearing suggesting that a pattern of muscle activation that may be an integrated pattern established in our central nervous system.

REFERENCES:


ABSTRACT

Background: The use of foam rollers to provide tissue massage is a commonly used intervention by rehabilitation professionals for their patients and clients. Currently, there is no consensus on the optimal foam rolling treatment approach. Of particular interest are the effects of different instructional methods of foam rolling, as individuals ultimately perform these interventions independently outside of formal care. Finding the optimal instructional method may help improve the individual’s understanding of the technique, allowing for a safe and effective intervention.

Purpose: The purpose of this study was to compare the effects of video-guided, live instructed, and self-guided foam roll interventions on knee flexion Range of Motion (ROM) and pressure pain thresholds.

Methods: Forty-five healthy adults were recruited and randomly allocated to one of three intervention groups: video-guided, live-instructed, and self-guided. Each foam roll intervention lasted a total of 2 minutes. Dependent variables included knee flexion ROM and pressure pain threshold of the left quadriceps. Statistical analysis included subject demographic calculations and appropriate parametric and non-parametric tests to measure changes within and between intervention groups.

Results: Each intervention group showed significant gains in knee flexion ROM (p ≤ 0.003) and pressure pain thresholds (p < 0.001). An approximate 5 degree increase of knee flexion and a 150 kPa increase in pressure pain threshold was observed at the posttest measure for all groups. There was no significant difference (p = 0.25) found between intervention groups.

Conclusion: All three foam roll interventions showed short-term increases in knee flexion ROM and pressure pain thresholds. The two instructional methods (video and live instruction) and the self-guided method produced similar outcomes and can be used interchangeably. Individuals can benefit from various types of instruction and in cases of limited resources video may offer an alternative or adjunct to live instruction or an existing self-guided program.

Key Words: exercise instruction, myofascial rolling, perceived pain, muscle soreness, recovery

Level of Evidence: 2c

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INTRODUCTION
The use of foam rollers to provide tissue massage is a commonly used intervention by rehabilitation professionals for patients and clients. Foam rollers come in several sizes and densities. Commercial foam rollers are typically available in two lengths 36 inch and 18 inch. The structure of foam rollers vary from a mild density foam to a more rigid solid plastic cylinder with a dense foam outer covering. Researchers have shown that higher density foam rollers produce more pressure to the target tissues and may have a stronger effect on the tissues than softer density foam rollers, which could be a potential benefit. However, patient tolerance is a factor that must be considered when using higher density foam rolls.

The current research suggests that foam rolling may offer short-term benefits for increasing joint range of motion (ROM) at the hip, knee, and ankle without affecting muscle performance. These findings further suggest that foam rolling for one to five minutes may be beneficial for enhancing joint flexibility as a pre-exercise warm-up and cool down due to identified short-term benefits (≤ 10 minutes). After intense exercise, decrements in muscle performance and delayed onset muscle soreness (DOMS) may be attenuated after foam rolling for 10 to 20 minutes. Continued foam rolling (20 minutes per day) over a period of three days may further decrease a patient's pain level and may be beneficial as a post-exercise intervention. Research has shown that foam rolling can increase posttreatment pressure pain thresholds, reduce arterial stiffness, and improve vascular endothelial function, all of which are associated with increased flexibility.

Due to the popularity of this intervention, foam rollers are commonly used in outpatient rehabilitation, fitness facilities, and as a home-based intervention. Currently, there is no consensus on the optimal foam rolling treatment time, cadence, and technique, amount of force, foam roller density, or instructional strategy. Of particular interest are the effects of different instructional methods for foam rolling. Finding the optimal instructional method may help improve the patient's performance of the technique, allowing for a safe and effective intervention. One method to improve patient adherence may be to use an Internet based instructional video to reinforce the foam roller techniques prescribed by the clinician. To date, no studies have compared the efficacy of an Internet based instructional video to live-instruction for learning the methods to perform foam rolling. The purpose of this study was to compare the effects of video-guided, live instructed, and self-guided foam rolling interventions on knee flexion ROM and pressure pain thresholds.

METHODS
This pretest, posttest randomized controlled trial was approved by the university Institutional Review Board (IRB# 16-180).

Subjects
Forty-five healthy adults (28 males, 17 females) (age= 26 ± 6.5 years, height= 1.68± 0.1m; body mass=74.1± 17.6; body mass index (BMI)=26.1± 5.3) were recruited via convenience sampling (e.g. flyers). Descriptive demographic information is provided in Table 1. Volunteers were randomly allocated into three groups of 15 subjects: (1) video-guided

| Table 1. Subject demographics. |
|-----------------------------|----------------|----------------|----------------|
| Characteristics             | Age (years)    | Height (m)     | Mass (kg)      |
| Video-Guided (N=15)         | 28.0 ± 9.5     | 1.66 ± 0.1     | 74.0 ± 18.5    |
|                             | (range 21-54)  | (range 1.5-1.9)| (range 43.1-101.2) |
|                             |                |                | 25.3 ± 3.8     |
|                             |                |                | (range 19.2-31.4) |
| Live Instruction (N=15)     | 25.5 ± 3.8     | 1.68 ± 0.1     | 75.1 ± 16.2    |
|                             | (range 20-33)  | (range 1.4-1.8)| (range 51.3-111.1) |
|                             |                |                | 26.5 ± 5.0     |
|                             |                |                | (range 19.4-36.3) |
| Self-Guided (N=15)          | 26.4 ± 5.1     | 1.66 ± 0.1     | 73.2 ± 19.2    |
|                             | (range 21-39)  | (range 1.5-1.8)| (range 50.1-113.3) |
|                             |                |                | 26.7 ±7.0      |
|                             |                |                | (range 19.1-46.5) |

Data reported as mean± SD; range (min-max); m= meters; BMI= body mass index; kg/m²= kilograms-meter squared
intervention, (2) live instructed intervention, and (3) self-guided intervention. The self-guided intervention was considered the control group for this investigation. Exclusion criteria included the presence of any musculoskeletal, systemic, or metabolic disease that would affect lower extremity joint range of motion or tolerance to pressure pain threshold testing and the inability to avoid medications that may have had an effect on testing (Table 2).

Instruments
Two measurement instruments were used in this investigation. First, the baseline digital inclinometer (Fabrication Enterprises, White Plains, NY, USA) was used to measure passive knee flexion ROM. This device has been shown to be valid and reliable for measuring lower extremity ROM (Figure 1).7-10 Second, the JTECH (Midvale, UT) Tracker Freedom® wireless algometer (Figure 2) was used with the accompanying Tracker 5® Windows® based software to measure pressure pain threshold. Algometry is a valid and reliable tool for measuring pressure pain thresholds.5,11-13

Instructional Video and Foam Roll
A commercial Internet based video and accompanied foam roller (GRID) were used in this investigation (Trigger Point Technologies, Austin, TX, USA). The short foam rolling instructional video demonstrated the use of the 18-inch size GRID foam roller on the left quadriceps muscle group. The GRID foam roll is a rigid solid plastic cylinder with a dense foam outer covering which has been used in prior research (Figure 3).14 More details of the video instructions are discussed in the procedures section.

Table 2. Consort flow diagram.

<table>
<thead>
<tr>
<th>Enrollment</th>
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<tr>
<td></td>
<td>Randomized (n= 45)</td>
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<td>• Received allocated intervention (n= 15)</td>
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<td>Allocated to Live-Instruction (n= 15)</td>
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<td>• Received allocated intervention (n= 15)</td>
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<td></td>
<td>Allocated to Self-Guided (Control Group) (n= 15)</td>
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<td></td>
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<tr>
<td>Follow-Up</td>
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<td></td>
<td>Discontinued intervention (n= 0)</td>
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<td>Analysed (n= 15)</td>
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<td></td>
<td>• Excluded from analysis (n= 0)</td>
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| Analysis   | Lost to follow-up (n= 0)        |
|            | Discontinued intervention (n= 0) |
|            | Analysed (n= 15)                |
|            | • Excluded from analysis (n= 0)  |

Consort flow diagram.
Outcome Measures

Two outcome measures were used for the pretest and posttest measures. For passive knee flexion, subjects lay prone on a yoga mat. The examiner grasped the left ankle and passively moved the left knee to the end of the available flexion ROM to the point where the knee could no longer be passively moved without providing overpressure\(^{15-17}\), a measurement was then taken by the examiner. The examiner monitored for any compensatory movement through the lower extremity and pelvis. This testing technique was chosen since it replicated the same hip position and knee movements that occurred during the foam roll interventions and has been used in prior research\(^{15-17}\). For pressure pain threshold, the left quadriceps group was tested with the subject in the relaxed standing position (two measurements)\(^{18}\). The 1.0-cm\(^2\) probe of the algometer was placed into the midline of the left quadriceps (rectus femoris) midway between the iliac crest and superior border of the patella. The graded force was applied at a constant rate of 50-60 kilopascals per second (kPa/sec) until the subject indicated the presence of pain\(^{18}\).

Pilot Study

Prior to data collection, a two session pilot training was conducted to establish intrarater reliability and practice testing procedures for all interventions. Two examiners were involved with data collection. The primary investigator took all the measurements while a second investigator participated in the live-instruction intervention. The primary investigator was a licensed physical therapist with over 12 years of experience and board certified in orthopedics. Ten independent subjects were recruited and tested for the pilot portion of the study. The intrarater reliability was calculated using the Intraclass Correlation Coefficient (ICC model 3, k). Good intrarater reliability was established for passive knee flexion measurements (ICC = 0.95; 95% CI 0.83-0.99) and pressure algometry (ICC = 0.94; 95% CI 0.61-0.90)\(^{19}\). These coefficients are in accordance with the minimum threshold of ≥ 0.90 for ICC values postulated to be acceptable for clinical decision making\(^{19}\).

Procedures

All eligible participants were given an IRB approved consent form to read and sign before testing. Participants then completed a questionnaire to provide
demographic information. All participants were tested by one investigator and were blinded from the results and other participants enrolled in the study. A second investigator participated in the live-instruction group procedures but was blinded to the testing results. Testing was conducted between the hours of 10 A.M. and 2 P.M. and subjects were instructed to refrain from any strenuous activity three hours prior to testing and from taking any medication that would interfere with testing. The intervention was performed on the left quadriceps for all groups. All subjects underwent pretest measures, followed by the instruction and rolling intervention, then immediate posttest measures. The specific procedures for each intervention are discussed below.

For the video-guided intervention, subjects followed an instructional video that demonstrated the use of the foam roll on the left quadriceps muscle group. Subjects had their own foam roll and followed the video with no feedback from the observing primary investigator (Figure 4). The instructor in the video provided a brief introduction and then discussed the foam rolling technique. The instructor divided the left quadriceps into zone one: top of patella to middle of the quadriceps and zone two: middle quadriceps to anterior superior iliac spine. The model in the video was instructed to get in the plank position allowing moderate weight bearing to the anterior thigh. Then to position the roller above the left patella and roll back and forth in zone one, four times at a cadence of one inch per second. The model was then instructed to stop at the top of zone one followed by four knee bends to 90 degrees. This sequence was repeated for zone two. The intervention portion lasted a total of two minutes.

For the live-instruction intervention, subjects followed the examiner's instructions which were the same as the video-guided intervention. The video was transcribed into a text-based script that the examiner followed while teaching the foam rolling technique. The examiner began by demonstrating the foam rolling sequence for zone one and zone two of the left quadriceps then had the subject perform the two-minute sequence of rolling and knee bends. The examiner was observed by the primary investigator during the intervention to ensure accuracy and consistency of the teachings.

For the self-guided or control intervention, the primary investigator demonstrated the plank position and placement of the roller under the left quadriceps group. Subjects performed their own preferred method of foam rolling on the left leg for two minutes. The investigator monitored the intervention time and did not provide any feedback.

STATISTICAL ANALYSIS
Statistical analyses were performed using SPSS version 24.0 (IBM SPSS, Chicago, IL, USA). Subject descriptive data was calculated and reported as the mean and standard deviation (SD) for age, height, body mass, and body mass index (BMI) (Table 1). Group differences were calculated using the ANOVA test for continuous level data and the Kruskal Wallis test for ordinal level data. A factorial repeated ANOVA was used to compare pretest and posttest knee flexion ROM and pressure pain threshold for all three intervention groups. Post hoc testing was conducted using the Tukey post hoc test. The mean
of two PPT measures was used for the statistical analysis. Statistical significance was considered when \( p < 0.05 \).

**RESULTS**

Forty-five subjects aged 20-54 (age = 26 ± 6.5) years completed the study. There were no adverse events and no subjects withdrew during data collection. Statistical analysis of the descriptive data revealed no significant differences between the three groups for age (\( p = 0.57 \)), height (\( p = 0.74 \)), body mass (\( p = 0.96 \)), and BMI (\( p = 0.75 \)) (Table 1).

**Within Group Comparison**

For passive knee flexion ROM, a significant time effect was found for the video-guided [\( F(1,14)=118.5, p< 0.001, \text{partial } \eta^2=0.89 \)], live-instruction [\( F(1,14)=112.3, p<0.001, \text{partial } \eta^2=0.89 \)], and the self-guided intervention [\( F(1,14)=12.9, p=0.003, \text{partial } \eta^2=0.48 \)]. Post hoc testing revealed a mean increase of approximately five degrees (\( p \leq 0.003 \)) from pretest to posttest for all three groups (Table 3).

For pressure pain threshold, a significant time effect was found for the video-guided [\( F(1,14)=52.8, p< 0.001, \text{partial } \eta^2=0.79 \)], live-instruction [\( F(1,14)=40.2, p<0.001, \text{partial } \eta^2=0.74 \)], and self-guided intervention [\( F(1,14)=37.9, p <0.001, \text{partial } \eta^2=0.73 \)]. Post hoc testing revealed a mean increase of approximately 150 kPa (\( p<0.001 \)) from pretest to posttest for all three groups (Table 3).

**Between Group Comparison**

Statistical analysis revealed no significant difference between groups for knee flexion ROM [\( F(2,42)=1.44, \ p = 0.25, \text{partial } \eta^2=0.25 \)] and pressure pain threshold [\( F(2,42)=1.45, p = 0.25, \text{partial } \eta^2=0.06 \)].

**DISCUSSION**

This investigation sought to compare the efficacy of a video-guided, live instructed, and self-guided (control) foam roll intervention in healthy adults. The results suggest that foam rolling interventions produce short-term gains in knee flexion ROM and can increase pressure pain threshold levels (improve individual tolerance to pain) in the target muscle group regardless of instructions given for performance. These short-term gains have been observed in prior research.\(^1,5\) Perhaps, the effects that occur from foam rolling are independent of the type of instruction and may occur from the physical force applied by the body's weight on the foam roller.

Two proposed theories suggest that foam rolling can cause a mechanical or neurophysiological effect.\(^22,23\) Mechanical theory suggests that the viscoelastic properties of fascia are affected by the pressure of the foam roll. Other mechanisms involved may include reduced thixotrophy, alteration in myofascial restriction and trigger points, fluid changes, cellular responses, and fascial inflammation.\(^22,23\) Neurophysiological theory suggests that mechanical pressure from the foam roll influences tissue relaxation and pain reduction through

<table>
<thead>
<tr>
<th>Table 3. Pretest, posttest descriptive results.</th>
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<tr>
<td>Video-Guided</td>
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<tr>
<td>Knee ROM (degrees)</td>
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<td>Pressure Pain Threshold (kPa)</td>
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<td>Live Instruction</td>
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<td>Knee ROM (degrees)</td>
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<td>Pressure Pain Threshold (kPa)</td>
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<td>Self-Guided</td>
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<td>Knee ROM (degrees)</td>
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<td>Pressure Pain Threshold (kPa)</td>
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Data reported as mean ± SD, kPa= kilopascals; statistical significance considered \( p<0.05 \)
central nervous system afferent input from the Golgi tendon reflex, mechanoreceptors (e.g. Golgi tendon organ), and nocioceptors. These hypotheses still need further investigation. Lastly, the lack of between group differences do indeed have practical implications, as it seems that individualized instruction may not be necessary if indeed other instructional methods are available.

Clinicians must consider that the results of this investigation suggest that the two instructional methods (video and live instruction) and the self-guided method produced similar outcomes and can be used interchangeably. Clinically, live instruction may be more practical since the clinician can teach and observe the patient performing the foam rolling technique and provide any corrections as needed. The clinician could reinforce the technique taught by recommending an instructional internet video for the patient to follow or follow up with the patient after they have attempted the technique themselves. Clinicians often use live-instruction to teach the patient an exercise technique. This traditional method has been shown to have limitations due to poor patient compliance. Researchers have suggested that up to 70% of patients do not adhere to a home exercise program. Patients often have better adherence with a structured and monitored home exercise program. The use of Internet based video instruction may enhance the patient's understanding of the technique. The most recent statistics from 2012 report that 71% of all Internet users had accessed the Internet to search for health related information or interact with a health professional and that 35% of adults in the United States report having used the Internet to specifically diagnose a health condition. This growing trend may eventually become the standard way patients access information. Clinicians may need to utilize current technology in order to provide their patients with the best care.

Limitations
Several limitations need to be discussed in relation to this investigation. First, this investigation tested only healthy subjects which limits the generalizability of these results to other populations. Second, the short-term effects of each instructional foam roll method were studied, thus, similar results may not be present in the long-term. This may specifically be a concern to those who used the self-guiding method as a divergence in technique may occur over time. Third, the video-guided intervention and live instruction only demonstrated only a single foam rolling technique on the quadriceps group for a short duration. This must be considered for clinical practice or prescription of a video based instructional program provided in a static format. Fourth, the GRID foam roll was used in this study, which is a rigid cylinder with an outer foam layer. Foam rollers with different densities may have produced different results.

Future research
Future research should attempt to determine the optimal teaching strategy for different patient populations and among various cohorts of the general population such as distance runners and recreational athletes. Specifically, determining whether any teaching strategy is more effective for patients with different medical conditions and at different stages in the rehabilitation process. Future research should also focus on determining the optimal foam rolling treatment including: cadence, technique, amount of force, and optimal type of foam roller for different musculoskeletal conditions.

Conclusion
This investigation compared an Internet based instructional video to live-instruction and no instruction for a common foam rolling intervention. All intervention groups showed gains in ROM and pressure pain thresholds, indicating no difference attributable to instructional strategy. The research on foam rolling is still developing with no current consensus on the most optimal instructional strategy. This investigation provides some insight into options for teaching techniques to healthy individuals. Individuals can benefit from various types of instruction and in cases of limited resources video may offer an alternative or adjunct to live instruction or an existing self-guided program. Future research should focus on determining the optimal teaching strategy for different patient populations.

REFERENCES


ABSTRACT

Background: Limited quantitative, physiological evidence exists regarding the effectiveness of Kinesio® Taping methods, particularly with respect to the potential ability to impact underlying physiological joint space and structures. To better understand the impact of these techniques, the underlying physiological processes must be investigated in addition to the examination of more subjective measures related to pain in unhealthy tissues.

Hypothesis/Purpose: The purpose of this study was to determine whether the Kinesio® Taping Space Correction Method created a significant difference in patellofemoral joint space, as quantified by diagnostic ultrasound.

Study Design: Pre-test/post-test prospective cohort study

Methods: Thirty-two participants with bilaterally healthy knees and no past history of surgery took part in the study. For each participant, diagnostic ultrasound was utilized to collect three measurements: the patellofemoral joint space, the distance from the skin to the superficial patella, and distance from the skin to the patellar tendon. The Kinesio® Taping Space Correction Method was then applied. After a ten-minute waiting period in a non-weight bearing position, all three measurements were repeated. Each participant served as his or her own control.

Results: Paired t tests showed a statistically significant difference (mean difference = 1.1 mm, $t_{[3,1]} = 2.823, p = 0.008, g = .465$) between baseline and taped conditions in the space between the posterior surface of the patella to the medial femoral condyle. Neither the distance from the skin to the superficial patella nor the distance from the skin to the patellar tendon increased to a statistically significant degree.

Conclusions: The application of the Kinesio® Taping Space Correction Method increases the patellofemoral joint space in healthy adults by increasing the distance between the patella and the medial femoral condyle, though it does not increase the distance from the skin to the superficial patella nor to the patellar tendon.

Level of Evidence: 3

Key words: Diagnostic ultrasound, Kinesio® tape, patellofemoral joint space, tibiofemoral joint
INTRODUCTION
The application of kinesiology tape is a conservative care therapy often touted as being able to alleviate pain, affect skeletal muscles and joints, and generally bring about physiological changes in order to improve patient health. Nevertheless, limited empirical evidence exists to support evidence-based practice, and the wide-ranging methodologies employed in previous research make the rationale for effected change difficult to ascertain. Further compounding this issue is the increasing number of taping protocols and various brands of kinesiology tape, which potentially confound clinically-relevant findings, given the many variables which could contribute to research findings.

To provide a product-related example, the first type of kinesiology tape, Kinesio® Tape (Kinesio Holding Corp, Albuquerque, NM), was introduced to the market in 1982. The developer of the tape claimed that it was designed to possess elasticity and thickness similar to human skin and would allow for normal range of motion. While various kinesiology tape brands are manufactured and marketed as interchangeable in terms of effectiveness, careful consideration should be given to comparability across studies that employ different products.

Of equal methodological concern is the variety of application processes for Kinesio® Taping methods and whether results derived from dissimilar techniques can be compared. Campolo et al explicitly study this possibility in a comparison of two taping applications, namely Kinesio® Taping Method and McConnell Taping technique for anterior knee pain, and find similar results when compared to a non-taped group. Yet, as Juhn and Parreira et al note, the literature on taping has not always been in agreement with respect to clinical effectiveness, potentially indicating discrepancies in study variables such as tape application, placement, or direction.

In the current study Kinesio® Tape was used to examine the Kinesio® Taping Space Correction Method, both developed and proposed by Kase, in an effort to understand the underlying physiological effects of its application to the patellofemoral joint and evaluate claims of space correction. Six corrective techniques have been published as means to treat pathomechanics and pathophysiology, including fascial, space, ligament/tendon, functional, and lymphatic corrections. In the current study, the focus was placed on space correction to evaluate the potential of a Kinesio® Taping Method to lift the structures under which the tape has been applied to increase interstitial space.

The technique under consideration, namely the Kinesio® Taping Space Correction Method, purports to create a suction-like force which lifts structures under the applied tape. Kase suggests that the application of Kinesio® Tape in this manner can increase joint space, thereby reducing pain from diminished interstitial space, and that the tape’s application can create additional space between the skin and superficial structures for lymphatic correction. In the context of this study, the tape was applied over the patella and diagnostic ultrasound was used as a means to measure space in three anatomical regions unique to the patellofemoral joint. Diagnostic ultrasound has only recently begun to be used in studies focused on the impact of Kinesio® Tape, yet its clinical use in diagnosing pathomechanics in joints demonstrates its appropriateness for use in a study of this type. Moreover, the use of similar measurement techniques in both clinical and research settings improves comparability of results and strengthens claims related to evidence-based clinical relevance.

Therefore, the purpose of this study was to determine whether the Kinesio® Taping Space Correction Method created a significant difference in patellofemoral joint space, as quantified by diagnostic ultrasound. The research focused on three different measurements unique to patellofemoral structures: (1) the patellofemoral joint (i.e., underside of the patella to the femur); (2) skin to the superficial patella; and (3) the skin to the patellar tendon. These three measures allow for claims initially proposed by Kase with respect to joint space and the potential for lymphatic correction to be empirically tested in healthy tissue.

METHODS
To investigate the anatomical impact of the Kinesio® Taping Space Correction Method on underlying anatomical structures, a pre-test/post-test cohort
The International Journal of Sports Physical Therapy | Volume 12, Number 2 | April 2017 | Page 252

study was conducted. This design eliminates potential confounding variables (individual differences) between participants, with each participant serving as his or her own control.

Participants
Thirty-two individuals (16 males and 16 females) with bilaterally healthy knees participated in the study. Approval from the Institutional Review Board (IRB) at a large U.S. university was granted prior to participant enrollment. Participation in the study was voluntary and all participants were provided a written copy of an informed consent. In addition, the study was explained to potential participants and they had the opportunity to ask any questions prior to enrollment. Inclusion criteria for the study included self-report of: (1) bilaterally healthy knees; (2) being recreationally active; and (3) no medical conditions involving bones or joints. Exclusion criteria also included any reported knee pain in the prior six months or any allergy to Kinesio® Tex Gold™ FP 2″ Tape. All thirty-two individuals met these criteria and no attrition occurred throughout the study. Participants were between 18 and 30 years of age, with a mean age of 20.69 years ± 2.681.

Diagnostic Ultrasound
The Terason t3200 diagnostic ultrasound unit was used to measure three areas specific to patellofemoral structures: (1) the patellofemoral joint space; (2) the distance between the skin and the superficial patella; and (3) the distance between the skin and the patellar tendon. The patellofemoral joint space is operationalized in this study as the distance from the underside of the patella to the medial femoral condyle. Diagnostic ultrasound is ideally suited for this type of research, given the ability to visualize both bone and soft tissue, which allows for measurement of joint space. Previous research employing diagnostic ultrasound imaging has shown high degrees of inter- and intra-rater reliability for measurements of a wide range of structures of the knee.31-34 While much of the literature on diagnostic ultrasound of the knee has measured the tibiofemoral joint, the technique has also been used to image the patellofemoral joint.35 The non-invasive nature of the imaging technique, coupled with the near-real-time measurements, augment the case for using diagnostic ultrasound when investigating these types of conservative care interventions.

Study Procedures
Each participant enrolled in the study had the three anatomical areas measured using diagnostic ultrasound to serve as baseline measures against which the post-tape-application measures could be compared. To do so, the diagnostic ultrasound unit was placed on a high frequency setting. The transducer was then positioned in the long axis view over the patellar tendon in order to ensure viewing of the lower aspect of the patella. From this initial location, the transducer was moved medially ensuring the patella's medial border was detected in the image. Upon visualization of the medial femoral condyle, the screen was frozen and the caliper function was used to collect measurements of the three previously described anatomical regions. The ultrasonographer for this research had one year of experience using the diagnostic ultrasound equipment for the patellofemoral joint. In addition, all measurements were confirmed by an ultrasonographer with over six years of clinical and research experience. One benefit of the measurement technique is that the frozen images are available for remeasurement, allowing a high degree of accuracy and reproducibility. Prior to removing the transducer, the skin of each participant was marked to indicate the position of the superior and inferior borders of the transducer to allow for the same measurements to be made after application of the Kinesio® Taping Space Correction Method.

Kinesio® Tape Application
Once the initial baseline measurements of each participant had been made, the researchers then applied tape over the patellofemoral joint. The tape used in this study is Kinesio® Tex Gold™ FP 2″; tape that is purported to affect superficial structures such as the skin and the superficial patella.24 Tape application followed the Kinesio® Taping Space Correction Method described in the Kinesio® Taping Manuals.24 The skin at the site of application was first cleaned with an alcohol prep pad and excess was hair trimmed to ensure tape adherence. The tape was cut to a length approximately 2” longer
than the patella. Then, the tape was folded in half and three longitudinal cuts were made, keeping the ends intact.

To apply the tape, the tibiofemoral joint was flexed to 120 degrees. A goniometer was used to ensure flexion to the appropriate degree and was read by a certified athletic trainer with more than 10 years of practice. The rationale for knee flexion is the increased epidermal tension under the tape in order to assist with the "lifting phenomenon." The paper on the back of the tape was torn in the middle third and stretched with light to moderate tension (~35%) over the patella. For all participants, the tape was applied by a Certified Kinesio® Tape Faculty member with more than seven years of experience to help ensure consistency of tension and placement. Finally, the ends were applied to the superior and inferior aspects of the patella and then rubbed to activate the adhesive. Figure 1 illustrates the tape application. Participants remained on the treatment table for ten minutes in a non-weight-bearing position. The taped leg rested on the table in a comfortably extended position with no additional flexion or movement.

After the ten-minute wait period, the diagnostic ultrasound transducer was placed in the same position as the first measurement using the marked borders on the skin with the tape application still intact. The same three measurements were again made using the caliper function of the Tersaon T3200 diagnostic ultrasound unit, set on the high frequency setting (Figure 2).

**STATISTICAL METHODS**

In light of the pre-test/post-test research design, paired t tests were conducted for each of the three measurements ($\alpha = .05$). All collected data were included in the analysis. No confounding variables were controlled for and no tests were conducted on sub-groups of the data. Effect sizes were calculated using Hedges’ $g$ as an unbiased adjustment of Cohen’s $d$.36,37

Power analysis was conducted to determine the appropriate sample for the paired $t$ tests using an alpha of 5% and required power of 80%. With these parameters, the sample of 32 participants was deemed sufficient to identify a between-group difference of 2 mm in the patella-to-femur measurement with a standard deviation of 2.5 mm. Lanyon et al report average patellofemoral joint spaces of healthy knees between approximately 4 and 7 mm, which suggests that a change of 2 mm would represent a substantial increase.38

**RESULTS**

The means and standard deviations for the three measurements of the patellofemoral joint appear in Table 1. The largest mean difference occurred in the first measurement—the underside of the patella to the medial femoral condyle (mean difference = 1.1 mm). A statistically significant difference between pre- and post measurements of the patellofemoral joint space with a medium effect size was observed ($t_{31} = 2.823, p = .008, g = .465, 95\% CI [0.30, 1.89]$). Analysis of the pre-test/post-test measurements between the skin and the superficial patella were not statistically significantly different (mean difference = .045 mm, $t_{31} = 1.211, p = .24, g = .213, 95\%$ CI [0.10, 1.35]).

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1 If using the measurement markings provided on the back of the tape, this is equivalent to four squares.
The third measurement between the skin and the patellar tendon also was not statistically significantly different (mean difference = 0.0 mm, \( t_{31} = .017, p = .99, g = .002, 95\% \text{ CI } [-0.38, 0.37] \)). It should be noted that the means of the third measurement in both the taped and un-taped conditions were identical to two decimal places.

**DISCUSSION**

The purpose of this study was to investigate the physiological effects of the Kinesio® Taping Space Correction Method using diagnostic ultrasound, specifically focusing on three different measurements unique to patellofemoral structures. In light of the observed results, the application of tape for space correction purposes significantly increased the distance between the underside of the patella and the medial femoral condyle (patellofemoral joint) in healthy individuals. The tape application, however, did not increase distance in either of the other two measurements. This result is not unexpected given that tape was applied with tension only over the patella as the targeted treatment area and not over the patellar tendon at the inferior end of the tape.

While this is a statistically significant difference demonstrated in subjects with healthy tissue, whether this is a clinically significant difference remains unestablished. Unfortunately, no normative data exist regarding what constitutes an appropriate measurement difference in a healthy individual, and the more relevant question is whether the increase in joint space due to tape application can be replicated in a study of actual patients with unhealthy tissue. Previous studies of patients with unhealthy tissue have employed multiple variables such as tape and physical therapy,

**Table 1.** Descriptive measurements (in mm) and results of paired t-tests

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<th>Post-tape</th>
<th>( p )-value</th>
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<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
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<tr>
<td>Patella to femur</td>
<td>2.405</td>
<td>0.241</td>
<td>2.515</td>
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<tr>
<td>Skin to patella</td>
<td>0.745</td>
<td>0.250</td>
<td>0.700</td>
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<tr>
<td>Skin to patellar tendon</td>
<td>0.856</td>
<td>0.149</td>
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*Figure 2. Images from Terason t3200 diagnostic ultrasound.*
so that it is unclear if their reported changes are the result of tape application, therapy, or the combination of both. An individual with patellofemoral pain may experience improvement in subjectively reported symptoms due to an increase in patellofemoral joint space. Therefore, the results are potentially beneficial to clinicians in order to reduce pain in conditions such as chondromalacia and other conditions involving narrowing of the joint space. The present study is a first step to determining whether Kinesio® Tape is able to affect the underlying physiological structures in the knee. Replication in unhealthy tissue, coupled with the collection of a subjective measurement of pain, would help establish the minimal clinically relevant difference.

A paucity of evidence exists related to the use of space correction taping methods as a means to address patient complaints of pain. In a study conducted by Gonzalez-Iglesias et al., researchers investigate the Kinesio® Taping Space Correction Method to improve the range of motion and pain experienced by patients who suffered from whiplash-associated disorders (WAD). While the anatomical regions differ between the present study and Gonzalez-Iglesias et al., statistically significant results of the Kinesio® Tape application when compared to a placebo application are suggestive that the space correction application may prove useful as a conservative care strategy for pain management. The introduction of unhealthy tissue as a variable in musculoskeletal disorders, along with the facilitation of specific muscle groups, make comparisons tenuous between the present and aforementioned study. Nevertheless, the inclusion of the Kinesio® Taping Space Correction Method is suggestive that additional research using these specific taping methods in relation to the physiological changes brought about by its application may prove useful to developing evidence-based treatment strategies.

**Limitations**

While the results obtained in this study are promising as a potential means of increasing interstitial joint space, the findings are limited insofar as they are contained to healthy individuals. Further investigation involving pathomechanics and this same tape application is important to continuing to study the effectiveness of the Kinesio® Taping Space Correction Method in unhealthy tissue. Moreover, the employed ten-minute wait period to effect significant change in the joint space may not be indicative of results with tape in place for a greater length of time. Likewise, the static nature of the application and the non-weight-bearing position during the wait period equally limits the extent to which these findings can be generalized to an active population. The authors recognize these potential limitations as being inherent to the study design and the aim of understanding underlying physiological effects of the tape without introducing additional variables which could be confounding (e.g., variation in stress on the joint in a weight-bearing position or varying pathomechanics in unhealthy tissue). A possible additional consideration is measurement reliability, which is addressed in two ways. First, the data collection includes a saved image of each measurement, which allows for reproducibility and a high degree of accuracy, and second, musculoskeletal ultrasonography has demonstrated strong inter-rater reliability in previous studies.

The study design provides a useful baseline by demonstrating an increase in patellofemoral joint space from the underside of the patella to the medial femoral condyle with the application of Kinesio® Tape.

**Generalizability**

In light of the study limitations, the study is best generalized to the study population, namely adults with bilaterally healthy knees. Additional investigation which compares healthy and unhealthy tissue may help to explore this method as a potential conservative intervention for patients with patellofemoral syndromes. Moreover, the study's results should be interpreted with the understanding that the brand of tape employed in this study may have an impact on the effectiveness of this tape application to increase patellofemoral joint space and whether the difference is clinically relevant. This caveat is particularly important given the proliferation of commercially-available brands of kinesiology tape.

**CONCLUSION**

In sum, the results of the current study present findings that suggest that the Kinesio® Taping Space Correction Method, when applied over the patella, increases space in the patellofemoral joint in healthy
adults. However, the results did not demonstrate that the space between the superficial patella and the skin or the skin and the patellar tendon increased as the result of tape application. Additional inquiry is needed to investigate the physiological changes that may occur with similar applications in subjects who are not healthy, for example in alleviating pain in patients presenting with symptoms of chondromalacia or those with patellofemoral pain syndrome.

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isokinetic exercise in healthy non athlete women. 


ABSTRACT

Background and Purpose: Most rehabilitation interventions after total hip arthroplasty (THA) are not designed to return patients to high-levels of physical activity and, thus, low levels of physical activity and residual weakness are common. The purpose of this case series was to describe the feasibility and preliminary efficacy of an exercise and education intervention for patients after THA who have already completed formal outpatient physical therapy.

Study Design: Case series

Case Description: Two participants underwent unilateral THA seven (case A) or eight (case B) months prior to the intervention. Individuals participated in 18 treatment sessions that included progressive aerobic and strengthening exercises and meetings with a health coach. Change in function, strength, and self-reported physical activity were measured. Outcomes 12 months after surgery were compared to a historical cohort of patients after THA.

Outcome: There were no adverse events during the intervention. At the end of the intervention, hip and knee strength on the surgical side increased approximately 30% compared to baseline in both cases. Activity level, and recreational performance, including walking up stairs and hiking uphill (case A), and running and golfing (case B), improved by the end of the intervention. Most changes were maintained at follow-up, although hip strength for case B decreased 27% after discharge from the intervention. Outcomes for both cases exceeded historical averages for patients 12 months after THA, with the exception of strength in case B.

Discussion: The exercise intervention was well tolerated and without negative effects in two participants. Both participants increased their ability to complete demanding recreational and sports-related activities, physical activity, and demonstrated improved hip abductor and knee extensor strength. Further research is needed to evaluate the implementation and effectiveness of similar interventions after THA.

Level of Evidence: Level 4

Key words: Aerobic exercises, activity level, lower limb strengthening, total hip arthroplasty
BACKGROUND
The incidence of total hip arthroplasty (THA) has increased over the past 10 years.although this procedure improves pain and patient-reported outcomes,many individuals after THA exhibit impairments and functional limitations when compared to older adults without joint pathology. This is particularly concerning as the demographic of patients who elect to undergo THA has been getting progressively younger. Younger individuals may have higher functional and participation goals compared to older adults, which may require modification of current rehabilitation protocols to improve the likelihood of returning to recreational and vocational activities after THA.

Physical inactivity is one of the major public health problems of the 21st century. The health benefits obtained from physical activity surpass outcomes from pharmacological interventions by reducing the risk of death to a greater extent than medications. Identifying strategies to improve physical activity is critical for patients' health and well-being, as active lifestyle and participation in exercise improves health of individuals with many common chronic conditions.

Joint pain is a barrier to physical activity and exercise before arthroplasty surgery. Most of the patients with lower extremity osteoarthritis do not meet the recommended level of physical activity. Current physical therapy protocols post THA focus on resolving impairments and improving independent mobility. Despite the resolution of pain and improved perception of abilities, negligible improvements in physical activity have been measured up to one year following THA, suggesting that most patients do not adopt an active lifestyle. After THA, physical activity may not change without targeted intervention and evidence on rehabilitation protocols to improve physical activity and exercise participation is lacking.

Patients have to follow post-operative surgical precautions to allow tissue healing and prevent the risk of dislocation up to 6 to 12 weeks after THA. These precautions may limit progressively increasing or intense strengthening and functional training. Furthermore, although patients are typically not enrolled in formal interventions after the third post-surgical month, functional performance continues to improve, and reaches a plateau 12 months after surgery. Therefore, targeting impairments that are related to functional performance, such as residual weakness and aerobic capacity, may optimize outcomes for patients after THA. Considering the current evidence, an intervention was developed that included aerobic and strengthening exercises, as well as educational components that targeted behavioral changes. This intervention was designed for patients at least three months following THA, who were already discharged from physical therapy. The goal of this intervention was to increase lower limb strength, increase physical activity, and improve functional outcomes after THA. The purpose of this case series was to describe the feasibility and preliminary efficacy of this exercise and education intervention for patients after THA who have already completed formal outpatient physical therapy. Outcomes of the individuals who participated in this intervention were also compared to a historical cohort of subjects who underwent THA, but did not receive any targeted exercise and behavioral intervention after THA.

CASE DESCRIPTIONS
Participants were recruited from a larger longitudinal study. To be included in the parent study, participants had to be between the ages 40 and 70 and be scheduled for a unilateral THA. Participants were excluded from the parent study if they had: 1) neurological, vascular or other lower extremity musculoskeletal conditions that affected gait or functional performance, 2) uncontrolled hypertension, 3) self-reported lack of sensation in the lower extremities, and 4) history of cancer in the lower extremity. Participants included in this case series were recruited between three and nine months after THA. Because the intervention for the case series involved cardiovascular exercise, the participants met all the criteria above, but also did not have: 1) history of chest pain, heart attack, or heart failure, 2) complications after THA, and 3) previous THA or a planned future contralateral THA. The testing and intervention procedures were approved by the Institution review board and participants gave informed consent before starting any component of the protocol. Both cases underwent anterolateral THA by the same surgeon.
Case A
A 62-year-old female was recruited seven months after THA. She underwent four acute care physical therapy sessions while hospitalized. After discharge, she was enrolled in 12 outpatient physical therapy sessions. She sustained a fall four months after the surgery and fractured her wrist, but her past medical history was otherwise non-significant. At the time of enrollment, the wrist cast was removed and she was cleared to return to activity.

Case B
A 62-year-old male was recruited eight months after THA. He underwent three acute care physical therapy sessions while hospitalized. After discharge, he was enrolled in five home and 12 outpatient physical therapy sessions. The past medical history was non-significant, although the baseline graded exercises testing session was terminated due to presence of ectopic heart beats in the resting electrocardiogram. After he obtained clearance from his cardiologist, he was able to complete the graded exercise testing and was enrolled in the intervention.

HISTORICAL LONGITUDINAL COHORT
Thirty-two participants enrolled in the longitudinal parent study were included as historical cohort (THA approach: 11 anterolateral [34%], one direct lateral [3%], and 20 posterior [63%]). Physical therapy treatment after THA was not standardized and participants attended physical therapy as prescribed by their treating orthopaedic surgeon. In this cohort, 18 participants underwent a combination of home and outpatient physical therapy (56%); seven underwent only outpatient physical therapy (22%); and four underwent only home physical therapy (13%). Information regarding post-THA physical therapy was not available for three participants (9%).

PROCEDURE
Participants in the longitudinal parent study attended two testing sessions (2-4 weeks before THA and 12 months after THA), while participants in the case series attended four testing sessions (2-4 weeks before THA, immediately prior to the intervention, at the end of the intervention, and 12 months after THA, Figure 1).
Maximal voluntary isometric strength for the quadriceps muscle was measured using an electromechanical dynamometer (Kin-Com, Chattanooga Inc., Chattanooga, TN, USA). Participants were seated with the knee at 75° of flexion. After warm up contractions, three maximal contractions were performed with one minute of rest between repetitions. Force data were recorded in Newtons using a force transducer located at the distal anterior tibia two centimeters proximal to the lateral malleolus and were normalized to body mass (Kg).

Participants performed the Timed Up and Go (TUG), the timed Stair Climbing Test (SCT), and the Six-Minute Walk tests (6MW). For the TUG, participants stood up from a chair without using the armrests, moved as fast as possible for three meters, turned around, and returned back to sit on the chair. For the SCT, participants ascended and descended a set of 12 steps (15cm rise, 20cm run) “as fast as possible while still being safe”. If needed, participants were allowed to use one handrail, but were not allowed to skip steps. For the 6MW, participants walked as far as they could for six minutes along a 115 m square hallway. Participants were allowed to rest, if needed, but time was not stopped during rest.

OUTCOME MEASURES – CASE SERIES ONLY

Participants in the case series completed the Fatigue Severity Score (FSS), the International Physical Activity Questionnaire short form (I-PAQ), and Patient Specific Functional Scale (PSFS). The FSS is a nine item questionnaire that measure the severity of fatigue and its effect on participants activity and lifestyle. The maximum score is 63, which indicates the highest level of fatigue. The I-PAQ-short version asks participants to report the amount of days and time over the previous week that they spent sitting, walking, and doing vigorous and moderate activities. The metabolic equivalent (MET) energy expenditure over the week was calculated based on the participants’ answers. The PSFS asks patients to identify activities that are unable to complete due to their current injury. Participants are then asked to rate their level of impairment from “0, unable to perform” to “10, able to perform activity at the same level as before injury”. The minimum detectible change at the 90% confidence interval for a single activity is 3-points.

Leg loading during sit to stand was measured by asking participants to stand up from a piano stool with the arm crossed on their chest. Two force plates (Bertec Corp, Worthington, Ohio, USA) were used to collect ground reaction forces from the surgical and non-surgical leg. Signal was acquired at 1080Hz, and filtered with a low-pass Butterworth filter (cut-off frequency 40Hz). Symmetry index was obtained by dividing the peak vertical ground reaction force of the surgical leg by the peak of the non-surgical leg (100% represents perfect symmetry).

INTERVENTION

The two case report subjects underwent a medical screening and a graded exercise stress test prior to enrollment in the intervention. If no absolute or relative risks were indicated in the initial health history questionnaire, participants underwent resting electrocardiogram and blood pressure testing. Once cleared, participants completed a graded exercise testing according to the modified Bruce protocol. A cardiologist reviewed the results of the graded exercise to determine eligibility for the exercise intervention.

The exercise intervention included 18 supervised sessions over the course of six-weeks. Each session lasted one-hour and included two 15-minute aerobic components, one 20-minute strengthening component, and 10 total minutes for recovery and transfer between exercises. This exercise construct has been successfully and safely implemented in the IDEA trial. Methods of aerobic and resistive weight training were tailored to each participant’s baseline status and goals, as described in the PSFS. With regard to the PSFS, Case A desired to improve walking (fast speed and hiking uphill) and stair climbing. Therefore, treadmill with change in inclination and elliptical machine were used as preferred methods for aerobic training. Strengthening exercises included stepping activity (progressed with the addition of weight) and balance exercises on different surface to prepare walking on uneven surfaces. Case B desired to improve running and golfing. During treadmill training, speed increase was used to reach the targeted heart rate. After three weeks of conventional strength exercises (hip abductors set, shuffle gait, leg press, etc.), golf specific exercises were added (golf swing movements with exercise balls of differing weights). Case B performed simulated golf putting on different destabilizing surfaces and rocker boards. During these exercises, he was required to put a golf ball into a cup to add an additional layer of complexity (Table 1).
Table 1. Exercise intervention description according to the Consensus on Exercise Reporting

<table>
<thead>
<tr>
<th>Item #</th>
<th>EXERCISE INTERVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Aerobic component</strong></td>
</tr>
<tr>
<td>Materials/Equipment</td>
<td>Treadmill, stationary bicycle, and elliptical. Commercially available heart rate monitor</td>
</tr>
<tr>
<td>Provider</td>
<td>Licensed physical therapist</td>
</tr>
<tr>
<td>Delivery</td>
<td>Individual session</td>
</tr>
<tr>
<td></td>
<td>Supervised</td>
</tr>
<tr>
<td></td>
<td>Measurement taken by the physical therapist during each session</td>
</tr>
<tr>
<td></td>
<td>Motivation and feedback provided by the physical therapist as needed</td>
</tr>
<tr>
<td></td>
<td>Progressed to maintain target heart rate</td>
</tr>
<tr>
<td></td>
<td>Ability to perform 3 set of 10 minimal pain (1/10) and discomfort</td>
</tr>
<tr>
<td></td>
<td><strong>Lower Extremity Strength</strong></td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Treadmill" /></td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Sport specific Dynamic ex Golf" /></td>
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<tr>
<td></td>
<td><img src="image" alt="Elliptical" /></td>
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<tr>
<td></td>
<td><img src="image" alt="Dynamic Balance Sport Specific ex. Golf" /></td>
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<tr>
<td></td>
<td><img src="image" alt="Core stability/dynamic" /></td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="No home exercise program" /></td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Behavioral component: meeting and phone call with a health coach" /></td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="No adverse effect occurred during exercise" /></td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Outpatient physical therapy clinic" /></td>
</tr>
<tr>
<td>Location</td>
<td><img src="image" alt="Component duration: 20 minutes" /></td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Exercise per session: between 3 and 6" /></td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Sets: between 2 and 3" /></td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Repetition: between 5 and 10" /></td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Intensity: tailored to individual" /></td>
</tr>
<tr>
<td>Dosage</td>
<td>Component duration: 15 minute</td>
</tr>
<tr>
<td></td>
<td>Component per session: 2</td>
</tr>
<tr>
<td></td>
<td>Intensity: 65-80% predicted heart rate max</td>
</tr>
<tr>
<td>Tailoring</td>
<td>Tailored to individual</td>
</tr>
<tr>
<td></td>
<td>65% Heart rate max</td>
</tr>
<tr>
<td>Planned, Actual</td>
<td>Exercise intervention was delivered as planned</td>
</tr>
</tbody>
</table>

*Multiple exercises were used during the strengthening component. Pictures display only some of the exercises performed.*
The parent longitudinal study group was stratified by sex to allow comparison between cases. Relative and percentage difference scores were calculated between the two participants in the case series and averages from the historical cohort 12 months after THA for HOS score, performance of TUG, SCT, and 6MW, and quadriceps and hip abductors strength from the surgical side. Pre-operative demographic characteristics of the two cases and the historical sample are reported in Table 2.

OUTCOMES

Feasibility analysis
Both patients completed all exercise sessions. The exercise logs for the first, ninth, and eighteenth sessions are given in appendix A (case A) and appendix B (case B) as a representation of the content and progression of exercises. Case A reported one episode of severe hip pain on the operated side that developed after the eighth exercise session (Appendix C). However, the patient did not report hip pain immediately prior to or after the ninth session. Case A reported low back pain at the beginning of most exercise sessions; however, the pain decreased or did not change at the end of each session. Case B reported low-level pain in the surgical hip after the first two exercise sessions, but this pain did not persist (Appendix D).

INTERVENTION EFFECT

Case A
Compared to baseline, there was a 14% improvement of HOS score by the end of the intervention, which was maintained 12 months after THA (Table 3). Hip abductor and quadriceps strength on the operated side increased approximately 30% from baseline and quadriceps strength was symmetrical between legs (symmetry index [surgical/non-surgical] = 0.96). Between the end of the intervention and the twelfth month after THA, hip and knee strength increase 28 and 13%, respectively. Despite the improvement in strength and HOS, there were no substantial changes in performance-based measures of function (TUG, SCT, and 6MW).

At the end of the intervention, the FSS score improved 22% compared to baseline. The I-PAQ score increased to 12558 MET/week from 2838 for aerobic exercises, a heart rate monitor was used to confirm that exercise intensity ranged between 65–80% of the predicted heart rate maximum. The starting intensity and progression of the intervention components were dependent on the individual's tolerance to each exercise session and according to a pain-monitoring model. Low back and lower extremity joint pain was recorded before each exercise session (verbal analog scale: 0, no pain; 10, worst pain imaginable), and appearance of severe pain, swelling, and tenderness after the previous exercise session (yes/no question). At the end of the session, participants were asked to rate their current level of pain in the low back and lower extremity joints. These data were then used for the feasibility analysis.

Participants met with a health coach during the first week of the exercise intervention. This meeting focused on awareness of healthy eating habits, identifying barriers to participation, setting personal health goals, and identifying strategies to stay engaged in the program. These behavioral intervention components have been shown to change sedentary behaviors in older adults. The health coach followed-up weekly through phone calls to review exercise participation, answer questions, set new goals, and provide further information on possible lifestyle adjustments to promote active lifestyle. An activity monitor (FitBit Zip, FitBit, San Francisco, CA) was given to participants to provide feedback information of their activity. A custom questionnaire was used to measure each participants experience with the health coach. Participants were asked to rank their overall experience with the health coach (very positive, somewhat positive, neither positive or negative, somewhat negative, very negative), the likelihood of meeting with a health coach at the end of the study, and whether they would recommend others to meet with a health coach (very true, mostly true, somewhat true, not true at all).

DATA ANALYSIS

For the two cases, changes for each outcome were described as a percentage increase or decrease between: 1) baseline testing (just prior to exercise intervention) and the end of the intervention; and 2) end of the intervention and third month follow-up (12 months after THA).
tests of function, but hip abductor and knee strength on the operated side improved 22 and 31%, respectively. Despite the improvement during the course of the exercise intervention, hip and knee strength decreased 27% and 8% by the 12 months after THA follow up compared to the end of the intervention. There were no substantial changes in performance-based measures of function (TUG, SCT, and 6MW) during the intervention time frame.

The FSS score improved 47% compared to baseline, and he had substantial improvements in the I-PAQ, which increased to 4759.5 MET/week from 891 MET/week. The participant reported improvement in the PSFS, which reached a level of 9 for golfing and 7 for running. Improvements in the FSS, I-PAQ, and PSFS were maintained 12 months after THA.

Case B
At the end of the intervention, there were no improvements in HOS score and performance-based MET/week at baseline and the PSFS reached a score of 10 (maximum score) for all activities. These results were maintained 12 months after THA. Symmetry index for vertical ground reaction force increased 14% at the end of the intervention (Figure 2).

Before THA, Case A had lower score on the HOS, worse performance in the 6MW, and lower hip adductor and quadriceps strength compared to the average female patients in the longitudinal parent study (Table 2). When these outcomes were evaluated at the 12-month follow-up, she outperformed the average female patients in the longitudinal parent study (Table 4). Case A rated her overall experience with the health coach as “somewhat positive”, but reported that she would not continue to meet with a health coach after the study.

**Case B**
At the end of the intervention, there were no improvements in HOS score and performance-based MET/week at baseline and the PSFS reached a score of 10 (maximum score) for all activities. These results were maintained 12 months after THA. Symmetry index for vertical ground reaction force increased 14% at the end of the intervention (Figure 2).

Before THA, Case A had lower score on the HOS, worse performance in the 6MW, and lower hip adductor and quadriceps strength compared to the average female patients in the longitudinal parent study (Table 2). When these outcomes were evaluated at the 12-month follow-up, she outperformed the average female patients in the longitudinal parent study (Table 4). Case A rated her overall experience with the health coach as “somewhat positive”, but reported that she would not continue to meet with a health coach after the study.

**Table 2. Preoperative characteristics of the two participants recruited for the current study compared with the female and male participants of the parent longitudinal study**

<table>
<thead>
<tr>
<th></th>
<th>Case A</th>
<th>AVG (SD)</th>
<th>Case B</th>
<th>AVG (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Female</td>
<td>61</td>
<td>Female</td>
<td>63 (8)</td>
</tr>
<tr>
<td>Age, years</td>
<td>55</td>
<td>1.55</td>
<td>1.66 (0.07)</td>
<td>61</td>
</tr>
<tr>
<td>Height, m</td>
<td>22.89</td>
<td>28.06 (5.66)</td>
<td>31.51</td>
<td>29.66 (5.52)</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>39.47</td>
<td>62.40 (17.89)</td>
<td>71.05</td>
<td>57.46 (15.38)</td>
</tr>
<tr>
<td>BMI, kg*m^2</td>
<td>49</td>
<td>4.9 (2.8)</td>
<td>3</td>
<td>5.5 (1.5)</td>
</tr>
<tr>
<td>HOS, %</td>
<td>7</td>
<td>4.9 (2.8)</td>
<td>3</td>
<td>5.5 (1.5)</td>
</tr>
<tr>
<td>Hip SX, [0-10]</td>
<td>8</td>
<td>1.8 (2.5)</td>
<td>1</td>
<td>2.5 (2.5)</td>
</tr>
<tr>
<td>Knee SX, [0-10]</td>
<td>0</td>
<td>0.3 (0.7)</td>
<td>0</td>
<td>0.2 (0.4)</td>
</tr>
<tr>
<td>Hip NSX, [0-10]</td>
<td>0</td>
<td>0.7 (1.8)</td>
<td>0</td>
<td>0.5 (1.5)</td>
</tr>
<tr>
<td>Knee NSX, [0-10]</td>
<td>0</td>
<td>1.3 (1.7)</td>
<td>0</td>
<td>2.5 (2.2)</td>
</tr>
<tr>
<td>Symmetry index for vertical ground reaction force</td>
<td>6.11</td>
<td>9.67 (2.92)</td>
<td>5.11</td>
<td>8.72 (1.99)</td>
</tr>
<tr>
<td>6MW, m</td>
<td>12.3</td>
<td>17.78 (8.06)</td>
<td>9.11</td>
<td>15.81 (5.50)</td>
</tr>
<tr>
<td>Hip strength SX, N/Kg</td>
<td>435.2</td>
<td>447.30 (108.90)</td>
<td>523.69</td>
<td>456.28 (90.68)</td>
</tr>
<tr>
<td>Hip strength NSX, N/Kg</td>
<td>4.63</td>
<td>6.62 (2.12)</td>
<td>7.86</td>
<td>5.38 (2.81)</td>
</tr>
<tr>
<td>Symmetry index for vertical ground reaction force</td>
<td>5.65</td>
<td>8.24 (3.05)</td>
<td>8.63</td>
<td>7.30 (3.59)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>AVG (SD)</th>
<th>AVG (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 16</td>
<td>Male</td>
<td>65 (7)</td>
</tr>
<tr>
<td>N = 16</td>
<td>Female</td>
<td>61</td>
</tr>
</tbody>
</table>

*Abbreviation: AVG= average; SD= standard deviation; BMI= body mass index; HOS= hip outcome survey; SX= surgical; NSX= non-surgical; TUG= timed up and go; SCT= stair climbing time; 6MW= six minute walk*
better performance on these tests, his quadriceps and hip abductor strength were lower compared to the average male participant. Case B presented with symmetrical ground reaction force at baseline and no changes were measured after the intervention (Figure 2). Case B rated his experience with the health coach as “very positive” and would be likely to recommend that others meet with a health coach.

**DISCUSSION**

Reductions in joint pain and high satisfaction rates after THA often overshadow the persistent postsurgical impairments, such as muscle weakness and reduced levels of physical activity. Although these may be considered incidental impairments, they can have a substantial impact on patients’ quality of life, particularly in young and active patients. The results of this case series suggest that impairments, such as weakness and reduced physical activity, can be improved with targeted interventions, even late in

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**Table 3.** Patient-reported outcome, impairment-based, and performance-based measures for Case A and Case B assessed before and after the intervention, and at the third-month follow-up. Percentage change between the time points is also calculated.

<table>
<thead>
<tr>
<th>Patient-reported outcome, impairment-based, and performance-based measures</th>
<th>Case A</th>
<th>Percentage change</th>
<th>Case B</th>
<th>Percentage change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>End intervention</td>
<td>12-month post THA</td>
<td>Baseline - End intervention</td>
</tr>
<tr>
<td>Weight, Kg</td>
<td>55</td>
<td>54</td>
<td>55</td>
<td>-2</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>22.89</td>
<td>22.47</td>
<td>22.89</td>
<td>-2</td>
</tr>
<tr>
<td>SX hip pain, VAS [0-10]</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>SX knee pain, VAS [0-10]</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>NA</td>
</tr>
<tr>
<td>NSX hip pain, VAS [0-10]</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>NSX knee pain, VAS [0-10]</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Low back pain, VAS [0-10]</td>
<td>5</td>
<td>2</td>
<td>6</td>
<td>-60</td>
</tr>
<tr>
<td>HOS, %</td>
<td>87.5</td>
<td>100</td>
<td>99</td>
<td>14</td>
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<tr>
<td>TUG, s</td>
<td>4.94</td>
<td>4.96</td>
<td>5.04</td>
<td>0</td>
</tr>
<tr>
<td>SCT, s</td>
<td>9.82</td>
<td>8.92</td>
<td>9.28</td>
<td>-9</td>
</tr>
<tr>
<td>6MW, m</td>
<td>636.42</td>
<td>664.6</td>
<td>669</td>
<td>4</td>
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<tr>
<td>SX hip strength, N/Kg</td>
<td>1.37</td>
<td>1.76</td>
<td>2.26</td>
<td>29</td>
</tr>
<tr>
<td>SX knee strength, N/Kg</td>
<td>2.25</td>
<td>2.64</td>
<td>3.04</td>
<td>17</td>
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<td>NSX knee strength, N/Kg</td>
<td>6.8</td>
<td>9.25</td>
<td>10.45</td>
<td>36</td>
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<tr>
<td>NSX knee strength, N/Kg</td>
<td>7.83</td>
<td>9.61</td>
<td>10.7</td>
<td>23</td>
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<tr>
<td>I-PAQ, MET/week</td>
<td>2838</td>
<td>12558</td>
<td>13750</td>
<td>342</td>
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<tr>
<td>FFS, [0-69]</td>
<td>32</td>
<td>25</td>
<td>24</td>
<td>-22</td>
</tr>
<tr>
<td>PSFS, [0-10]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking long distances</td>
<td>7</td>
<td>10</td>
<td>10</td>
<td>43</td>
</tr>
<tr>
<td>Walking upstairs</td>
<td>5</td>
<td>10</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>Hiking uphill</td>
<td>4</td>
<td>10</td>
<td>10</td>
<td>150</td>
</tr>
<tr>
<td>Fast walking</td>
<td>5</td>
<td>10</td>
<td>10</td>
<td>100</td>
</tr>
</tbody>
</table>

**Figure 2.** Vertical ground reaction force symmetry index for Case A (black line and squares) and Case B (red line and circles) at baseline, end intervention and 3-months follow-up timepoints. Symmetry index is calculated by dividing the value of the operated leg with the value of the non-operated leg, and 100% represent perfect symmetry.
the recovery phase. The intervention was feasible in a clinical setting and showed an increased strength and functional abilities in two subjects without prolonged exacerbation of symptoms. Pain in the surgical hip at the end of a session was reported a total of three times, was limited to minimal pain, and may have been related to the beginning of an exercise routine or higher level of exercises. Assessing pain and potential exercise adverse effects may help clinician tailoring session that promote gains, while limiting patients’ discomfort.

At the end of the intervention, muscle strength on the operated side improved on average 25% for the hip abductors and 33% for the knee extensor. Case A strength exceeded pre-operative values for both the hip abductor and quadriceps muscles. Case A demonstrated symmetrical quadriceps strength, which was maintained 12 months after THA. When compared to female subjects in the longitudinal study, Case A had 53 and 43% greater hip abductor and quadriceps strength 12-months post THA. Case B demonstrated strength gains during the intervention, but was not able to achieve pre-operative levels and strength decreased at the 3-month follow-up. Compared to male subjects in the longitudinal study, Case B had 76% and 14% weaker hip abductor and quadriceps strength 12-months post THA. It is possible that strength gains in this individual were limited by tissue damage associated with the anterolateral surgical approach, or intraoperative considerations like insufficient femoral offset. In retrospect, Case B may have benefited from a longer duration program or continuation with an independent regimen after discharge from the intervention. However, currently there are no prognostics indicators to identify participants who will benefit from longer care or independent exercise regimens.

Both cases demonstrated changes in the PSFS that exceeded the minimal detectable change. Using exercises that target patient-specific goals may improve patient engagement, provide changes that are meaningful to the patient, and foster changes in overall physical activity. Although both individuals in this case series performed well on the common performance measures, they reported low levels of physical activity compared to previously reported data in patients after THA (approximately 3000met/week). Both individuals demonstrated large improvements in self-reported activity levels at the end of the intervention, which were

| Table 4. Patient reported outcome, performance-based, and strength measure of the two participants recruited for the current study and the female (N = 16) and male (N = 16) participants of the parent longitudinal study at the 12-month follow up visit |

<table>
<thead>
<tr>
<th>HOS, %</th>
<th>Case A</th>
<th>Parent longitudinal study [female N = 16]</th>
<th>Relative difference [case A - longitudinal]</th>
<th>Percentage difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>94.40</td>
<td>91.04</td>
<td>3.36</td>
<td>3.62</td>
</tr>
<tr>
<td>TUG, s</td>
<td>5.05</td>
<td>7.22</td>
<td>-2.17</td>
<td>-35.37</td>
</tr>
<tr>
<td>SCT, s</td>
<td>9.29</td>
<td>12.90</td>
<td>-3.62</td>
<td>-32.59</td>
</tr>
<tr>
<td>6MW, m</td>
<td>669.00</td>
<td>538.30</td>
<td>130.70</td>
<td>21.65</td>
</tr>
<tr>
<td>Knee strength SX, N/Kg</td>
<td>10.45</td>
<td>6.71</td>
<td>3.74</td>
<td>43.59</td>
</tr>
<tr>
<td>Hip strength SX, N/Kg</td>
<td>2.26</td>
<td>1.27</td>
<td>1.01</td>
<td>55.56</td>
</tr>
<tr>
<td>HOS, %</td>
<td>Case B</td>
<td>Parent longitudinal study [male N = 16]</td>
<td>Relative difference [case B - longitudinal]</td>
<td>Percentage difference</td>
</tr>
<tr>
<td>-------</td>
<td>--------</td>
<td>----------------------------------------</td>
<td>--------------------------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td></td>
<td>98.70</td>
<td>95.40</td>
<td>3.30</td>
<td>3.40</td>
</tr>
<tr>
<td>TUG, s</td>
<td>4.43</td>
<td>6.95</td>
<td>-2.52</td>
<td>-44.29</td>
</tr>
<tr>
<td>SCT, s</td>
<td>7.56</td>
<td>10.28</td>
<td>-2.72</td>
<td>-30.49</td>
</tr>
<tr>
<td>6MW, m</td>
<td>736.00</td>
<td>592.20</td>
<td>143.80</td>
<td>21.65</td>
</tr>
<tr>
<td>Knee strength SX, N/Kg</td>
<td>8.40</td>
<td>9.74</td>
<td>-1.34</td>
<td>-14.77</td>
</tr>
<tr>
<td>Hip strength SX, % N/Kg</td>
<td>0.78</td>
<td>1.76</td>
<td>-0.98</td>
<td>-76.92</td>
</tr>
</tbody>
</table>

Abbreviation: HOS= hip outcome survey; SX= surgical; NSX=non-surgical; TUG= timed up and go; SCT= stair climbing time; 6MW,=six minute walk
LIMITATIONS
The absence of a direct measure of physical activity (i.e., using an activity monitor) is considered a limitation of this study because patients post-arthroplasty tend to overestimate their self-reported activity level. Inherent limitation of this type of case-series include the lack of generalizability of the results, although the comparison with an historical cohort gives an interesting perspective on the changes promoted by the intervention.

CONCLUSION
The exercise intervention protocol used in this case series improved leg strength, weekly physical activity, and the ability to perform demanding recreational and sport participation, without producing adverse effects. These improvements occurred even though patients in this case series scored well on common performance tests, such as TUG, SCT, and 6MW. This intervention is a novel approach that could potentially increase activity levels and restore recreational participation in patients after THA.

REFERENCES


### Appendix A. Exercise Log for Sessions One, Nine and Eighteen for Case A

<table>
<thead>
<tr>
<th>Mode</th>
<th>Distance (m)</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aerobic Session 1</strong> Bike</td>
<td>4570</td>
<td>Resistance: 5; cadence &gt; 60</td>
</tr>
<tr>
<td><strong>Aerobic Session 2</strong> Elliptical</td>
<td>1432</td>
<td>Resistance: 1; crossramp: 1</td>
</tr>
</tbody>
</table>

#### Strengthening

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Sets</th>
<th>Repetition</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg press</td>
<td>2</td>
<td>10</td>
<td>10kg</td>
</tr>
<tr>
<td>Bridge with abductor rubber band</td>
<td>2</td>
<td>10</td>
<td>green band</td>
</tr>
<tr>
<td>Sideling hip abductor</td>
<td>2</td>
<td>10</td>
<td>green band</td>
</tr>
<tr>
<td>Leg extension (full range)</td>
<td>2</td>
<td>10</td>
<td>green band</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mode</th>
<th>Distance (m)</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aerobic Session 1</strong> Bike</td>
<td>4570</td>
<td>Resistance: 7; cadence &gt; 60</td>
</tr>
<tr>
<td><strong>Aerobic Session 2</strong> Elliptical</td>
<td>1609</td>
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#### Strengthening

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<thead>
<tr>
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<th>Sets</th>
<th>Repetition</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg press</td>
<td>3</td>
<td>10</td>
<td>20kg</td>
</tr>
<tr>
<td>Abductor rise</td>
<td>3</td>
<td>10</td>
<td>1.5kg</td>
</tr>
<tr>
<td>Single leg step down</td>
<td>3</td>
<td>10</td>
<td>16 cm block; holding 1kg ball</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mode</th>
<th>Distance (m)</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aerobic Session 1</strong> Bike</td>
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<td>Resistance:6; cadence &gt; 80</td>
</tr>
<tr>
<td><strong>Aerobic Session 2</strong> Elliptical</td>
<td>1657</td>
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#### Strengthening

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Sets</th>
<th>Repetition</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single leg bridge</td>
<td>3</td>
<td>10</td>
<td>20kg</td>
</tr>
<tr>
<td>Single leg stance</td>
<td>8</td>
<td>10</td>
<td>Multidirectional balance board; 10 ball tosses per set</td>
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<tr>
<td>Single leg step up</td>
<td>3</td>
<td>10</td>
<td>16 cm block with foam pad on top</td>
</tr>
<tr>
<td>Leg curls (prone)</td>
<td>3</td>
<td>10</td>
<td>5kg</td>
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### Appendix B. Exercise Log for Sessions One, Nine and Eighteen for Case B

#### Session #1

<table>
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<td>Treadmill</td>
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</tr>
<tr>
<td>Aerobic Session 2</td>
<td>Bike</td>
<td>Resistance 5 cadence &gt; 70</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Sets</th>
<th>Repetition</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridge with abduction</td>
<td>3</td>
<td>10</td>
<td>red band</td>
</tr>
<tr>
<td>Rubber band</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sideling hip abductor</td>
<td>2</td>
<td>10</td>
<td>2.5kg</td>
</tr>
<tr>
<td>Leg extension (full range)</td>
<td>3</td>
<td>10</td>
<td>30kg</td>
</tr>
<tr>
<td>Sit ups</td>
<td>3</td>
<td>10</td>
<td>foam pad</td>
</tr>
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#### Session #9

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<tbody>
<tr>
<td>Aerobic Session 1</td>
<td>Bike</td>
<td>Resistance: 7 cadence &gt; 80</td>
</tr>
<tr>
<td>Aerobic Session 2</td>
<td>Treadmill</td>
<td>Speed: 4.67 km/h; incline: 7.5%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Sets</th>
<th>Repetition</th>
<th>Resistance</th>
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<tbody>
<tr>
<td>Leg extension (full range)</td>
<td>3</td>
<td>10</td>
<td>50kg</td>
</tr>
<tr>
<td>Leg curl (full range)</td>
<td>3</td>
<td>10</td>
<td>40kg</td>
</tr>
<tr>
<td>Hip extension (prone)</td>
<td>3</td>
<td>10</td>
<td>1.5kg, hold for 5 sec</td>
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#### Session #18

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</tr>
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<td>Treadmill</td>
<td>Speed: 5.47 km/h; incline: 6.5%</td>
</tr>
<tr>
<td>Aerobic Session 2</td>
<td>Bike</td>
<td>Resistance: 5 cadence &gt; 90</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Sets</th>
<th>Repetition</th>
<th>Resistance</th>
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</thead>
<tbody>
<tr>
<td>Golf swing</td>
<td>2</td>
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<td>Holding 5kg ball</td>
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<tr>
<td></td>
<td>2</td>
<td>10</td>
<td>Holding 3kg ball, higher speed</td>
</tr>
<tr>
<td>Trunk rotation on exercise ball</td>
<td>2</td>
<td>10</td>
<td>Holding 5kg ball</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>10</td>
<td>Holding 3kg ball, higher speed</td>
</tr>
<tr>
<td>Golf swing</td>
<td>3</td>
<td>5</td>
<td>Different balance boards and BOSU</td>
</tr>
<tr>
<td>Golf put</td>
<td>3</td>
<td>5</td>
<td>Different balance boards and BOSU</td>
</tr>
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## Appendix C. Case A self-reported severe joint pain, swelling, tenderness, developed the day after each exercise session; and verbal analog scale (VAS) for pain before and after each exercise session

<table>
<thead>
<tr>
<th>Case A</th>
<th>Session</th>
<th>Symptoms the day after the exercise session</th>
<th>Before exercise session Pain, VAS [0-10]</th>
<th>After exercise session Pain, VAS [0-10]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Severe joint pain</td>
<td>Joint swelling</td>
<td>Joint tenderness</td>
</tr>
<tr>
<td>#1</td>
<td>NA</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>#2</td>
<td>No</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>#3</td>
<td>No</td>
<td>0</td>
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<tr>
<td>#4</td>
<td>No</td>
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<td>#6</td>
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<td>No</td>
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<td>0</td>
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<tr>
<td>#8</td>
<td>Yes&lt;sup&gt;1&lt;/sup&gt;</td>
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<td>#9</td>
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<td>0</td>
</tr>
</tbody>
</table>

---

<sup>1</sup>, Episode of groin pain that lasted for a few minutes.

<sup>2</sup>, Pain developed during the exercise intervention.

<sup>3</sup>, SX= surgical; NSX= non-surgical.

## Appendix D. Case B self-reported severe joint pain, swelling, tenderness, developed the day after each exercise session; and verbal analog scale (VAS) for pain before and after each exercise session

<table>
<thead>
<tr>
<th>Case B</th>
<th>Session</th>
<th>Symptoms the day after the exercise session</th>
<th>Before exercise session Pain, VAS [0-10]</th>
<th>After exercise session Pain, VAS [0-10]</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Severe joint pain</td>
<td>Joint swelling</td>
<td>Joint tenderness</td>
</tr>
<tr>
<td>#1</td>
<td>NA</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>#2</td>
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---

<sup>1</sup>, Pain developed during the exercise intervention.

<sup>2</sup>, SX= surgical; NSX= non-surgical.
ABSTRACT

Context: Recent advances within the field of genetics are currently changing many of the methodologies in which medicine is practiced. These advances are also beginning to influence the manner in which physical therapy services are rendered. Rotator cuff pathology is one of the most common diagnoses treated by the sports physical therapist. The purpose of this commentary is to educate sports physical therapists on the recent advances regarding how genetics influences rotator cuff pathology, including rotator cuff tears, and provide a perspective on how this information will likely influence post-operative shoulder rehabilitation in the near future.

Evidence Acquisition: A comprehensive review of the literature was completed using the Medline database along with individual searches of relevant physical therapy, surgical, cell biology, and sports medicine journals. Search terms included: shoulder, rotator cuff pathology, genetics, apoptosis, and physical therapy. Search results were compiled and evaluated; relevant primary studies and review articles were gathered; the results from this comprehensive review are summarized here.

Study Design: Clinical Commentary, Review of the Literature

Results: Recent advances within the understanding of rotator cuff pathology have further elucidated the cellular and molecular mechanisms associated with rotator cuff tears. There appears to be a hypoxic-induced apoptotic cellular pathway that contributes to rotator cuff tears. Activation of specific proteins termed matrix metalloproteinases appear to be involved in not only primary rotator cuff tears, but also may influence the re-tear rate after surgical intervention. Further advancements in the understanding of the cellular mechanisms contributing to rotator cuff tears and postoperative techniques to help prevent re-tears, may soon influence the methodology in which physical therapy services are provided to patients sustaining a rotator cuff injury.

Conclusions: At this time continued research is required to more fully develop a comprehensive understanding of the role of genetic variables both within primary rotator cuff tears and their influences on post-operative rehabilitation from rotator cuff repair surgery.

Level of Evidence: Level 5

Key words: Apoptosis, matrix metalloproteinases, post-operative rehabilitation, shoulder
INTRODUCTION
The power of genetics has already greatly altered the landscape in which medicine is practiced in many fields. An improved understanding of the influence of genetic variability among individuals is contributing to personalized medicine directed toward a patient's specific genetic profile. A specific example of these recent advancements is within pharmacogenomics where the ultimate goal is to design pharmaceuticals personalized to an individual's genetic make-up in order to improve outcomes and decrease risks. The utility of genetic information to personalize pharmacological interventions is logical, however, the impact of genetic information on the delivery of physical therapy services is a bit more challenging to conceptualize.

Improving the awareness of how the cellular and molecular processes influence tissue homeostasis can enhance a clinician's ability to deliver optimal care through the appropriate therapeutic intervention. The concept of how genetic information will influence the delivery of physical therapy interventions was highlighted in a review article within the December 2009 issue of PT in Motion Magazine. This review article summarized the opinions of several physical therapists regarding the impact of genetics on the field of physical therapy, and the necessity to expand the education of physical therapists to understand the implications of genetics for optimal patient care. These earlier predictions on the impact of genetics within the field of physical therapy seemed very futuristic, but more recent advances in both genetics and physical therapy are now making this relationship more of a reality than a theoretical dream.

The importance of genetic information and its influence on clinical decision-making for physical therapists was recently highlighted in a two part series on regenerative rehabilitation and genomics in Physical Therapy Journal in 2016. Norland et al, stressed the importance of staying abreast with medical advances, beginning with the initial coursework of graduate physical therapy programs. More importantly, their survey revealed that many academic programs have yet to adequately incorporate new medical knowledge and technology regarding regenerative medicine into their respective doctor of physical therapy (DPT) curriculum. As physical therapy education has transitioned to a doctorate degree, a greater understanding of the basic science of genetics, and its subsequent influence on a person's response to medical interventions is required. This dearth of fundamental genetic education within many DPT curriculums was also highlighted by Goldberg. This position paper emphasized the necessity of a physical therapist to understand the influence of genetic factors in maintenance of health and development of disease. Furthermore, the relevance of regenerative rehabilitation topics on the future of physical therapy practice was rated as being strongly relevant by 71.3% of polled DPT students and 67.3% of DPT faculty. Indeed, the need for the physical therapy profession to further advance its understanding of fundamental genetics and its influence on the development of disease was elucidated in an editorial by Ambrosio and Kleim, who proclaimed the ‘Genomic Era’ is already impacting the practice of physical therapy.

Norland et al reported that it is likely many physical therapists are unaware of the influence of genetics on a patient's response to medical interventions. It is also likely that therapists may not recall the basic science behind genetics from the four-letter DNA code through translation to proteins that constitute the fundamental makeup of an individual. Curtis et al reviewed the basic science of genetics and its implications for physical therapists. Even the American Physical Therapy Association has embraced the genomic era by developing a webpage that provides information about the role of genetic technology within patient care. Certainly, providing a comprehensive review of the basic science of genetics and the overall influence on the field of physical therapy is beyond the scope of this manuscript. However, readers are encouraged to reference these two sources for an excellent overview of the basic concepts behind genetics.

The purpose of this literature review and clinical commentary is to educate sports physical therapists on the recent advances regarding how genetics influences rotator cuff pathology, including rotator cuff tears, and provide a perspective on how this information will likely influence post-operative shoulder rehabilitation in the near future. Moreover,
physical therapists are an integral part of the post-op recovery from a rotator cuff repair; therefore, it is important that physical therapists begin to understand how genetic variables can influence a patient's overall recovery.

**GENETIC INFLUENCES ON ROTATOR CUFF PATHOLOGY**

**Family History of Rotator Cuff Tears**
A complete understanding of the exact etiology of rotator cuff tears remains elusive, however, there are likely several factors, both genetic and environmental, contributing to these tears. It has previously been determined that there is an increased risk of rotator cuff pathology among first and second degree relatives. Harvey et al showed siblings of individuals diagnosed with a rotator cuff tear had more than twice the relative risk for developing a rotator cuff tear. This finding was also supported by Tashjian et al who reported relatives with similar genetic profiles are afflicted with rotator cuff tendinopathies at a higher rate. Interestingly, they also found spouses also display an increased prevalence of rotator cuff pathology, suggesting an 'environmental' factor may also be present, as an individual's spouse would have a dissimilar genetic profile, but likely engage in similar activities. The interplay of genetic predisposition and environmental factors appears to play a role in the development and progression of rotator cuff pathology. The exact genetic profile responsible for being more susceptible to a rotator cuff tear is not currently entirely understood, but researchers have discovered a collection of genes that contribute to rotator cuff pathology.

**Cellular Mechanisms Orchestrating Rotator Cuff Pathology**
The confined position of the supraspinatus tendon within the subacromial space makes this tendon especially susceptible to degenerative changes. Impingement of the tendon has been suggested to cause mechanical damage and failure of the tendon. As noted previously by authors of the hereditary studies, mechanical strain is not exclusively responsible for the high prevalence of rotator cuff tears. Recent studies on rotator cuff tendinopathy reveal the process of 'apoptosis' is regularly involved in tendon degeneration. Apoptosis is a highly regulated cellular process during which cellular contents are recycled and remodelled. Apoptosis is an integral aspect of cellular homeostasis and directly influences important cellular processes such as embryonic development. For example, apoptosis is responsible for the coordinated elimination of tissue between fingers during the development of a defined hand within a vertebrate limb. Apoptosis not only occurs during development, but throughout the lifespan in order to promote tissue remodeling and turnover. Repressed apoptosis can result in pathology such as cancer where cellular tissue continues to expand unregulated since the processes of apoptosis are unable to effectively prevent continued expansion of a tumor. Conversely, excessive apoptosis can result in premature degradation of tissue such as that which occurs during autoimmune diseases. By comparison, excessive apoptosis within the rotator cuff tendon can alter the balance of normal tissue turnover and promote increased soft tissue degradation leading to tissue tearing. Yuan et al has shown an increased prevalence of apoptotic tissue within the edges of torn supraspinatus tissue compared to the control subscapularis tendon. Consequently, the management of apoptosis is highly regulated at the cellular level and is dependent on a variety of cellular signals to ensure the proper balance of apoptosis for normal tissue homeostasis.

For example, the regulation of apoptosis is coordinated by cellular signaling proteins (such as cytochrome C) that are responsible for activating a family of protease enzymes called caspases (Figure 1). Caspases in turn promote the degradation of cellular contents during apoptosis. Individuals with a rotator cuff tear display increased expression of cytochrome C and caspase 3/7, 8 and 9 at not only the distal aspect of the tear, but also within regions more proximal to the tear. This expression response was not observed in control patients undergoing surgery for proximal humeral fractures. Millar et al also described that an increase in caspase expression was noted in both animal and human subjects with rotator cuff tears. They suggested that these cytokines may play a role in oxidative-stress induced apoptosis, however, the exact mechanisms and signaling that initiate the cascade toward apoptosis is not fully understood.
The poor blood supply to the distal supraspinatus tendon has long been established. As a consequence, it has been proposed that one possible mechanism of excessive apoptosis within the rotator cuff tendon may be due in part to poor vascularity, which may cause a hypoxia trigger creating a cascade of signals initiating apoptosis. For example, two proteins, Hypoxia Inducible Factor 1α (HIF1α) and Bcl-2 Nineteen kilodalton interacting protein (BNip3), have been shown to promote a pro-apoptotic response in cells (Figure 1). It has also been established that over-expression of HIF1α can cause a successive expression of BNip3. Thus it appears that HIF1α is an upstream regulator of BNip3 as part of a signaling cascade that elicits apoptosis within a hypoxic environment. Downstream of these signaling proteins are the previously mentioned cytochrome C and caspases, which further propagate the cellular signaling associated with apoptosis within rotator cuff tissue. (Figure 1) However, the connection between BNip3 and pro-apoptotic pathway via a cytochrome C and caspase dependent pathway is still controversial.

A study exploring the ‘hypoxia/cascade mechanism’ of apoptosis activation, investigated rotator cuff tissue from individuals experiencing various degrees of impingement, various stages of rotator cuff tears, and control individuals undergoing surgery for a shoulder stabilization procedure. Interestingly, Benson et al found that indeed a high level of expression of the protein, HIF1α, could be observed in the partial, small, medium, large, and massive rotator cuff tears. Also, a concomitant increase in expression of the protein BNip3 in these tissues was seen, except for the massive tears, where BNip3 actually decreases. The reduction of BNip3 in the massive tears was hypothesized to be due to an adaptation of the remaining tenocytes into chondrocyte-like cells, which would tolerate the hypoxic environment better.
No increased expression was noted within the control subjects. Interestingly, Benson et al also saw a spike in expression of HIF1α in the mild impingement group without a subsequent increase in BNip3. This may be due to vascularity changes during the early stages of impingement and enough regulatory processes within the cell to inhibit the apoptotic pathway from progressing further. Consequently, this study supports the early initiation of conservative care such as physical therapy to help improve oxygen flow to the tissue and open the subacromial space through stretching of the pectoralis minor musculature and strengthening of the periscapular musculature.30,31 Early intervention of physical therapy may prevent the initiation of an 'aggressive apoptosis cascade' which could progress toward a full blown apoptotic response within the rotator cuff tissue.

Another component of apoptosis within the rotator cuff is the expression of proteins called matrix metalloproteinases (MMP). Once activated, these enzymes degrade all components of connective tissue.32 This enzymatic breakdown of connective tissue is an essential component to apoptosis, but is also deleterious to conservative care and post-operative healing of rotator cuff pathology.33 MMPs are a family of 23 proteins precisely regulated by endogenous inhibitors and induced by factors such as physical stress and cytokines.34,35 Therefore, the balance between suppression and induction of the MMPs can determine the overall level of degradation within the connective tissue extracellular matrix. Specifically regarding rotator cuff degeneration, multiple authors have described alterations in protein expression levels of MMP1, MMP2, and MMP3, with the majority of studies finding increased expression of MMP1 within torn supraspinatus tissue.36-38 Castagna et al found these increased enzyme levels not only in the region of the torn supraspinatus tissue, but also in intact portions of the medial supraspinatus and the subscapularis, which suggests a more global breakdown of tissue may be occurring.37 The global expression of MMPs within this study was suggested as a possible precursor for subsequent rotator cuff tearing. The exact role in which MMPs are regulated is not fully understood, but again oxidative stress is predicted to induce a signaling cascade.39 The contribution of MMPs in the degradation of rotator cuff tissue support the role of early intervention by physical therapist to promote an environment within the distal supraspinatus tendon to help prevent progression of this hypoxic induced apoptotic cascade.

**Individual Differences in Cellular Driven Apoptotic Rotator Cuff Degeneration**

With a more complete understanding of some of the cellular and molecular mechanisms contributing to rotator cuff pathology, the next question is whether there are unique differences within an individual's genetic makeup increasing propensity and/or risk for rotator cuff pathology. Genetic differences uniquely distinguish one individual from the next. The variability of these differences at the DNA level have been reported to be very small, approximately 0.1% between individuals.40,41 Although a small percentage, with the human genetic code being three billion letters long, these differences account for much of the variability among people. The variations in the genetic code between individuals are termed single nucleotide polymorphisms (SNPs).42,43 These SNPs can account for everything from a person's response to medication to their susceptibility to numerous medical conditions including, asthma, cancer and diabetes to name a few.44-48 Tashjian et al determined there are two SNPs in genes associated with apoptosis that may make an individual more susceptible to a rotator cuff tear.49 Their study involved genetic analysis of 311 subjects with a full thickness rotator cuff tear. Those with a partial thickness tear were excluded from the study. The subjects were compared to a control database of 3293 individuals. The results showed a statistically significant association of SNPs within the genes of SAP30BP and SASH1, both of which are associated with the apoptotic process. The authors concluded that alterations within these genes might promote increased protein activity, thus leading to a higher tendency of tissue breakdown and subsequent rotator cuff tears in individuals with these SNPs.

In summary, the cellular and molecular mechanisms involved with rotator cuff tears are both highly regulated and complex. Researchers are just beginning to understand the milieu of cellular signaling that induces apoptosis within the rotator cuff tissue contributing to an intrinsically driven process that promotes both the initiation and subsequent propa-
This understanding now has the potential to help implement specific interventions to prevent the initiation of a rotator cuff tear and also help advance treatment strategies to optimize post-operative outcomes.

GENETIC INFLUENCES ON POST-OPERATIVE ROTATOR CUFF REPAIR

A recent commentary by Dr. Theodore Blaine states: "the molecular therapeutics and targeted gene therapies are the new frontier in treatment of rotator cuff disease". Several recent studies have investigated how the cellular processes regarding the intrinsic formation of rotator cuff tears can also influence the post-operative outcome of surgically repaired rotator cuff tissue.

Tashjian et al recently identified a SNP within the estrogen-related receptor beta (ESRRB) gene that appears to promote increased susceptibility to re-tears after a rotator cuff repair. SNPs within ESRRB have previously been shown to correlate with increased prevalence of rotator cuff tearing. Indeed, the ESRRB protein is believed to promote increased HIF activity through an upregulation of HIF transcription. As noted previously, HIF activity is associated with the process of apoptosis. The Tashjian et al study examined 72 patients undergoing an arthroscopic repair of a full thickness rotator cuff tear. They then completed MRI analysis at least one year post-operatively and detected a 42% re-tear rate. The patients with a re-tear were found to display a statistically significant increased prevalence of a SNP within the ESRRB gene compared to patients that did not re-tear. Additionally, they did not find any difference in age, supraspinatus muscle quality, or single versus double row repair type in tears that healed or re-tore. This finding indicates that the genetic profile, i.e. presence or absence of the SNP within the ESRRB gene, may be a better predictor of future rotator cuff post-operative re-tearing than some of the traditional factors such as muscle quality or age.

The negative implications of increased MMP protein expression on the integrity of rotator cuff tissue has been established. For example, Gotoh et al investigated the presence of MMP gene expression during rotator cuff repairs by harvesting a marginal section of the torn tendon and analyzing expression activity of various MMPs and MMP inhibitors. Twenty-four patients were included in the study and repeat imaging was completed at greater than one year post-op and revealed that six patients experienced a re-tear. Within the patients with a re-tear they found a statistically significant increase in MMP3 gene expression compared to individuals within the study that did not experience a re-tear. One limitation to this study was that they were measuring gene expression and not actual protein activity. Another limitation noted is the patients that experienced re-tear also demonstrated an increased duration of time from injury to surgical intervention compared to the group that did not display a re-tear. This finding emphasizes a potential urgency of surgical intervention following the initial injury. Furthermore, if there is such a delay, then it seems as if the expression of MMP3 may need to be monitored to help predict patients that may re-tear.

Robertson et al examined 30 patients with a supraspinatus tear in a similar study, with the tear being classified as full thickness or high-grade partial-thickness (>80% torn), and massive tears were excluded. At the time of surgery, a tissue sample of the torn supraspinatus was harvested along with a sample of the subscapularis to be used as a control. Several genes involved in inflammation and tendon degradation were then analyzed for expression levels in the harvested tissues. At greater than six months post-op, ultrasound was used to detect any re-tears and seven patients were found to have re-tears. Within this study, they found an increase in MMP1 and MMP9 gene expression within the patients that re-tore, compared to the group that displayed good healing. Unlike the Gotoh et al study, no difference in duration of symptoms was noted between the defect group and the healed group. Interestingly, they also found increased MMP9 gene expression within the healthy subscapularis tendon of the re-tear group which was not found in the healed group. MMP3 gene expression was not examined within this study.

From these three studies, it can be concluded that it may be possible to predict which patients will respond well to rotator cuff repairs and which patients will face an increased risk of re-tear based
on genetic profiles and from tissue samples. This information has led several researchers to investigate if exogenous inhibitors of MMPs applied during tendon repairs in an animal model could improve repair strength. One study utilized the MMP inhibitor, α-2-macroglobulin protein, and applied this protein to the tendon-bone interface during a rotator cuff repair in rats. Increased collagen organization and reduction in collagen degradation was noted at two and four-weeks compared to the control group where this inhibitor was not utilized. The antibiotic doxycycline is another inhibitor of MMPs and an animal study by Pasternak et al found that rat Achilles tendons repaired with doxycycline coated sutures resulted in improved suture-holding capacity compared to a control group with uncoated sutures. Furthermore, rats who underwent a detachment and immediate repair of the supraspinatus displayed improved healing enthesis when started on oral doxycycline preoperatively or at post-operative day five compared to control animals where doxycycline was not administered. This study also found a reduction of MMP13 protein activity at post-operative day eight in the doxycycline treated rats compared to controls, suggesting that inhibition of this MMP promoted aspects of improved rotator cuff healing. At this time MMP inhibitors have not been investigated in human subjects for surgical repair of the rotator cuff.

Ling et al took an alternative approach by not examining the expression level of the MMP3 gene, but rather investigated the presences of SNPs within the MMP3 gene and also interleukin 6 (IL-6) gene. IL-6 is an inflammatory cytokine, which has been associated with the presence of subacromial bursitis. In contrast to previous studies, they focused on the influence of SNPs within these two genes on post-operative stiffness rather than the rate of post-operative re-tearing. Ling et al examined 188 patients undergoing a mini-open rotator cuff repair and found the presence of SNPs within both IL-6 and MMP3 genes that significantly correlated with increased post-operative stiffness. These SNPs may result in different isoforms of the MMP3 protein, where a structurally similar protein from the same gene may display slightly different functions between people based on the SNP that is present. The authors suggest the presence of these SNPs in a post-operative patient may justify a more aggressive post-operative rehabilitation approach to help prevent excessive post-operative stiffness. This study contrasts previous reports that indicate excessive expression of the MMP3 gene may result in an increased presence of re-tear rates in individuals having a rotator cuff repair. Therefore, one can conclude from this study that not only the expression level, but also the unique isoform of the MMP protein may need to be examined to determine if a patient can be categorized into an increased risk of re-tear or post-operative stiffness susceptible group. The SNP within the MMP3 gene of this recent study may have influenced the activity of the MMP3 protein, thus preventing normal collagen remodeling, resulting in excessive collagen deposition and subsequent stiffness. The role of this SNP on MMP3 protein function was not explored within this study, therefore, the cause of the increased tightness within patients displaying this SNP remains hypothetical. Ling et al highlight how further research is required to more fully elucidate how the complex interplay between these numerous proteins can influence a patient’s post-operative recovery and return to a high level of function.

**CLINICAL REHABILITATION IMPLICATIONS**

It is not understood whether changing the biological environment by improving vascularity or alleviating mechanical stress has any effect on the apoptotic cascade once it is initiated. However, the authors argue in favor of utilizing physical therapy interventions to address impairments contributing to rotator cuff impingement. This includes, but is not limited to: thoracic mobilizations, capsular stretching/mobilizations of the shoulder girdle joints, scapular stabilization exercises, and rotator cuff strengthening.

Kokmeyer et al outlined several rotator cuff repair prognostic indicators and recommended post-operative protocols based on several key factors, however the inclusion of genetic factors was not considered with these initial recommendations. The future of sports medicine is to consider these genetic factors when choosing a rehabilitation protocol (Table 1). It is not known if altering a rotator cuff repair protocol based on genetic factors will ultimately improve surgical outcomes, but we advocate that it is reasonable to modify the rehabilitation progression in light of the patient’s unique genetic presentation (Table 2). Complications following arthroscopic rotator cuff repair are common. One of the most common complications
is post-operative stiffness. Huberty et al outlined several risk factors for developing post-operative stiffness (Table 3). The presence of SNPs within MMP3 and IL-6 genes could be added to this list of risk factors. Meijden et al presented evidence-based guidelines for rehabilitation following arthroscopic rotator cuff repair. The “moderate” rehabilitation protocol is designed for the young patient with good tissue quality or a small tear. The moderate protocol calls for PROM to begin immediately without restrictions. Koo et al presented a modified accelerated rehabilitation program beginning with active assisted table slides immediately. They stated that this modification helped to keep the rate of stiffness low (<1%) in the high-risk group of patients. Uhl et al showed the prayer stretch position used to regain forward elevation ROM has minimal supraspinatus and infraspinatus activation, with only 2-10% maximum voluntary isometric contraction (MVIC). Adding table slides and/prayer stretch immediately in the group with high risk of developing post-operative stiffness, including those with SNPs within the MMP3 and IL-6 genes, is recommended by the authors of this clinical commentary to avoid this complication.

Another common complication of arthroscopic rotator cuff repair is re-tear of the repaired tendons. Galatz et al report re-tear rates as high as 94%. Thomazeau et al state that, in the presence of rotator cuff atrophy, recurrent rotator cuff tears occur

| Table 1. Rotator Cuff Repair Rehabilitation Protocols Classified by Prognostic Factors |
|----------------------------------------|--------|--------|--------|
| Moderate | Intermediate | Conservative |
| Age | < 50 | 50-60 | >60 |
| Bone Mass Density | > -1 | -2.4 to -1 (osteopenia) | < -2.5 (osteoporosis) |
| Fatty Infiltrate, Atrophy | Stage 0 | Stage 0-1 | Stage 1-2 |
| Diabetes Mellitus | + | + | - |
| Body Mass Index | <25 | 25-30 | >30 |
| Smoker | - | - | + |
| Tear Size | Partial Thickness - Small | Small - Medium | Large - Massive |
| Retraction | None | In-between | >Glenoid |
| Tissue Quality | Good | Fair | Poor |
| Pre-Op Strength | Good | Fair | Poor |
| SNPs in IL-6 and/or MMP3 | Present | Absent | Absent |
| SNPs in SAP30BP, SASH1 and/or ESRRB | Absent | Absent | Present |
| Increased expression of MMP 1, 3, 9 | Absent | Absent | Present |

Adapted from Kokkneyer's Prognostic Spectrum.

SNP = single nucleotide polymorphism; MMP = matrix metalloproteinase; IL-6 = interleukin 6 gene; SAP30BP = 30kDa Sin3-associated binding protein gene; SASH1 = sterile alpha motif and sarcoma homologous 3 domain-containing protein 1 gene; ESRRB = estrogen-related receptor beta gene

| Table 2. Rotator Cuff Repair Prognosis-Based Rehabilitation Protocols |
|----------------------------------------|--------|--------|--------|
| Moderate | Intermediate | Conservative |
| Sling | 0-2 weeks | 4-6 weeks | 6+ weeks |
| PROM | Begin immediately Full PROM | Begin 0-4 weeks 30 ER, 90 Abd, 120 FE Full PROM 4-6 weeks | Begin 4-6 weeks 30 ER, 90 Abd, 120 FE Full PROM 6-8 weeks |
| AAROM | 0-2 weeks | 4 weeks | 6 weeks |
| AROM | 0-2 weeks | 4-6 weeks | 6-8 weeks |
| Strengthening | 4-6 weeks | 8-10 weeks | 10-12 weeks |

Adapted from Kokkneyer’s Prognosis-based Rehabilitation.
PROM = passive range of motion; AAROM = active assistive range of motion; AROM = active range of motion; ER = external rotation; Abd = abduction; FE = forward elevation
in 25% of patients. Koo et al report those with a large tear (>5cm) or involving more than two tendons also have an elevated risk of re-tear. Patients with increased MMP gene expression are at a higher risk for recurrent tear of the repaired rotator cuff. Mejden et al outline a conservative protocol for the older patient with poor tissue quality or large tears. Their protocol outlines the patient wears a sling for six to seven weeks with PROM beginning at week three. PROM in the conservative protocol is restricted to 120 degrees of flexion, 30 degrees of external rotation, internal rotation to the belly and 90 degrees of abduction until week five. AROM is delayed until week six to seven in the conservative protocol. There are several genetic risk factors for recurrent tear following a rotator cuff repair (Table 4). When a dysfunctional apoptotic cascade is present, such as increased expression of MMP1, 3, 9 genes or the presence of SNPs within SAP30BP, SASH1 or ESRRB genes, the authors of this commentary recommend following the conservative protocol. Dockery et al investigated seven passive shoulder motion modes and found CPM, Codman’s and therapist-assisted PROM, generated the lowest percentage of MVIC of rotator cuff activity. Therefore, such exercises or mobility interventions are recommended for the PROM stage. At six weeks post-surgery AAROM should begin progressing slowly to AROM. This progression should account for progressive increases in rotator cuff activation. Wise et al demonstrated vertical wall slides have relatively low rotator cuff activation (8-13%) whereas unsupported vertical slides increases cuff activation (10-17%). Therefore, considering not only the rate of exercise progression, but the selection of exercise within the post-operative rehabilitation process, is vital to help prevent re-tearing in patients that may be susceptible to re-tearing due to their specific genetic profile.

**CONCLUSION**

The techniques used to repair torn rotator cuff tendons has evolved immensely since Karl Hüter performed the first rotator cuff repair in 1870. The innovation of utilizing arthroscopic techniques on the shoulder in the 1980s was a major breakthrough in the advancement in addressing shoulder pathology and more specifically rotator cuff tears. The next such innovation appears to be within the realm of utilization of genomic information to improve outcomes.

One concern about utilization of genetic information is the potential increased cost associated with analyzing a patient’s genetic profile and gene expression levels during rotator cuff repair surgery. With exploding healthcare costs, this is a very real concern. However, as the understanding of the cellular processes associated with rotator cuff tears has advanced, so has the technology associated with sequencing DNA samples. Recent advances have reduced the cost of sequencing a million base pairs of DNA from thousands of dollars to mere cents. Genomic sequencing has become such commonplace that individuals now have the liberty of examining part of their genetic profile at home through kits available from various websites for a moderate fee. If individuals are willing to pay for genetic information from these sites out of curiosity, they would also likely be willing to accept extra expenses associated with this analysis during a rotator cuff

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**Table 3.** *Post-Operative Stiffness Risk Factors*

<table>
<thead>
<tr>
<th>Risk Factors</th>
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<tbody>
<tr>
<td>Small tear size / single tendon repair</td>
</tr>
<tr>
<td>Worker's compensation</td>
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<tr>
<td>Age &lt;50</td>
</tr>
<tr>
<td>PASTA lesion repair</td>
</tr>
<tr>
<td>Possible genetic risk factors:</td>
</tr>
<tr>
<td>Presence of SNP within IL-6</td>
</tr>
<tr>
<td>Presence of SNP within MMP3</td>
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**Table 4.** *Possible Post-Operative Re-Tear Genetic Risk Factors*

**Increased expression of the following MMPs:**

- MMP1
- MMP3
- MMP9

**Presence of SNPs in apoptotic genes:**

- SAP30BP
- SASH1
- ESRRB

**Possible prophylactic interventions:**

- α-2-macroglubulin protein
- Doxycycline (oral or coated sutures)

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MMP=matrix metalloproteinase; SNP=single nucleotide polymorphism; SAP30BP=30kDa Sm3-associated binding protein gene; SASH1=sterile alpha motif and sarcoma homologous 3 domain-containing protein 1 gene; ESRRB=estrogen-related receptor beta gene
ready to embrace a new framework for understanding not only the structural aspects of a rotator cuff repair, but also the cellular mechanisms that facilitate a successful surgical outcome. Adopting this knowledge into routine patient care may optimize post-operative outcomes and help substantially reduce post-operative re-tear rates.

REFERENCES


ABSTRACT
Sports-related concussions are receiving growing attention in healthcare. Most concussions resolve spontaneously with little or no treatment, but twenty percent of concussions take longer than three weeks to resolve. In some cases, symptoms can last for five years following a traumatic brain injury. Physical Therapists have unique skills that can assist patients experiencing protracted recovery.

The purpose of this clinical commentary is to describe a new conceptual model that provides a framework for Physical Therapy management of patients with protracted recovery following a sports-related concussion. The end product is a visual diagram that represents the full scope of clinical practice that Physical Therapy can provide to an athlete following a concussion.

Level of Evidence: 5

Key Words: Conceptual Model, Post-Concussion Management, Sports
INTRODUCTION

Background
A concussion is a mild traumatic brain injury caused by a direct or indirect biomechanical force to the brain.1 This initial injury is followed by a secondary insult on the brain due to a metabolic cascade that places increased energy demands on the brain.2,3 Each year 1.6 to 3.8 million sports-related concussions occur in the United States.4 Eighty percent of concussions have been observed to recover within 7-10 days.1 Twenty percent of the sports-related concussions take longer than three weeks to resolve.5,6 Symptoms such as headaches (54%), dizziness (37%), and anxiety (63%) may persist for five years after a head injury, regardless of the severity of the injury.7

Predictors for having a protracted recovery include: loss of consciousness,8 post-traumatic amnesia and retrograde amnesia,8 and elevated symptom scores early after concussion.8,9 Females have been shown to have increased risk of longer recovery compared to their male counterparts in the same sports.8-11 Those with a prior history of migraine and those with post-traumatic migraines are slower to recover.9,12 In collegiate football players, a statistically significant association exists between history of multiple concussions and a longer recovery time.13 High school athletes took longer to recover from neurocognitive deficits than collegiate athletes following a concussion.14

THE ROLE OF PHYSICAL THERAPY
Those who have protracted recovery can experience symptoms, impairments and functional losses that can be managed by Physical Therapists. These include headaches, dizziness, neck pain, fatigue, balance disturbances, oculomotor changes, and decreased coordination.15,16 Physical Therapists are part of the multidisciplinary team that has the ability to manage patients with vestibular rehabilitation, spine rehabilitation and controlled activity progression.15-20

Vestibular-Ocular Rehabilitation
The forces that cause a concussion can disrupt the neurons that run along the vestibulospinal tracts, control the vestibular-ocular reflex, and link central vestibular pathways.21,22 The peripheral vestibular receptors can also be injured during a concussion.21,23 Physical Therapists can provide treatment for balance dysfunctions, gaze stabilization activities, vestibular habituation activities, and canolith repositioning.24-26 In the same way, oculomotor control can be compromised through axonal injury or blunt trauma to the visual control systems.27-32 Physical Therapists can provide treatments that are directed towards addressing impairments in ocular motor control such as convergence,33-37 smooth pursuits,38-43 saccades,41-45 and ocular fixation.42-44

Cervical Rehabilitation
Dysfunctions of the neck, particularly the upper cervical spine, can be responsible for producing neck pain and headaches,46-50 dizziness,51-53 oculomotor disturbances,50,53-56 and postural dysfunctions.53,57-59 There are multiple isolated impairments that can potentially exist in the cervical spine following a concussion. Each of these impairments can be responsible for producing one or more of the symptoms noted above.

Physical Therapists can refine their cervical-based care into three broader components of treatment that address:

- Cervical mobility dysfunctions
- Neuromuscular control
- Strengthening

Cervical Mobility Dysfunctions
The first component to address is cervical mobility, which can be influenced by intra and extra articular factors. Although all segments of the cervical spine should be considered, the mobility of C1/C2 should be of particular importance. This area of the upper cervical spine can produce pain, loss of rotational mobility, headaches, and alter postural control.46,51,52,60 Manual Therapy has been shown to have positive benefits for treatment of hypomobile segments in the cervical and thoracic spine for individuals following a concussion and whiplash associated disorders.50,51,61,62 Since the thoracic spine can influence the cervical spine, it should also be considered with evaluation and treatment of the cervical spine.63
Neuromuscular Control
The rapid acceleration/deceleration of the head can result in trauma to the mechanoreceptors in the cervical spine. The deep cervical flexor muscles are richly innervated with muscle spindles that provide proprioceptive and kinesthetic feedback. Altered proprioceptive input in the neck can result in altered perceived head position. Higher rates of joint position error are noted in subjects with chronic whiplash-associated disorder compared to controls without cervical injury. This is consistent with altered proprioceptive function observed after injuries in other areas of the body.

Treatment for neuromuscular control needs to include activities that involve the ability to coordinate muscle contraction in order to maintain a cervical posture. Cranio cervical flexion (CCF) with pressure biofeedback is a low load exercise approach that helps refine the individual's ability to grade muscle activity of the deep neck flexors (longus capitus and longus colli), while inhibiting the sternocleidomastoid and anterior scalene muscles. A randomized controlled trial by Jull, found this training technique helpful in treating cervicogenic headaches.

Joint reposition sense is another component for normal cervical function. A head mounted laser and a target can be used to track relocation accuracy after active horizontal head movements. In individuals with chronic neck pain, improvements in cervical kinesthesia (head reposition accuracy) was associated with decreased neck pain, improved cervical range of motion, and improved self-reported functional improvement.

Good postural alignment helps improve muscular function by maximizing length tension relationships. Suboccipital and anterior chest wall tightness should be addressed with stretching to help facilitate improved cervical spine posture. Addressing body mechanics and posture during school, activities of daily living and work can reduce strain on the spine that can lead to headaches and neck pain.

Strengthening
The final component of overall cervical treatment is strengthening the cervical and periscapular muscles. The Deep Neck Flexor Endurance (DNFE) Test is a way to measure the strength of the neck stabilizers. Hold time durations for the DNFE test were statistically and clinically significantly different between individuals without and with neck pain. Mean time for those without neck pain was 39 seconds. Normative times for asymptomatic men and women have be documented (Men = 39 seconds, Women = 29 seconds). It is reasonable to use these outcomes as goals for muscle strength during the late phase of deficit management or early return to sports phase of recovery.

Smaller mean neck circumference, smaller mean neck to head ratio and weaker mean overall neck strength were significantly associated with concussion. Collins reported for each one pound increase in neck strength, there was a 5% reduction in the risk of concussion. A program of general muscular strengthening for the neck and periscapular muscles should be considered during late phase rehabilitation.

Exertional Activity Progression
There are three strategies for Physical Therapists to organize exertional aerobic activities:

- Light to moderate aerobic exercise
- Controlled graded aerobic exercise
- Exercise as an Adjunct to Managing Anxiety, Depression, and Sleep Disturbances

Light to Moderate Aerobic Exercise
Gagnon noted that children and adolescents who participated in light aerobic exercise had improved post-concussion outcomes compared to those who did not. Their patients exercised at 50-60% of their predicted max heart rate (220-age). Reed also found similar improvements with light aerobic activity in youth athletes done at the same intensities. In college athletes, mild to moderate activity was found to be a safe adjunct to care.

Graded Aerobic Exercise
Some athletes may experience exercise intolerance following a concussion that has not resolved within 7-10 days. These athletes may be experiencing dysfunctions in their autoregulatory control of heart
rate responses attributed to imbalances in sympathetic/parasympathetic activity. Leddy initially proposed a system of subsymptom threshold exercise that was based on the Balke Protocol. Exercise for individuals with post-concussion syndrome was prescribed at 80% of the heart rate at which concussion symptoms were provoked during exercise testing. Interrater reliability for performing the Balke protocol was found to be high in a follow up study. Leddy refined the testing procedures by modifying the protocol treadmill speed, and incorporating thresholds for changes in symptoms and rate of perceived exertion (RPE). This new protocol is known as the Buffalo Concussion Treadmill Test and is recommended for patients with noted exercise or autonomic sensitivity.

Exercise as an Adjunct to Managing Anxiety, Depression, and Sleep Disturbances
Following a concussion an athlete is at risk of secondary conditions such as anxiety, depression, and sleep disturbances. A Cochrane Review on exercise and depression for adults 18 years and older, reported a small effect over control interventions in reducing depression symptoms. It was also shown to be no more effective than standard psychological or pharmacological treatments. The Cochrane Review reported that exercise was a good adjunct to treating depression due to its associated benefits and having very few associated negative side effects.

Another Cochrane Review examined the effect of exercise on treating anxiety and depression in children, adolescents and young adults no older than 20 years old. Again, a small effect was noted in the ability of exercise to lessen anxiety and depression in this population. This benefit was maintained regardless of whether the exercise was performed at low or high intensity levels. Exercise therapy has a place in mitigating the effect of depression due to withdrawal from normal daily activities, and as an adjunct to typical medical care in those patients that are experiencing clinical anxiety and depression.

Sleep can often be disrupted in the post-concussion populations. The Clinical Practice Guidelines for Concussion/Mild Traumatic Brain Injury and Persistent Symptoms recommends considering exercise as part of sleep management.

Addressing Challenges Facing Physical Therapists
A concussion is a functional disturbance to the brain without observable structural injury. The lack of a pathoanatomical model, the multitude of non-specific symptoms, and the potential for confounding influence from co-morbidities is a challenge for Physical Therapists in developing appropriate treatment plans.

Conceptual models can be used to organize physical and abstract information. This can assist the clinician to synthesize complex clinical information into meaningful groups or patterns. Well-developed models can allow the user to visualize complex relationships into simple and discrete visual forms. The initial concepts for a conceptual model for the Physical Therapy management of protracted recovery were proposed by the author. These concepts were refined and expanded as part of this commentary.

Purpose
The purpose of this clinical commentary is to describe a new conceptual model that provides a framework for Physical Therapy management of patients with protracted recovery following a sports-related concussion.

CONCEPTUAL MODEL
This conceptual model is for post-concussion patients that do not recover spontaneously within 7-10 days. This model is made up of four levels of treatment considerations. The levels of treatment consideration are: Recovery Time Line, Phases of Recovery, Progression of Treatment, and Physical Therapy Treatment Domains. (Figure 1)

Recovery Time Line
The Recovery Time Line is on the bottom of the model. It starts with the onset of the concussion and moves right with the passage of time. The time line ends with unrestricted return to sports. The time line does not provide any discrete time intervals, since the recovery time from a concussion can be variable.

Phases of Recovery
The next level of treatment above the Recovery Time Line is Phases of Recovery. There are three phases that run from left to right. The first phase is termed
the Protection Phase. It is represented by a red circle. The color strengthens the concept of protection and stresses preventing additional trauma and avoiding overtasking the neurometabolic recovery process. The second phase is represented by a yellow circle and is named the Deficit Management Phase. This phase is focused on addressing impairments, neuroplasticity, and normalizing full function. The last phase in this model is the Return to Sport Phase and is represented by a green circle. This phase represents progressive return to safe sporting activities. The Return to Sports Phase ends when the athlete safely returns to full and unrestricted sports participation. There is overlapping between the Deficit Management Phase and the two other phases, since there is no clear indication when one phase ends and the next starts.

**Progression of Treatment**

The third level of treatment consideration is termed Progression of Treatment. As time passes from the initial injury, there needs to be an evolving focus on the goals of treatment and the types of treatment activities emphasized. There are five treatment progressions that move from left to right, also using the red, yellow, green color coding.

Relative Rest is the initial treatment focus in the progression of care. Relative Rest is controlled
activity and “rest as needed”. Symptoms are closely monitored and patient clinical status is assessed to determine appropriate activities.\textsuperscript{101,105,106} The patient is educated regarding which activities should be avoided and which activities should be modified.\textsuperscript{107}

Symptom Management is the second treatment focus in the progression of care. There is a proactive shift towards managing potential symptom triggers.\textsuperscript{80-82,86,100-102,108} These triggers may arise from an underlying autonomic dysfunction from the concussion or developing deconditioning from reduced activity levels.\textsuperscript{83,86,109} Triggers can also exist from impairments to the cervical spine or vestibular system.\textsuperscript{20,110} Physical Therapy should focus on progressing activity level and function by mitigating existing barriers.\textsuperscript{6}

Neuropsychology is the third treatment focus in the progression of care. Treatment activities incorporated should stimulate neurological plasticity in order to maximize long term neurological recovery.\textsuperscript{98,99,111-114} Multi-sensory activities in situations that are purposeful and meaningful result in neuropsychology.\textsuperscript{111,113,115}

Complex Functional Activities is the fourth treatment focus in the progression of care. Treatment should emphasize maximizing full functional recovery.\textsuperscript{15,115} Full functional recovery rehabilitation would involve real-life functional movements, occurring in a variety of sensory environments, and incorporating dual task activities that would approximate normal daily function for the individual.\textsuperscript{116,117}

Guided Return to Sports is the last treatment progression of care. Sports-specific activities that are determined to be safe are emphasized. Each sport and position has a different relative risk to the athlete that must be considered when selecting appropriate activities.\textsuperscript{118-120} The individual’s prior history of concussions and baseline function must also be considered before the patient is released back to their sport without restrictions.\textsuperscript{5,121-123}

Physical Therapy Domains:
The Physical Therapy Domains are situated at the top of the conceptual model. They are the areas of Physical Therapist practice through which the clinician can directly impact the care of an athlete following a concussion. Previous discussion in this commentary supports their place within this model. Specific treatment activities selected for any domain are dependent on the residual deficits and the point of recovery on the time line.

There are three domains in which Physical Therapist can impact the residual deficits that remain during protracted recovery:

1. Vestibular-Ocular Rehab
2. Cervical Spine Rehab
3. Exertion Activity Progression

A Physical Therapist may encounter patients with multiple deficits that require multiple domains of care.\textsuperscript{124} If one type of treatment domain is outside the therapist’s knowledge base, they should consider collaborating with another therapist that is able to address the specific deficit that cannot be appropriately managed by a single therapist.

CONCLUSION
This conceptual model was developed from a thorough review of the literature to specifically describe the full scope of care that Physical Therapy can provide to patients recovering from a sports-related concussion. The conceptual model is made up of four levels of treatment consideration oriented vertically. Each level is dependent on the level of treatment consideration below it. The model progresses vertically, the levels become more specific to the role of Physical Therapy in the management of the recovering athlete. Horizontally, as the time line moves away from the onset of concussion, the model provides a pathway for progressing treatment.

This model can help an individual therapist organize their treatment plan, and improve their understanding of when they may need to collaborate. In addition, this model can be used by physicians and other healthcare professionals to recognize which deficits are best managed by Physical Therapy in order to make appropriate referrals. The end product of this commentary is a visual representation of Physical Therapy management of protracted recovery following a sports related concussion.

REFERENCES
Consensus statement on concussion in sport: The


ABSTRACT

The foundation of evidence-based practice lies in clinical research, which is based on the utilization of the scientific method. The scientific method requires that all details of the experiment be provided in publications to support replication of the study in order to evaluate and validate the results. More importantly, clinical research can only be translated into practice when researchers provide explicit details of the study. Too often, rehabilitation exercise intervention studies lack the appropriate detail to allow clinicians to replicate the exercise protocol in their patient populations. Therefore, the purpose of this clinical commentary is to provide guidelines for optimal reporting of therapeutic exercise interventions in rehabilitation research.

Level of Evidence: 5

Key words: Evidence-based practice, clinical research, exercise intervention reporting
INTRODUCTION
Scientific reporting requires adequate and detailed explanation of research methodology for both study replication (reliability) and quality (validity). Rehabilitation research that explores or reports on therapeutic exercise intervention protocols often lacks a detailed description of the interventions used. In contrast, basic science research publications tend to have more precise reporting and highly detailed methodological descriptions, typically conducted within a well-controlled environment. Surprisingly, many authors of rehabilitation research lack the detail to adequately describe the exercise intervention for replication in their research methods, sometimes only using generic terms such as “stretching and strengthening” to describe their intervention. This lack of detail in intervention reporting contributes to a “worldwide waste in research funding”.

STANDARD REPORTING GUIDELINES
Reporting guidelines have been recommended by scientific journals in order for authors to include the necessary details of all facets of a study. The EQUATOR Network (Enhancing the Quality and Transparency of Health Research; www.equator-network.org) promotes these guidelines in order to improve accuracy and completeness of reporting, which aids in research quality and repeatability. As of January 1 2015, 28 rehabilitation journals have agreed to require authors to use several specific guidelines to report research methods and findings. Of note, The International Journal of Sports Physical Therapy (IJSPPT) requires authors to use checklists from established reporting guidelines based on their study design such as “CONSORT” for randomized controlled trials (RCT) or “STROBE” for cohort studies (Table 1). These guidelines often include “checklists” for authors to use to ensure that several key items are addressed, unique to publication type. Requiring checklist review as part of journal submission improves the numbers of items reported in articles, thereby providing more study details and completeness of reporting.

INTERVENTION GUIDELINES
While standard reporting guidelines focus on making sure that specific components of specific study designs are included, these guidelines often provide minimal reporting requirements for the intervention component. For example, CONSORT lists “interventions” as one of 22 items to address, asking authors to provide “precise details of the intervention intended for each group and how and when they were actually administered.” Furthermore, a lack of detailed intervention limits the evaluation and interpretation of systematic reviews and meta-analyses, as well as the replication of research methods. Therefore, the purpose of this clinical commentary is to describe guidelines for optimal reporting of therapeutic exercise interventions in rehabilitation research.

<table>
<thead>
<tr>
<th>Table 1. Current Reporting Requirements from IJSPT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Original Research</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Systematic Review/Meta Analysis</strong></td>
</tr>
<tr>
<td><strong>Clinical Commentary/Current Concepts</strong></td>
</tr>
<tr>
<td><strong>Case Reports</strong></td>
</tr>
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</tbody>
</table>
True implementation of evidence-based practice requires clinicians to be able to replicate the research methods of a study with their own clinical population. For example, if a clinical trial demonstrates a clinically important outcome in a relevant population for a clinician, the same intervention would need to be applied in that clinician's setting in order to determine whether similar results can be achieved in a different clinical population. Perhaps Hoffman et al. stated it best: “Without a complete published description of the intervention, clinicians and patients cannot reliably implement interventions that are shown to be useful, and other researchers cannot replicate our build on research findings”.

Detailed descriptions of therapeutic exercise interventions are also important for researchers performing systematic reviews and meta-analyses. Insufficient detail in the description of interventions does not allow researchers to combine results of multiple studies into a meta-analysis due to potential lack of homogeneity. In their systematic review on post-operative rehabilitation after meniscectomy, Reid et al. noted, "The lack of detail in conjunction with the types of intervention provided meant that quantitative analysis was unable to be performed. Similarly, a qualitative comparison across the programmes was challenging." Poor description of the utilized interventions ultimately limits the usefulness of such reviews. For example, Crossley et al in their review of patellofemoral pain interventions noted, “the lack of detailed description of the exercise therapy interventions limits the translation of the research findings into clinical practice.”

Case report research often suffers from lack of clarity in reporting of interventions, especially on first submission for publication. Lack of detail regarding intervention makes peer review of case report research difficult and ultimately inhibits creative sharing of ideas for practice. The authors of this commentary believe that it is imperative that case report research describing innovative or combination interventions provide abundant clarity and detail regarding the interventions that were used so that such research can be analyzed for implementation in practice and inform the design of future research.

Hoffman and colleagues found that only 39% of non-pharmacological interventions (including surgery, rehabilitation, etc.) were adequately described. Interestingly, pharmaceutical interventions have better intervention reporting than non-pharmacological interventions (67% vs. 29%, respectively) such as education and surgery. Furthermore, Schroter et al. reported that a majority (57%) of interventions in clinical trials could not be replicated or clinically implemented based on the authors' description of the treatment. As rehabilitation scientists and researchers, we must improve the quality of reporting. The IJSPT is committed to leading this initiative and supporting “new” guidelines for standardized reporting of therapeutic exercise interventions.

PHYSICAL THERAPY INTERVENTION REPORTING GUIDELINES

Physical therapy interventions are often multimodal, complex, and individualized. They include modalities, manual therapy techniques, education, and therapeutic exercise. Unfortunately, only general descriptions of exercise interventions tend to be provided in research protocols, which allows for individuality and variability between clinicians and patients. However, such generality in description of interventions leads to a lack of detail available in a publication to allow for replication or implementation in a real-life clinical setting, thereby limiting translation into practice. Explicit reporting of therapeutic exercise interventions is important not only for researchers and clinicians, but also for journal reviewers who must assess the quality of articles in the peer-review process that occurs before consideration for publication. A lack of detail in intervention reporting may also be wasteful: the money and resources spent on performing the research would essentially be lost without effective clinical implementation. Most importantly, however, incorrect implementation of an intervention because of a lack of detail may actually cause harm to patients.

In physical therapy literature, Gianoloa et al. found that less than 20% of RCTs investigating lower back pain rehabilitation reported the necessary details to transfer research into practice. In a recent review of 200 physical therapy RCTs in the PEDro database, Yamato et al. found 77% of articles reported more than half of intervention description checklist items for the experimental groups, while only
25% reported more than half of the items for the control group. They noted the most common intervention description item missing from all 200 RCTs was modification of intervention during the trial, both for experimental and control groups. Yamato and colleagues further noted that physical therapy RCTs described interventions simply with the name of the developer (Pilates, McKenzie, etc), which is not an adequate explanation of the intervention. Obviously, physical therapists would not be able to replicate these interventions based on inadequate descriptions in the literature.

A particularly common practice is for authors to simply use exercise names unique to a clinic or exercise developer. Obviously, only using an exercise name without appropriate detail and description prevents replication or integration of the intervention protocol in clinic practice. This is particularly difficult for international audiences, who may not understand “jargon-laden” exercise names.

Until recently, there were no widely accepted guidelines for reporting interventions in the literature. In 2006, Toigo and Boutellier provided a list of important descriptors specific to resistance exercise training based on factors leading to distinct muscular adaptations (Table 2). These 13 factors are important to identify in both planning and reporting a resistance exercise intervention.

Schroter et al first provided a checklist of minimal details needed to assess the quality of descriptions of treatments (Table 3). The checklist items are based on how clear authors were in providing detail on the setting, recipient, provider, procedure, materials, intensity, schedule, and missing sessions.

The authors then reviewed 51 trials published in BMJ for checklist items. They found that over half of the articles did not include sufficient detail for clinicians or researchers to implement or replicate clinical research findings.

In 2014, the Template for Intervention Description and Replication (TIDieR) guidelines and checklist were established by extending from the minimal recommendation of CONSORT and SPIRIT in order to improve the “completeness of reporting, and ultimately the replicability, of interventions”.

### Table 2. Descriptors for resistance training interventions (modified from Toigo & Boutellier)

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load magnitude</td>
<td>75% IRM</td>
</tr>
<tr>
<td>Number of repetitions</td>
<td>6</td>
</tr>
<tr>
<td>Number of sets</td>
<td>1</td>
</tr>
<tr>
<td>Rest in-between sets (seconds or minutes)</td>
<td>None</td>
</tr>
<tr>
<td>Number of exercise interventions (per day or week)</td>
<td>2 per week</td>
</tr>
<tr>
<td>Duration of the experimental period (days or weeks)</td>
<td>10 weeks</td>
</tr>
<tr>
<td>Fractional and temporal distribution of the contraction modes per repetition and duration (seconds) of one repetition</td>
<td>10 s shortening 10 s isometric 4 s lengthening</td>
</tr>
<tr>
<td>Rest in-between repetitions (seconds or minutes)</td>
<td>None</td>
</tr>
<tr>
<td>Time under tension (seconds or minutes)</td>
<td>96 + 10 s</td>
</tr>
<tr>
<td>Volitional muscular failure</td>
<td>Yes</td>
</tr>
<tr>
<td>Range of motion</td>
<td>100%</td>
</tr>
<tr>
<td>Recovery time in-between exercise sessions (hours or days)</td>
<td>72 hr</td>
</tr>
<tr>
<td>Anatomical definition of the exercise</td>
<td>Yes, must be included</td>
</tr>
</tbody>
</table>

### Table 3. Interventions Checklist (modified from Schroter et al)

<table>
<thead>
<tr>
<th>Setting</th>
<th>Is it clear where the intervention was delivered?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recipient</td>
<td>Is it clear who is receiving the intervention?</td>
</tr>
<tr>
<td>Provider</td>
<td>Is it clear who delivered the intervention?</td>
</tr>
<tr>
<td>Procedure</td>
<td>Is the procedure (including the sequencing of the technique) of the intervention sufficient clear to allow replication?</td>
</tr>
<tr>
<td>Materials</td>
<td>Are the physical or informational materials used adequately described?</td>
</tr>
<tr>
<td>Intensity</td>
<td>Is the dose/duration of individual sessions of the intervention clear?</td>
</tr>
<tr>
<td>Schedule</td>
<td>Is the schedule (interval, frequency, duration, or timing) of the intervention clear?</td>
</tr>
<tr>
<td>Missing</td>
<td>Is there anything else missing from the description of the intervention? If yes, what?</td>
</tr>
</tbody>
</table>
TIDieR has been recommended specifically for physical therapy intervention studies. The Journal of Orthopaedic and Sports Physical Therapy endorses the TIDierR checklist, and includes it in the editorial policy. Alvarez et al recommended the use of TIDier in manual therapy publications. Delahunt et al authored reporting guidelines specifically for groin pain in athletes, endorsing and recommending the TIDier with CONSORT and STROBE guidelines for RCTs and observational studies, respectively. Physical therapists provide a broad range of interventions, including manual therapy, modalities, and therapeutic exercise prescription. While physical therapy-related journals recognize the importance of requiring several forms of guidelines to encourage authors to provide detail, none are specific to detail related to therapeutic exercise intervention.

<table>
<thead>
<tr>
<th>Item</th>
<th>Item Number</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brief Name</td>
<td>1</td>
<td>Provide the name or a phrase that describes the intervention</td>
</tr>
<tr>
<td>Why</td>
<td>2</td>
<td>Describe any rationale, theory, or goal of the elements essential to the intervention</td>
</tr>
<tr>
<td>What</td>
<td>3</td>
<td>Materials: Describe any physical or informational materials used in the intervention, including those provided to participants or used in intervention delivery or in training of intervention providers. Provide information on where the materials can be accessed (such as online appendix, URL)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Procedures: Describe each of the procedures, activities, and/or processes used in the intervention, including any enabling or support activities</td>
</tr>
<tr>
<td>Who provided</td>
<td>5</td>
<td>For each category of intervention provider (such as psychologist, nursing assistant), describe their expertise, background, and any specific training given</td>
</tr>
<tr>
<td>How</td>
<td>6</td>
<td>Describe the modes of delivery (such as face to face or by some other mechanism, such as internet or telephone) of the intervention and whether it was provided individually or in a group</td>
</tr>
<tr>
<td>Where</td>
<td>7</td>
<td>Describe the type(s) of location(s) where the intervention occurred, including any necessary infrastructure or relevant</td>
</tr>
<tr>
<td>When and how much</td>
<td>8</td>
<td>Describe the number of times the intervention was delivered and over what period of time including the number of sessions, their schedule, and their duration, intensity, or dose</td>
</tr>
<tr>
<td>Tailoring</td>
<td>9</td>
<td>If the intervention was planned to be personalised, titrated or adapted, then describe what, why, when, and how</td>
</tr>
<tr>
<td>Modifications</td>
<td>10</td>
<td>If the intervention was modified during the course of the study, describe the changes (what, why, when, and how)</td>
</tr>
<tr>
<td>How Well</td>
<td>11</td>
<td>Planned: If intervention adherence or fidelity was assessed, describe how and by whom, and if any strategies were used to maintain or improve fidelity, describe them</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Actual: If intervention adherence or fidelity was assessed, describe the extent to which the intervention was delivered as planned</td>
</tr>
</tbody>
</table>
EXERCISE INTERVENTION GUIDELINES

It is important to note that TIDieR is not specific to exercise interventions, making it globally applicable for any clinical intervention study. The general recommendations of TIDieR are not adequate to provide all necessary details of an exercise intervention; therefore, an international panel of exercise experts published recommendations in Physical Therapy for researchers reporting on exercise interventions in. The Consensus on Exercise Reporting Template (CERT) was also developed and published following Delphi survey methodology using exercise experts. The experts used the EQUATOR Network recommendations to reach consensus on key exercise descriptors that would “encourage transparency, improve trial interpretation and replication, and facilitate implementation of effective exercise interventions into practice”.

The CERT is a 16-item checklist consisting of seven categories: materials, provider, delivery, location, dosage, tailoring, and compliance. The CERT is consistent with TIDieR domains and headings (what, who, how, etc), and is compatible with both CONSORT and SPIRIT statements. Authors of clinical intervention studies should use established reporting guidelines and checklists (CONSORT, STROBE, etc) based on the study design (See Table 1), and include the TIDieR checklist, as well as the CERT if an exercise intervention was included. Furthermore, if an author references an exercise program or protocol published in the literature, they should (at a minimum) cite the source and provide detail in an Appendix, as well as any specific modifications that have been made to the program or protocol altering it from the published protocol. If the original source did not clearly provide TIDieR or CERT required items, it is recommended to include those checklists at the time of manuscript submission.

While the CERT is specific to exercise interventions, therapeutic exercise programs delivered in the physical therapy clinic may need even more detail for clinical implementation or replication. The column added by the authors of this commentary to the original CERT checklist in Appendix 1 provides further guidance on reporting therapeutic exercise intervention within the context of the CERT checklist. Because many physical therapy interventions include both in-clinic and home exercise programs, it is important to include details on both interventions.

CONCLUSION

If the goal of clinical research is to provide evidence-based, real world interventions, clinicians must rely on detailed information provided in publications on therapeutic exercise programs in order to translate research into practice. Research is not beneficial to the clinician or patient if it cannot be replicated in the clinic. Interventions cannot be validated if they cannot be replicated. Systematic reviews on the efficacy of clinical interventions are limited without specific details of an intervention. The inability to properly replicate research findings is wasteful, and may actually harm patients.

Journals often require authors follow specific guidelines when reporting specific types of studies, but these generally do not provide specific guidance on detailing the therapeutic interventions utilized within a study. Recently, guidelines and checklists have been recommended for reporting interventions in the clinical literature. A specific guideline for exercise intervention reporting (CERT) can be used to provide necessary detail on exercise interventions in physical therapy research, which will benefit researchers, clinicians, and patients. The International Journal of Sports Physical Therapy now requires all applicants to use the TIDieR checklist, or the Modified CERT checklist (Appendix 1) if exercise interventions are included in a manuscript.

REFERENCES


Appendix 1. Modified Consensus on Exercise Reporting Template (CERT) for Therapeutic Exercise Interventions. Last column has been added to the original CERT from Slade et al\textsuperscript{17} by the authors of this commentary.

<table>
<thead>
<tr>
<th>Item Category</th>
<th>Item No.</th>
<th>Abbreviated Item Description</th>
<th>Therapeutic Exercise Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHAT: materials</td>
<td>1</td>
<td>Type of exercise equipment</td>
<td>Provide equipment manufacturer, city, state, country, if appropriate, and appropriate copyright</td>
</tr>
<tr>
<td>WHO: provider</td>
<td>2</td>
<td>Qualifications, teaching/supervising experience, and/or training of the exercise instructor</td>
<td>If exercise program is administered by multiple therapists, provide detail on how each therapist was trained in the intervention</td>
</tr>
<tr>
<td>HOW: delivery</td>
<td>3</td>
<td>Whether exercises are performed individually or in a group</td>
<td>If group exercise, note the size of the group</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Whether exercises are supervised or unsupervised</td>
<td>Note if exercise is 'direct' one-on-one or indirect supervision</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Measurement and reporting of adherence to exercise</td>
<td>Provide exercise log in appendix, or specify method for both in-clinic and home program compliance recording</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Details of motivation strategies</td>
<td>Note behavioral strategies to improve compliance with home exercise program (See #10)</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Decision rules for progressing the exercise program</td>
<td>Provide criteria for progression of each exercise both in the clinic and in home program (See #13)</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Each exercise is described so that it can be replicated (eg, illustrations, photographs)</td>
<td>Provide detailed instructions (including cues and modifications) for each exercise, including patient booklets in a table, appendix, or supplement. Avoid using only exercise names as descriptors.</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Content of any home program component</td>
<td>Provide details on how home program was instructed, delivered, and progressed throughout intervention (Note #1, 5, 7, 8, 11, 13, 14, 15)</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Non-exercise components</td>
<td>Include education (posture, ergonomics, modalities) in appendix or where materials can be accessed</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>How adverse events that occur during exercise are documented and managed</td>
<td>Reported and addressed in limitations or future research considerations</td>
</tr>
<tr>
<td>WHERE: location</td>
<td>12</td>
<td>Setting in which exercises are performed</td>
<td>Note which exercises were performed in clinic and/or home</td>
</tr>
<tr>
<td>WHEN, HOW MUCH: dosage</td>
<td>13</td>
<td>Detailed description of the exercises (eg, sets, repetitions, duration, intensity)</td>
<td>Compliments #7, and provide progression rules for individual exercises, including the home exercise program. Do not simply refer to the protocol based on the name of the developer.</td>
</tr>
<tr>
<td>TAILORING: what, how</td>
<td>14</td>
<td>Whether exercises are generic (“one size fits all”) or tailored to the individual</td>
<td>If tailored, detail how decisions are made for choosing/progressing exercises, including options for therapist. Provide algorithm or flow chart for tailored exercises.</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>Decision rules that determines the starting level for exercise</td>
<td>Provide how specific sets, repetitions, resistances are determined initially, including the home program</td>
</tr>
<tr>
<td>HOW WELL: planned, actual</td>
<td>16</td>
<td>Whether the exercise intervention is delivered and performed as planned</td>
<td>Define markers of ‘success’ (compliance, outcomes)</td>
</tr>
</tbody>
</table>
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EVERYTHING CHANGES

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April 29-30, 2017  Boston, MA
May 6-7, 2017  Orange, CA
September 16-17, 2017  Chicago, IL
Sept 30-Oct 1, 2017  Fayetteville, NY

More dates being scheduled

Fundamental understanding of the Foot & Ankle and the Biomechanics of Human Gait

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