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IJSPT is a bimonthly publication, with release dates in February, April, June, August, October and December. It is published by the American Academy of Sports Physical Therapy.

ISSN 2159-2896

INTERNATIONAL JOURNAL OF SPORTS PHYSICAL THERAPY

IJSPT is an official journal of the International Federation of Sports Physical Therapy (IFSPT).
# TABLE OF CONTENTS

## VOLUME 13, NUMBER 5

<table>
<thead>
<tr>
<th>Page</th>
<th>Article Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>773</td>
<td>ERRATUM</td>
</tr>
<tr>
<td>774</td>
<td>SYSTEMATIC REVIEW – META ANALYSIS</td>
</tr>
</tbody>
</table>
| 778  | Accuracy of the Lever Sign to Diagnose Anterior Cruciate Ligament Tear: A Systematic Review with Meta-Analysis.  
Authors: Reiman MP, Reiman CK, Decary S |
| 789  | Is Pre-Performance Massage Effective To Improve Maximal Muscle Strength and Functional Performance? A Systematic Review.  
Authors: Mine K, Lei D, Nakayama T |
| 800  | ORIGINAL RESEARCH |
| 808  | Evaluation of Vertical and Horizontal Saccades using the Developmental Eye Movement Test Compared to the King-Devick Test.  
Authors: Heick JD, Bay C, McLeod TCV |
| 819  | The Relationship Between Trunk Rotation, Upper Quarter Dynamic Stability, and The Kerlan-Jobe Orthopaedic Clinic Overhead Athlete Shoulder and Elbow Score in Division I Collegiate Pitchers.  
Authors: Chasse P, Bullock GS, Schmitt AC, Little BA, Diehl LH, Butler RJJ |
| 828  | The Impact of Warm-Up on Youth Golfer Clubhead Speed and Self-Reported Shot Quality.  
Authors: Coughlan D, Taylor MJ, Jackson J |
| 835  | Four Weeks of Roller Massage Training Did Not Impact Range Of Motion, Pain Pressure Threshold, Voluntary Contractile Properties Or Jump Performance.  
Authors: Hodgson DD, Lana CD, Lui JL, Behn DG |
| 846  | Acute Effects of Two Hip Flexor Stretching Techniques on Knee Joint Position Sense and Balance.  
Authors: Aslan HIY, Buddhadev HH, Suprak DN, Juan JGS |
| 850  | Validity and reliability of the Fitbit FlexTM and ActiGraph GT3X+ at Jogging and Running Speeds.  
Authors: Jones D, Crossley K, Dascombe B, Hart HF, Kemp J |
| 857  | Comparison Of Bilateral and Unilateral Squat Exercises On Barbell Kinematics And Muscle Activation.  
Authors: Elkassen W, Saeetbakken AH, van den Tillaar RVD |
| 882  | Isokinetic Muscle Performance After Anterior Cruciate Ligament Reconstruction: A Case-control Study.  
Authors: Pelegrinelli ARM, Guenka LC, Dias JM, Bela LFD, Silva MF, Moura FA, Brown LE, Cardoso JR |
| 890  | Acute Effect of Low-Intensity Eccentric Exercise on Angle of Peak Torque in Subjects With Decreased Hamstring Flexibility.  
Authors: Nishida S, Tomoto T, Maehara K, Miyakawa S |
| 896  | Testing Infraspinatus and Deltoid Muscles with A New Technique to Decrease Deltoid Activity During Testing Using EMG Analysis.  
Authors: Forbush SW, Bandy WD, Garrison MK, Graves LC, Roberts R |

## CASE SERIES / STUDIES

<table>
<thead>
<tr>
<th>Page</th>
<th>Article Title</th>
</tr>
</thead>
</table>
| 905  | A Novel Approach to Treatment Utilizing Breathing and a Total Motion Release® Exercise Program in a High School Cheerleader with a Diagnosis of Frozen Shoulder: A Case Report.  
Authors: Tyree KA, May J |

## CLINICAL COMMENTARY

<table>
<thead>
<tr>
<th>Page</th>
<th>Article Title</th>
</tr>
</thead>
</table>
| 920  | Roller Massage: Survey of Physical Therapy Professionals and A Commentary On Clinical Standards- Part II.  
Authors: Cheatham SW, Stall KR, Wright TA |
ERRATUM


Dr. Erik N. Mayer was inadvertently omitted as a contributing author. This change does not affect the content or commentary associated with this publication. Corrected author list includes Dr. Mayer:

ABSTRACT

Background: The Lever sign has gained recent notoriety for its purported anterior cruciate ligament (ACL) diagnostics and simplicity of performance.

Purpose: The purpose of this systematic review with meta-analysis is to summarize the diagnostic accuracy of the Lever sign for use during assessment of the knee for an ACL tear in subjects with suspected acute and chronic knee injury.

Study Design: Systematic review with meta-analysis

Methods: A computer-assisted literature search of MEDLINE, CINAHL, and EMBASE databases using keywords related to diagnostic accuracy of the knee joint. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used for the search and reporting phases of the study. Quality assessment of bias and applicability was conducted using the Quality of Diagnostic Accuracy Studies (QUADAS). Mixed effects models were used to summarize accuracy.

Results: Eight articles, with only two demonstrating high quality, were included. Six of the articles were included in a meta-analysis. Diagnostic values, utilizing arthroscopy as a gold standard, were: pooled SN 0.55 (95% CI 0.22 to 0.84), pooled SP 0.89 (95% CI 0.44 to 0.99), positive likelihood ratio (+LR) 9.2 (95% CI 0.70 to 46.1), negative likelihood ratio (-LR) 0.58 (95% CI 0.18 to 1.28). Post-test probability with a positive finding (57% sampling prevalence) reached 92% (95% CI 83 to 97%). Post-test probability with a negative finding (57% sampling prevalence) reached 43% (95% CI 39 to 47%).

Conclusions: Based on limited evidence of heterogeneous methodological quality, the Lever sign can moderately change post-test probability to rule in an ACL tear. These results should be interpreted cautiously due to a limited number of studies, with small sample sizes and study quality affecting test accuracy. Future investigation should be expanded to include additional high-quality studies examining diverse clinical contexts, as they become available, to enable a more comprehensive clinical examination of this test.

Key words: anterior cruciate ligament, diagnostic accuracy, Lever Sign, knee, sensitivity, specificity

Level of evidence: 3a

PROSPERO Registration # CRD42018084954

CORRESPONDING AUTHOR
Michael P. Reiman, PT, DPT, SCS, ATC, FAAOMPT, CSCS
Duke University School of Medicine
Department of Orthopedic Surgery
DUMC 104002
Durham, NC 27710
Phone: (919) 668-3014; Fax: (919) 684-1846
E-mail: reiman.michael@gmail.com

1 Duke University Medical Center, Department of Orthopedic Surgery, Durham, NC, USA
2 Duke University Orthopaedic Fellowship, Duke University Medical Center, Durham, NC, USA
3 Department of Biological Sciences, North Carolina State University, Raleigh, NC, USA
4 Université Laval, Faculty of Medicine, Québec, Canada.

We declare that we have no financial disclosures or conflicts of interest regarding the authorship or publication of this contribution.

Acknowledgement: Leila Ledbetter, MLIS for assisting with the literature search for this study.
INTRODUCTION
A tear of the anterior cruciate ligament (ACL) is a significant knee injury which can leave patients with sustained complaints of instability in daily and sporting activities as well as increasing their risk of knee osteoarthritis later in life. Current best practices for the management of symptoms in young adults propose early rehabilitation or surgery. Thus, there is a need for an accurate initial diagnosis based on history and physical examination, although this may be difficult to achieve.

Diagnostic accuracy of physical examination tests for ACL tear has been extensively studied. The three most studied tests, the Lachman, the pivot shift and the anterior drawer test have shown overall adequate accuracy for clinical use. However, these tests also yielded lower accuracy when utilized acutely post injury compared to a chronic tear, when the knee has a combined lesion to the meniscus instead of an isolated ACL tear, and when the tear is partial compared to complete. Moreover, inter-rater reliability of these tests may be lower when executed by non-expert clinicians because of technical difficulties and interpretation of the outcomes.

In response to these limitations, Lelli et al. proposed a new physical examination test to diagnose ACL tear called the Lever sign. This test requires the evaluator to place his or her fist under the calf muscle to create a “fulcrum” extending the knee while applying a moderate downward force to the distal part of the femur. In an intact knee, the ACL completes a lever mechanism, making the heel rise in response to the force applied to the femur. In an ACL-deficient knee, the heel does not rise indicating a positive Lever sign. In their initial study, the authors demonstrated a perfect sensitivity and specificity in a sample of acute and chronic patients with both partial and complete ACL tears.

Several years following its introduction, this test is rapidly gaining the interest of clinicians due to its simplicity. Yet, none of the recent systematic reviews examining accuracy for ACL clinical tests have included this test to verify if subsequent studies supported the initial claims. Therefore, the purpose of this systematic review with meta-analysis is to summarize the diagnostic accuracy of the Lever sign for use during assessment of the knee for an ACL tear in subjects with suspected acute and chronic knee injury.

METHODS
Registration
The study was registered with the International Prospective Register of Systematic Reviews (PROSPERO#CRD42018084954) on January 15, 2018. PROSPERO is a database of prospectively registered systematic reviews for health and social topics. The study was registered after the pilot search and prior to updated data search and extraction.

Data Sources
The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were utilized during the search and reporting phase of this review. The PRISMA statement includes a 27-item checklist that is designed to be used as a basis for reporting systematic reviews of randomized trials, but the checklist can also be applied to multiple forms of research methodologies.

A computer-assisted literature search of MEDLINE, CINAHL, and EMBASE databases was performed from inception of each respective database to December 23, 2017, and updated on April 2, 2018. The goal was to optimize the sensitivity of the search strategy, increasing the likelihood that all appropriate studies were identified. The search strategy was developed in collaboration with a medical information specialist and used controlled vocabulary and key words related to diagnostic accuracy of the lever test relative to ACL tear. Screening filters were initially used during assessment of title, abstract and full text documents. The search was further limited to humans and English or French-only publications. The search strategy for MEDLINE is provided in Appendix 1.

Selection criteria
Articles were eligible if they met all of the following criteria: 1) it included participants with suspected ACL tear/injury, 2) it included the Lever sign test to diagnose ACL tear/injury, 3) it utilized an acceptable reference standard, 4) it reported diagnostic values in sufficient detail to allow reconstruction of
contingency tables, and 5) it was written in English or French.

An article was excluded if: 1) the pathology assessed was associated with a condition not located at the knee joint, 2) the study did not evaluate the Lever sign test, 3) the study did not provide sufficient detail to calculate diagnostic accuracy, 4) the clinical tests were performed on cadavers, 5) the study reported on specialized instrumentation, questionnaires or performance measures, or 6) the study was performed on infants/toddlers.

**Study selection**
Two reviewers (MPR, CKR) independently performed the search. Because computerized search results for diagnostic accuracy data frequently omit many relevant articles,16 the reference lists of all selected publications were checked to retrieve relevant publications that were not identified in the computerized search. Unpublished literature was also hand searched and included publications, posters, abstracts, or conference proceedings. To identify relevant articles, titles and abstracts of all identified citations were independently screened. Full-text articles were retrieved if the abstract provided insufficient information to establish eligibility or if the article passed the first eligibility screening.

All criteria were independently applied by two reviewers (MPR, CKR) to the full text of the articles that passed the first eligibility screening. Disagreements among the reviewers were discussed and resolved by consensus. Articles to be included (for meta-analysis) were determined by using clinical and statistical judgment of study heterogeneity. Clinical judgment criteria involved assessment of similarity of populations, assessment context (e.g., test performed a priori), reference standard (e.g. MRI or arthroscopy), and method in which specific tests were applied.17 In addition, after approval using clinical judgment, studies were statistically pooled for meta-analysis when ≥ 2 studies examined the Lever sign test and diagnosis with the same reference standard.

**Risk of Bias/Quality Assessment**
The Quality Assessment of Diagnostic Accuracy Studies tool (QUADAS), the original tool for quality assessment in diagnostic accuracy studies, was used to analyze the quality of the study. QUADAS consists of 14 items with each having a “yes”/”no”/”unclear” answer options. A “yes” score indicated sufficient information, with bias considered unlikely. A “no” score indicated sufficient information, but with potential bias from inadequate design or conduct. An “unclear” score indicated that insufficient information was provided in the article or the methodology was unclear. The total score is formed by the count of all of the criteria scored “yes”, valued as “1” whereas, “no” and “unclear” scores carried a zero score value. If a “yes” score was present for all 14 items, the maximum attainable unweighted score is 14/14. The methodological quality and risk of bias of each of the studies was independently assessed by two reviewers (MPR, SD). Disagreements among the reviewers were discussed and resolved with consensus. Inter-rater reliability was calculated with weighted Kappa.

Qualitatively, studies that exhibit higher QUADAS values are associated with less risk of design bias than those of lower values. Studies were stratified as “high quality/low risk of bias” if the QUADAS score was ≥10/14, and “low quality/high risk of bias” of the study score < 10/14. This dichotomizing stratification level was chosen since it has been utilized successfully previously and no other strategy is advocated to discriminate low and high bias diagnostic accuracy studies.18-23

**Data extraction and analysis**
One reviewer (MPR) independently-extracted information and data regarding study population, setting, examiner, duration of symptoms, mechanism of injury, test performance, diagnostic reference-standard, and number of true positives, false positives, false negatives, and true negatives for calculation of sensitivity (SN), specificity (SP), positive likelihood ratios (+LR), and negative likelihood ratios (-LR) when not provided. Extracted data was verified by the other study authors (CKR, SD).

It has been suggested that post-test probability can be altered to a minimal degree with +LRs of 1 to 2 or -LRs of 0.5 to 1, to a small degree with +LRs of 2 to 5 or -LRs of 0.2 to 0.5, to a moderate degree with +LRs of 5 to 10 and -LRs of 0.1 to 0.2) and to a large
and almost conclusive degree with $+LR$s greater than 10 and $-LR$s less than 0.1. Pretest probability is defined as the probability of the target pathology before a diagnostic test result is known. It represents the probability that a specific patient, with a specific past history, presenting to a specific clinical setting, with a specific symptom complex, has a specific pathology.

**STATISTICAL METHODS**

**Meta-Analysis**

Der-Simionian and Laird mixed effects models, which incorporate both between and within study heterogeneity, were used to produce summary estimates of SN, SP, LR+, LR-, PPV, and NPV. An $I^2$-squared value of >50% and Cochrane’s-Q p-value of <0.10 were the criteria to indicate significant between-study heterogeneity, of SN and SP and likelihood ratios respectfully. Publication bias was not formally tested due to low power of the tests with limited included studies. All analyses were conducted in R version 3.4.2 (package: mada, http://cran.r-project.org/).

**RESULTS**

**Selection of Studies**

The systematic searches of MEDLINE, CINAHL, and EMBASE, as well as hand search, netted 305 abstracts after duplicates were removed. Abstract and full text review reduced the acceptable papers to eight (Figure 1 and Table 1). Abstract screening inter-rater agreement was $\kappa = 0.80$ (95% CI: 0.60 to 0.94) and full text agreement was $\kappa = 0.92$ (95% CI: 0.85 to 0.99); both indicating almost perfect agreement. The search strategy utilized for MEDLINE is listed in Appendix I. Excluded studies are listed in Appendix II.

This review included 977 subjects across the eight studies (Tables 1 & 2). The sample size of the studies ranged from 33 to 400 subjects (Table 1). All studies were prospective in study design (Table 1). Sources of support and conflicts of interest reporting is detailed in Appendix III.

**Quality Scores**

Inter-rater agreement was $\kappa = 0.62$ (95% CI: 0.48 to 0.78), indicating substantial agreement. Table 1 provides the overall risk of bias score, with two studies demonstrating low risk of bias. Details of each the individual study quality scores are presented in Appendix IV.

**Study Characteristics**

Detail on subject sex, mean age, duration of symptoms, and mechanism of injury are listed in Table 1. The clinicians performing the examination and the setting in which the examination was performed are listed in Table 2. The reference standards utilized, as well as the professional training of the clinicians performing the Lever sign are also listed in Table 2.

**META-ANALYSIS**

Six studies qualified for meta-analysis (Tables 1-3). Three studies (n = 234 subjects) utilized arthroscopy as a gold standard in surgical candidates, while three studies (n = 539 subjects) utilized MRI as a reference standard. All analyses were conducted in R version 3.4.2 (package: mada, http://cran.r-project.org/).

Figures 2 through 4 illustrate pre- to post-test probability changes utilizing the Lever sign with arthroscopy and MRI reference standards, respectively. Diagnostic accuracy and probability shifts were calculated utilizing MRI as a reference standard with high quality/low risk of bias studies only (Figure 2) and with all studies (one additional study was low quality/high risk of bias). Pre- to post-test probability for positive and negative findings on the Lever sign are presented in Table 3. As shown in this table, the adding of one high risk of bias study substantially change the estimates.

**RESULTS OF INDIVIDUAL DIAGNOSTIC STUDIES**

One study utilized arthroscopy as a gold standard, but did not qualify for meta-analysis as the subjects were examined under anesthesia, unlike the other two studies. The prevalence of ACL tear in this study with this gold standard was 54%. Post-test probability with a positive finding was 86%, while a post-test probability with a negative finding was 16%.

Three studies examining those with ACL tear/injury reported only SN (Table 4). Two studies utilized arthroscopy as a reference standard, and both examined the Lever sign pre- and post-anesthesia.
Chong et al.\textsuperscript{27} found a SN range of 0.82 (physician assistant examiner) to 0.88 (orthopaedic surgeon examiner) pre- and 0.97 (orthopaedic surgeon) to 1.0 (physician assistant) post-anesthesia in a group of 33 subjects with ACL tear of at least 72 hours prior to examination. Deveci et al.\textsuperscript{32} demonstrated a SN of 0.94 pre- and 0.98 post-anesthesia in a group of 117 subjects with ACL tear of a mean of 8.7 (4 to 25 weeks) from onset of injury.

One of the studies\textsuperscript{30} utilized a separate reference standard, therefore not qualifying for meta-analysis. Besides arthroscopy as a gold standard, Mulligan et al.\textsuperscript{30} also utilized a clinical test cluster as a reference standard in 41 subjects, demonstrating diagnostic values of: SN 0.44 (95\% CI 0.17 0 to 0.74), SP 0.75 (95\% CI 0.67 to 0.83), +LR 1.78 (95\% CI 0.69 to 4.58), -LR 0.74 (95\% CI 0.40 to 1.37). The prevalence of ACL tear in this study with clinical test cluster reference standard was 22\%. Post-test probability with a positive finding was 33\%, while a post-test probability with a negative finding was 17\%.

**DISCUSSION**

The aim of this systematic review with meta-analysis was to summarize the diagnostic accuracy of the Lever sign when used to diagnose an ACL tear. Based on limited evidence of heterogeneous methodological quality, the Lever sign can moderately
change post-test probability to rule in or rule out an ACL tear based upon studies with lower risk of bias. Interpretation of the methodological quality of the primary diagnostic studies is presented, as well as comparisons to the findings of previous meta-analyses of other ACL tests.

<table>
<thead>
<tr>
<th>Study</th>
<th>Level of Evidence</th>
<th>Study Design</th>
<th>Risk of Bias (QUADAS)</th>
<th>Subjects; Gender; Mean Age; Duration of Symptoms</th>
<th>Mechanism of Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chong et al. (2017)</td>
<td>III</td>
<td>Cohort study</td>
<td>High</td>
<td>33 patients diagnosed with ACL injury at least 72 hours prior to examination</td>
<td>NR</td>
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<td></td>
<td></td>
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<td>Females (n=12)</td>
<td></td>
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<td>Mean age: 30.6 ± 17.0 (15-60) years (females)</td>
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<td>30.9 ± 14.3 (11-62) years (males)</td>
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<td></td>
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<td></td>
<td></td>
<td>Injury onset: knee injury was not sustained within 72 hours prior to data collection</td>
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<tr>
<td>Deveci et al. (2015)</td>
<td>IV</td>
<td>Cohort study</td>
<td>High</td>
<td>117 patients diagnosed with ACL tear based on symptoms, physical exam and (+) 1.5T MRI</td>
<td>NR</td>
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<td>Females (n=21)</td>
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<td>Mean age: 25.8 = 5.9 (17-45) years</td>
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<td>Injury onset: 8.7 (4-25) weeks</td>
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<tr>
<td>Jarbo et al. (2017)</td>
<td>II</td>
<td>Cohort study (diagnosis)</td>
<td>Low</td>
<td>102 patients with acute (&lt;4 weeks) symptomatic knees</td>
<td>NR</td>
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<tr>
<td></td>
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<td></td>
<td>Females (n=44)</td>
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<td>Mean age: 23 years</td>
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<td>Injury onset: within 4 weeks of their injury or the onset of symptoms</td>
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<tr>
<td>Lichtenberg et al. (2018)</td>
<td>II</td>
<td>Cohort study (diagnosis)</td>
<td>High</td>
<td>94 patients with trauma to the knee. Patients with locking knee complaints or previous ACL were excluded.</td>
<td>Trauma to the knee</td>
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<td></td>
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<td>Females (n=37)</td>
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<td>Mean age: 34 ± 15 years</td>
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<td></td>
<td>Injury onset: ranging from acute (&lt; 3 weeks) to chronic (&gt; 12 weeks)</td>
<td></td>
</tr>
<tr>
<td>Lelli et al. (2014)</td>
<td>IV</td>
<td>Cohort study</td>
<td>High</td>
<td>400 patients</td>
<td>NR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Group A (acute injury, (+) MRI for complete ACL rupture); 29 females; 27 years</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Group B (chronic injury, (+) MRI for complete ACL rupture); 35 females; 26 years</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Group C (acute injury with (+) MRI for partial ACL rupture); 24 females; 26.8 years</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Group D (chronic injury with (+) MRI for partial ACL rupture); 31 females; 25.9 years</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean age: 26.4 ± 14.9 years</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Injury Onset:</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• acute phase: 20 days from injury</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• chronic phase: more than 20 days from injury (range 20 days - 4 years)</td>
<td></td>
</tr>
<tr>
<td>Massey et al. (2017)</td>
<td>II</td>
<td>Cohort study</td>
<td>Low</td>
<td>91 patients subjects after a knee injury with subjective swelling, or an objective effusion</td>
<td>Noncontact or</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30 females</td>
<td>contact knee</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean age: 28±11 years</td>
<td>injury</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Injury onset: NR</td>
<td></td>
</tr>
<tr>
<td>Mulligan et al. (2017)</td>
<td>III</td>
<td>Cohort study</td>
<td>High</td>
<td>60 patients with complaint of knee pain (&lt;7/10)</td>
<td>NR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>22 females</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean age: 42±13.4 (18-65) years</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Injury onset: 55±80 (1-304) days</td>
<td></td>
</tr>
<tr>
<td>Thapa et al. (2015)</td>
<td>II</td>
<td>Cohort study</td>
<td>High</td>
<td>80 patients with complaints of knee symptoms of giving way/locking/pain</td>
<td>Sports activities</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30 females</td>
<td>(62.8%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean age: 32.12 (21-42) years</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Injury onset: NR</td>
<td></td>
</tr>
</tbody>
</table>

NR, not reported; QUADAS, Quality Assessment of Diagnostic Accuracy Studies scores; studies were stratified as “high quality/low risk of bias” if the QUADAS score was ≥10/14, and “low quality/high risk of bias” of the study score < 10/14.

Methodological quality of the primary diagnostic studies and impact on accuracy

Eight primary diagnostic studies, including the original article by Lelli et al., have investigated this test. Only two studies were considered to have a low risk of bias.28,31 Out of the five other studies, three
low-quality studies\(^{11,27,28}\) included 644 out of the 977 patients (66%) in this systematic review.

An important bias in these three studies is the assessment of the Lever sign on cohorts including only ACL-deficient knees prior to obtaining arthroscopic surgery.\(^{11,27,28}\) Accordingly with QUADAS methodological assessment, this bias precludes investigators from adequate blinding when the index test was executed, which likely overestimated accuracy.\(^{34}\) More
so, because of the absence of non ACL-deficient cases is these cohorts, only SN could be calculated. Thus, these studies only informed on the capacity of the Lever sign to assist in “ruling out” the presence of injury when the test is negative.35 Lastly, Lelli et al. measured SP of the Lever sign by evaluating the test on the healthy knees of the patients as a control.11 This represents a case-control bias which can also overestimate accuracy.34,36

This meta-analysis demonstrates the impact of low-quality studies on analysis of accuracy. The pooled estimates for positive and negative LR using MRI as a reference standard was 13.1 and 0.28 when considering only the two high-quality studies.29,31 When adding one low-quality study11 to the meta-analysis, pooled estimate for +LR increased approximately 10-fold to 128.0 and negative LR to 0.18. The addition of 400 true positives and true negatives without added false positive and false negative findings because of possible biases yielded wide 95% CI and unprecise estimates to guide clinical decision-making.

Clear utilization of blinding for test interpretation was reported in only one study29 in this review. Test interpretation with knowledge of index test findings is a significant bias in diagnostic accuracy studies. A meta-review37 and one review38 have reported that overall accuracy was higher in the presence of diagnostic review bias (person interpreting the reference standard was aware of the index test results).

These biases were also found in recent diagnostic studies investigating other ACL tests.8 Researchers are urged to follow Equator Network guidelines (http://www.equator-network.org) and QUADAS,39 in future study designs to advance our understanding of these diagnostic tests.

Comparison of the accuracy of Lever sign to other ACL tests

The accuracy estimates from this meta-analysis must be compared with meta-analyses of other ACL tests5 to inform regarding clinical utilization of these tests. The studies in this review report a SN of 55% to 95% (depending on the gold standard), yielding negative LR of 0.18 to 0.58. This induces a small to moderate change in negative post-test probability of 14% to 40% to rule out an ACL tear when the test is negative. A SP of 88% to 97% was also reported in the included studies, yielding a positive LR of 9.2 to 128. This induces a moderate change in positive post-test probability of 30 to 35% to rule in an ACL tear when the test is positive. Because of the limited number of patients included in this meta-analysis, estimates from this review demonstrate wide 95% CI and should be interpreted cautiously. From the two high-quality studies, one found SN of 63% and SP of 90%,29 while the other found SN of 83% and SP of 80%.31

The most comprehensive meta-analysis summarizing the accuracy of other ACL tests included 28 primary studies and demonstrated the following statistics.6 For the Lachman test, SN and negative LR was 85% and 0.2, while SP and positive LR was 94% and 10.2. For the Pivot shift test, SN and negative LR was 24% and 0.90, while SP and positive LR
was 98% and 8.5. For the anterior drawer test, SN and negative LR was 55% and 0.50, while SP and positive LR was 92% and 7.3. When comparing estimates and 95% CI from meta-analyses, the Lever sign may demonstrate diagnostic accuracy comparable to other ACL tests. This conclusion mirrors one high-quality study\textsuperscript{31} in this review which directly compared all ACL tests in one cohort and found no significant difference between the estimates. Video performance of the Lachman test and Lever sign are demonstrated in Figure 5, available online.

**Future direction**
The results from this first meta-analysis regarding diagnostic accuracy of the Lever sign show potential for its use in clinical practice. Given the available scarce evidence and low to moderate study quality, further investigation is required to match the level of understanding of the other common tests used to examine those with suspected ACL tear.\textsuperscript{5} Other high-quality diagnostic studies are required to better understand the accuracy of this test in diverse clinical contexts and in various patient profiles. Notably, it remains to be demonstrated that this test can replace other ACL tests for contexts such as acute presentation or for partial ACL tears. Also, while the test was developed as a simplified alternative to other more technically challenging tests or for evaluators with small hands compared to a patient’s muscle size, only three studies have shown inter-rater reliability to be “fair” or “high”.\textsuperscript{27,28,33} Previous evidence examining ACL diagnostic tests indicates that reliability can be lowered when the evaluator is inexperienced.\textsuperscript{10} In most studies on the Lever test, there were only experienced clinicians. Future studies should assess if this test can be valid and reliable when used by clinicians with a diversity of clinical experience, with an emphasis on primary care clinicians. It is likely that the required training for this test, as well as describing optimal condition for execution (eg. cushioning of the examination table, amount of force applied), must be standardized.

**Limitations**
Due to heterogeneity of studies and variable reference standards only five of the seven studies qualified for meta-analysis with two different reference standards (MRI and arthroscopy). Despite moderate shifts in

### Table 4. Summary of independent articles reporting on the diagnostic accuracy of Lever sign for ACL tear/injury.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Subjects (n)</th>
<th>SN/SP (95% CI)</th>
<th>+LR/LR-</th>
<th>PPV/PPV</th>
<th>Reference Standard</th>
<th>Post-Test Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chong et al. (2017)\textsuperscript{27}</td>
<td>33</td>
<td>OS 0.88 SN (NR) (pre-anesthesia); 0.97 (NR) (post-anesthesia) PA 0.82 SN (NR) (pre-anesthesia); 1.0 SN (NR) (post-anesthesia)</td>
<td>NA</td>
<td>NA</td>
<td>Arthroscopy</td>
<td>NA</td>
</tr>
<tr>
<td>Deveci et al. (2015)\textsuperscript{28}</td>
<td>117</td>
<td>0.94 (NR) (pre-anesthesia) 0.98 SN (NR) (post-anesthesia)</td>
<td>NA</td>
<td>NA</td>
<td>Arthroscopy</td>
<td>NA</td>
</tr>
<tr>
<td>Jarbo et al. (2017)\textsuperscript{29}</td>
<td>54</td>
<td>0.86 (0.68 to 0.96)/0.85 (0.64 to 0.96)</td>
<td>5.4/0.16 0.86/0.84</td>
<td>Arthroscopy</td>
<td>86% with (+) test 16% with (-) test (54% pre-test prevalence)</td>
<td></td>
</tr>
<tr>
<td>Mulligan et al. (2017)\textsuperscript{30}</td>
<td>41</td>
<td>44 (14 to 78)/75 (57 to 89)</td>
<td>1.8/0.74 0.33/0.83</td>
<td>Clinical test cluster</td>
<td>33% with (+) test 17% with (-) test (22% pre-test prevalence)</td>
<td></td>
</tr>
</tbody>
</table>

SN=sensitivity, SP=specificity, +LR=positive likelihood ratio, -LR=negative likelihood ratio, (+)=positive, (-)=negative, PPV=positive predictive value, NPV=negative predictive value, CI=confidence interval, n=number, NR=not reported, OS=orthopedic surgeon, PA=physician assistant, NA=not applicable
positive and negative post-test probability using the Lever sign compared to both reference standards, caution is warranted due to study quality. Other limitations of this study include: limiting the search strategy to only those articles written in English or French, lack of comparison of subject inclusion and exclusion across the studies and primary studies performed in settings of high pre-test probability. Lastly, only one author extracted the data points, but both of the other authors verified all data points.

CONCLUSION
This meta-analysis summarizes the diagnostic accuracy of the Lever sign when used to diagnose ACL tear. Based on limited evidence of heterogeneous methodological quality, the Lever sign can moderately change post-test probability to rule in or rule out an ACL tear in studies with lower risk of bias. These results should be interpreted cautiously due to the limited number of studies in this review, and the likelihood that small sample sizes and study quality may have affected test accuracy. The Lever sign is simple to use and could complement a complete physical examination, specifically in contexts where the traditional tests may be difficult to execute. The evidence for the Lever sign remains scarce and warrants additional investigation to guide clinical utility.

REFERENCES

Figure 3. Pre- to post-test probability shifts for Lever sign with MRI reference standard (only low risk of bias studies in pooled analysis). Blue line represents positive and red line represents negative probability shifts.

Figure 4. Pre- to post-test probability shifts for Lever sign with MRI reference standard (low and high risk of bias studies included in pooled analysis). Blue line represents positive and red line represents negative probability shifts.


26. Sterne JA, Gavaghan D, Egger M. Publication and related bias in meta-analysis: power of statistical


APPENDIX I. MEDLINE SEARCH STRATEGY

### Appendix II. Excluded Studies (Abstract & full text review)

<table>
<thead>
<tr>
<th>Study</th>
<th>Title</th>
<th>Reason Excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chong et al. (2017)</td>
<td>Evaluating Different Clinical Diagnosis of Anterior Cruciate Ligament Ruptures In Providers with Different Training Backgrounds.</td>
<td>Reliability study; diagnostic accuracy not reported</td>
</tr>
<tr>
<td>Orlando Junior N, et al. (2015)</td>
<td>Diagnosis of knee injuries: comparison of the physical examination and magnetic resonance imaging with the findings from arthroscopy.</td>
<td>Lever test not utilized in study</td>
</tr>
<tr>
<td>Srisuwanporn P, et al. (2016)</td>
<td>Accuracy of a New Stress Radiographic Device in Diagnosing Anterior Cruciate Ligament Tear.</td>
<td>Not physical examination diagnostic accuracy study</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### REFERENCES


### Appendix III. Potential Sources of Support (if reported in study, statements are in quotations)

<table>
<thead>
<tr>
<th>Study</th>
<th>Potential Sources of Support (if reported in study)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chong et al. (2017)27</td>
<td>“Conflict of Interest Statement: This study did not receive any funding support for this research. The participants and authors of this study did not receive any payments or other personal benefit, or commitments or agreements that were related in any way to the subject of the research that was conducted. No benefits of any form have been received directly or indirectly to the subject of this article. The authors report no actual or potential conflict of interest in relation to this article.”</td>
</tr>
<tr>
<td>Deveci et al. (2015)28</td>
<td>“Competing interests The authors declare that they have no competing interests.”</td>
</tr>
<tr>
<td>Jarbo et al. (2017)29</td>
<td>“The authors declared that they have no conflicts of interest in the authorship and publication of this contribution.”</td>
</tr>
<tr>
<td>Lelli et al. (2014)11</td>
<td>No acknowledgement or reporting of sources of support or conflict of interest in manuscript</td>
</tr>
<tr>
<td>Lichtenberg et al. (2018)33</td>
<td>The authors declared that they have no conflicts of interest in the authorship and publication of this contribution. Ethical approval for this study was obtained from VU University Medical Center Amsterdam (MTC/2015.327).</td>
</tr>
<tr>
<td>Massey et al. (2017)31</td>
<td>“The authors report the following potential conflicts of interest or sources of funding: J.D.H. receives support from NIA Magellan and Slack. He is a member of editorial board of Arthroscopy and Frontiers in Surgery, and a committee member of AOSSM Self-Assessment and AAOS OAFP Workgroup. P.C.M. receives support from NIA Magellan, Genzyme, Slack, DePuy, A Johnson &amp; Johnson Company, Arthrex, and Zimmer. He is a member of editorial board of Journal of Knee Surgery and Orthobullets.com.”</td>
</tr>
<tr>
<td>Mulligan et al. (2017)30</td>
<td>“We declare that we have no conflicts of interest in the authorship or publication of this contribution.</td>
</tr>
<tr>
<td>Thapa et al. (2015)32</td>
<td>“Conflict of interests: None declared.”</td>
</tr>
</tbody>
</table>

### Appendix IV. QUADAS Values for Accepted Studies.

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<tr>
<th>Article</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chong et al. (2017)27</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>U</td>
<td>Y</td>
<td>Y</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>N</td>
<td>N</td>
<td>6</td>
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<tr>
<td>Deveci et al. (2015)28</td>
<td>U</td>
<td>U</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>U</td>
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<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
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</tr>
<tr>
<td>Jarbo et al. (2017)29</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>U</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>11</td>
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<tr>
<td>Lichtenberg et al. (2018)33</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>U</td>
<td>U</td>
<td>Y</td>
<td>N</td>
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<td>Y</td>
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<td>U</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>8</td>
</tr>
<tr>
<td>Lelli et al. (2014)11</td>
<td>U</td>
<td>U</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
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<td>U</td>
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<td>Massey et al. (2017)31</td>
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<td>U</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>11</td>
</tr>
<tr>
<td>Mulligan et al. (2017)30</td>
<td>Y</td>
<td>Y</td>
<td>U</td>
<td>U</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
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<td>U</td>
<td>Y</td>
<td>Y</td>
<td>9</td>
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<tr>
<td>Thapa et al. (2015)32</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>U</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
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<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>9</td>
</tr>
</tbody>
</table>

Abbreviations: Y, yes; N, No; U, Unknown; QUADAS, Quality Assessment of Diagnostic Accuracy Studies scores; studies were stratified as “high quality/low risk of bias if the QUADAS score was ≥10/14, and “low quality/high risk of bias of the study score < 10/14.
ABSTRACT

Background: Although pre-performance massage is frequently used in sports settings, the evidence regarding its effects on muscle strength and functional performance is equivocal.

Purpose: The purpose of this systematic review was to synthesize the findings of randomized controlled trials (RCTs) investigating the effects of pre-performance massage on strength and functional performance.

Study Design: Systematic review with qualitative analysis.

Methods: Eight electronic databases were searched from inception until June 2017. Methodological quality of included studies were assessed using Physiotherapy Evidence Database scale. Data was synthesized qualitatively.

Results: Nine crossover RCTs with varied methodological qualities met inclusion criteria. Six out of nine studies had low quality, while two were of moderate-quality and one was high-quality. Following the descriptive analysis using within-group effect sizes of interventions used in included studies, no evidence was found to support the use of any kind of massage interventions (passive manual massage or self-massage) to enhance maximal strength, sprint or jump performances of young healthy subjects. In fact, there appears to be limited evidence which implies the negative effects of passive manual massage. In particular, longer-duration (> 9 minutes) of massage interventions tended to result in negative effects on lower-limb maximal strength, sprint performance and jump height.

Conclusion: In conclusion, the use of longer-duration pre-performance massage cannot be recommended for enhancing young athletes' strength and performance in sprint and vertical jump. More high-quality RCTs are necessary to examine overall effects of pre-performance massage on athletes' performance.

Level of Evidence: 1a

Key Words: Functional performance, muscle strength, pre-performance massage, systematic review

CORRESPONDING AUTHOR

Koya Mine
Department of Physical Therapy, School of Health Sciences, Tokyo University of Technology, 5-23-22 Nishi-kamata, Ota ward, Tokyo, Japan 144-8535
Telephone: +81 364242210
E-mail: Koya.Mine@unisa.edu.au

1 Tokyo University of Technology, Tokyo, Japan
2 International Centre for Allied Health Evidence, University of South Australia, Adelaide, South Australia, Australia
3 Department of Rehabilitation Medicine, The First Affiliated Hospital, Sun Yat-sen University, Guangzhou, China

The authors declare that they have no conflicts of interest related to this work.
INTRODUCTION

Pre-performance massage is frequently utilized in various sports settings, attempting to prevent injuries, increase range of motion, decrease stiffness and soreness, and enhance athletes’ maximal strength and functional performance during competitions. Proposed rationales for improved strength and functional performance generally involve the following; increasing blood flow to provide more efficient metabolism for muscles, releasing trigger points, which are believed to cause muscle weakness and positive psychological effects, such as mood enhancement and increased perceived performance.

The research evidence regarding the immediate effects of pre-performance massage to improve muscle strength and functional performance is equivocal. Some studies have demonstrated that massage might inhibit neurological excitability, which might theoretically decrease motor outputs. However, some authors have speculated that the effects of massage on neurological excitability, and hence muscle strength and functional performance, would depend on the types of massage. Based on this assumption, it has been anecdotally suggested that superficial and stimulating massage should be used before competitions to enhance motor output, while deep and relaxing massage should be adopted to encourage relaxation and post-exercise recovery. However, there is no empirical data to support the claim that fast and stimulating massage techniques can increase spinal reflex excitability.

To the best of the authors’ knowledge, there is no article which has systematically reviewed relevant papers to address this particular clinical question “is pre-performance massage effective to improve athletes’ strength and functional performance?” Thus, it would be valuable to undertake a systematic review to enable more evidence-based clinical decision making in sporting environments for clinicians, coaches and athletes.

The purpose of this systematic review was to synthesize the findings of randomized controlled trials (RCTs) investigating the effects of pre-performance massage on strength and functional performance.

METHODS

Study protocol and registration

This systematic review was written in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement. This review was registered in the international prospective register of systematic reviews PROSPERO network before the study was commenced (registration number CRD42016037609).

Search strategy

A systematic search was undertaken by one author (KM) with seven electronic databases (CINAHL, Cochrane Library, Embase, Ichushi, MEDLINE, SPORTDiscus and Web of Science) to find relevant studies. A search in Google Scholar was also undertaken to strengthen the comprehensiveness of the search strategy. Databases were searched from inception to June 2017. After the initial search, duplicates were removed and titles and abstracts were screened subsequently. Full texts of articles which remained at this stage were retrieved and further assessed for eligibility. Reference lists of included papers were also hand-searched.

A clinical question and search terms were developed based on a PICO (Participants, Intervention, Comparator and Outcome measures) format for this systematic review (Table 1). This systematic review included all relevant English- and Japanese-language studies. Studies with human participants were considered. Intervention of interests included any types of massage (passive manual massage or active self-massage) performed immediately before physical exertions. Studies examining recovery effects of massage during physical exertions were excluded. No limitation was set for comparator interventions. Included studies were required to use specific outcome measures, such as maximal muscle strength and/or functional performances related to sports, such as sprinting, jumping or throwing. In terms of research design, RCTs based on the National Health and Medical Research Council (NHMRC) hierarchy were considered for eligibility. Only papers published in peer-reviewed academic journals were included.

Assessment of methodological quality

Methodological quality of included studies were assessed using Physiotherapy Evidence Database
This critical appraisal tool has been demonstrated to be both reliable and valid. The quality of each study was classified as ‘high’ (7/10 or more), ‘moderate’ (5 or 6/10) or ‘poor’ (4/10 or less) according to a total score.

When included studies had been already critically appraised in the PEDro database, those scores were extracted. All PEDro scores in the databases are based on critical appraisal by trained PEDro assessors. The remaining papers were independently assessed by two reviewers (LD, KY). Discrepancies regarding study qualities were mediated through discussion. Both reviewers had completed the online PEDro scale training program.

Data extraction and synthesis
Data with regards to study designs, sample characteristics (sample size, age, gender, sports experiences, diagnosis, pain level and functional disability), types of pre-performance massage, outcome measures, results (pre- and post-intervention data, statistical significance and effect size if available) and conclusions were collected from all included papers. Attempts were made to perform subgroup analysis on the basis of types of massage (passive massage versus self-massage) or outcome measures when two or more homogenous studies were available in each group.

RESULTS
Study selection
The systematic search process is shown in Figure 1. The initial electronic database search yielded a total of 483 papers. After the exclusion of duplicates and irrelevant papers through screening, nine papers were chosen for full-text evaluation. After a full-text assessment, four papers were excluded due to incomplete, unclear or no randomisation processes. Four additional relevant articles were identified through references or Google Scholar. As a result, nine English-language RCTs were included in this review.

Study characteristics
A summary of included studies is presented in Table 2. Nine studies were included as crossover RCTs. Although one study used a non-random allocation for a control group, this study was also included by dismissing the control group and regarding it as a crossover RCT. Participants were predominantly college-age and healthy. The mean sample size across the included studies was 56. Sample size ranged from 26 to 90 and the cumulative sample size was 510 (188 women and 322 men), including duplicate participants in different intervention groups in each crossover RCT.

There were 24 intervention or comparator arms in the included nine papers. There was a considerable variability in types of massage techniques examined. Various types of passive massage techniques, such as effleurage, petrissage and tapotement were performed by physiotherapists, massage therapists or masseurs in five papers. Self-massage using manual massage device was examined in three papers. In the remaining study, passive massage was conducted by a custom-made machine with a roller-massager. The total duration of massage interventions ranged from five seconds to 30 minutes. In most studies, treatments were performed on lower-limb muscles, except for one study, where massage was also performed for neck and shoulder girdle.

Comparator interventions included active static stretching, warm-up exercise, sham massage.
or electrophysical agents, motor imagery, and no intervention. In terms of outcome measures, strength was evaluated as forms of isometric or isokinetic maximal strength, or maximal voluntary contraction (MVC) measured via electromyography in four studies. Vertical jump or drop jump height were examined in four studies. In the drop jump, athletes were instructed to step off the 30-centimeter step and jump upwardly as high as possible. Short-distance sprint performance was also investigated in four articles. Additionally, two papers also evaluated balance and agility respectively.

**Methodological quality**
The results of quality assessment are presented in Table 3. As three included papers had been already evaluated in the PEDro database, those scores were utilized. Included studies had a median score of 4 out of 10, ranging from 3 to 7. Six out of nine studies were low-quality, while two studies were moderate-quality and only one study was considered to be high quality. Common methodological flaws were no blinding for therapists or participants (100%), no allocation concealment (89%), and no blinding for assessors, failing to report if 85% participants completed reassessments and no intention to treat analysis (78%).

**Data extraction and synthesis**
Due to the absence of common types of massage interventions, comparator interventions and outcome measures in the included studies, it was not appropriate to perform a meta-analysis. A qualitative descriptive synthesis of the available data was undertaken instead. The subsequent intention was to compare within-group effect sizes of different interventions by calculating mean changes and 95% confidence intervals, based on means and standard deviations in each pre- and post-intervention arm (Table 4). Since pre-intervention baseline data were lacking in three studies, however, it was not possible to calculate effect sizes in those studies. Four first authors were contacted and requested to provide additional data to enable further analysis. This request was met from two author groups.
<table>
<thead>
<tr>
<th>Authors</th>
<th>Participants</th>
<th>Targeted Muscles</th>
<th>Massage Interventions</th>
<th>Comparator Interventions</th>
<th>Outcome Measures</th>
<th>Between-Group Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halperin et al. 2014</td>
<td>N = 28 14 collegiate active healthy participants (2 women and 12 men)</td>
<td>Triceps surae muscles</td>
<td>Self-massage with a roller massager (30 sec × 3 sets)</td>
<td>Active static stretching (30 sec × 3 sets)</td>
<td>MVC in ankle plantarflexion</td>
<td>Participants in the massage group showed significantly greater MVC 10 min after interventions compared to stretching. There was no difference in changes in single-leg balance between the 2 groups.</td>
</tr>
<tr>
<td>Healey et al. 2013</td>
<td>N = 52 26 college-aged healthy participants (13 women and 13 women)</td>
<td>Quadriceps, hamstring, biceps brachii, pectoralis major, and rhomboid muscles</td>
<td>Self-massage using a foam roller (30 sec for each muscle group)</td>
<td>Isometric exercises (eg. planks) to activate the same muscle groups (30 sec for each position)</td>
<td>Maximal isometric squat force, Vertical jump height, 5-10-5 yard shuttle run, Muscle Soreness, Fatigue, Perceived Exertion</td>
<td>Baseline data were not collected. According to the post-intervention data, there were no significant differences between foam rolling and plank for strength and functional performance.</td>
</tr>
<tr>
<td>Arroyo-Morales et al. 2011</td>
<td>N = 46 23 collegiate active healthy participants (11 women and 12 men)</td>
<td>Calf, hamstring, quadriceps and craniocervical muscles in the dominant side</td>
<td>Passive massage consisted of effleurage, petrissage and finally tapotement (a total of 20 min). They were performed by one physiotherapist.</td>
<td>Detuned, sham ultrasound was applied to the same part in the same position for the same amount of time. Participants were informed that ultrasound would be as effective as massage</td>
<td>Isokinetic peak torque in knee flexion and extension, Mood states, Salivary flow rate, Cortisol concentration, a-amylase activity, MDT</td>
<td>There were no statistically significant differences between the conditions for MVC and isometric force. Main effects for sets and duration demonstrated that evoked contractile force significantly decreased (p&lt;0.05).</td>
</tr>
<tr>
<td>Fletcher, 2010</td>
<td>N = 60 20 male collegiate athletes</td>
<td>Calf, tibialis anterior, hamstring, quadriceps and gluteal muscles</td>
<td>Passive massage consisted of effleurage and petrissage (a total of 9 min). They were performed by one massage therapist in superficial and fast manners.</td>
<td>Active warm-up exercises, Combined interventions of massage and warm-up</td>
<td>30-metre sprint performance, Time, Knee angular velocity, Step length, Step rate</td>
<td>Baseline data were not collected. According to the post-intervention data, participants in the massage alone group showed significantly increased time, and slower knee angular velocity and step rate, compared to warm-up alone group or the combined group.</td>
</tr>
<tr>
<td>Arabaci, 2008</td>
<td>N = 72 24 male active healthy participants</td>
<td>Gluteal, hamstring, quadriceps and calf muscles</td>
<td>Passive Swedish massage consisting of effleurage, friction, petrissage, vibration and tapotement, was performed by 2 masseurs simultaneously for 15 min.</td>
<td>15-min active stretching program for both lower limb muscles (20 sec × 2 sets for each)</td>
<td>Vertical jump, 30-metre sprint performance, Sit and reach test</td>
<td>Compared to rest, both massage and stretching led to significantly compromised 10-metre acceleration time and vertical jump, and significantly improved sit and reach test.</td>
</tr>
<tr>
<td>McKeechnie et al., 2007</td>
<td>N = 57 19 collegiate active healthy participants (8 women and 11 men)</td>
<td>Calf muscles</td>
<td>Passive massage performed by one massage therapist</td>
<td>Control: Participants lay in prone and therapists rested hands on each leg over calf for 3 min.</td>
<td>Drop jump performance, Dorisflexion ROM</td>
<td>Baseline data regarding jump performance were not collected. There was no significant change in jump performance in any groups. Dorisflexion ROM significantly increased in both 2 massage groups compared to the control group.</td>
</tr>
<tr>
<td>Miksky et al. 2002</td>
<td>N = 90 30 collegiate athletes (23 women and 7 men)</td>
<td>Hamstring, gluteal, calf and quadriceps muscles</td>
<td>Self-massage using the stick was performed for 2 min before each test.</td>
<td>Vertical jump, Flying-start 20-yard sprint, SLR with ankle dorsiflexed</td>
<td>Baseline data were not collected. According to the post-intervention data, there was no significant difference between 3 groups.</td>
<td></td>
</tr>
<tr>
<td>Harmer et al. 1991</td>
<td>N = 28 14 young male sprint-related athletes</td>
<td>Neck, shoulder girdle, chest, toes, foot, ankle, leg, thigh and buttoc muscules</td>
<td>Passive massage, including effleurage, petrissage and tapotement, were performed by one massage therapist for approximately 30 min in total.</td>
<td>Control: No intervention</td>
<td>Stride frequency</td>
<td>Baseline data were not collected. According to the post-intervention data, there was no significant difference between 2 groups.</td>
</tr>
</tbody>
</table>

MVC = maximal voluntary contraction in electromyography, EMG = electromyography, ROM = range of motion, MDT = mechanical detection threshold, SLR = straight leg raise.
* Nine participants were chosen for a control group.
### Table 3. Critical appraisal of included studies using the PEDRO scale.

<table>
<thead>
<tr>
<th>Study</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>Total</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halperin et al., 2014</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>4/10</td>
<td>Low</td>
</tr>
<tr>
<td>Healey et al., 2013</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>3/10</td>
<td>Low</td>
</tr>
<tr>
<td>Sullivan, et al., 2013</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>4/10</td>
<td>Low</td>
</tr>
<tr>
<td>Arroyo-Morales et al., 2011</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>5/10</td>
<td>Moderate</td>
</tr>
<tr>
<td>Fletcher, 2010</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>3/10</td>
<td>Low</td>
</tr>
<tr>
<td>Arabaci, 2008</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>7/10</td>
<td>High</td>
</tr>
<tr>
<td>McKeechnie et al, 2007</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>5/10</td>
<td>Moderate</td>
</tr>
<tr>
<td>Mikesky et al, 2002</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>4/10</td>
<td>Low</td>
</tr>
<tr>
<td>Harned et al, 1991</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>3/10</td>
<td>Low</td>
</tr>
</tbody>
</table>

**PEDro scale:**
1, eligibility criteria; 2, random allocation; 3, concealed allocation; 4, similarity at baseline; 5, blinding of participants; 6, blinding of therapists; 7, blinding of assessors; 8, measures of at least one key outcome from at least 85% of participants initially allocated to groups; 9, intention to treat analysis; 10, between-group comparison; 11, point measures and measures of variability
1= Yes (1 point), 0 = No (0 point), maximum score = 10 (criterion 1 is not included in scores)

### Table 4. A comparison of within-group effect sizes, when able to be calculated.

<table>
<thead>
<tr>
<th>Study</th>
<th>Outcome measure (timeframe)</th>
<th>Intervention</th>
<th>Effect size (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Halperin et al., 2014</strong></td>
<td>Maximal isometric force (1 min after)</td>
<td>RM*30s</td>
<td>0.05 (-50.61 to 50.70)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ST</td>
<td>-0.14 (-55.24 to 54.96)</td>
</tr>
<tr>
<td></td>
<td>Maximal isometric force (10 min after)</td>
<td>RM*30s</td>
<td>0.21 (-51.33 to 51.74)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ST</td>
<td>-0.28 (-52.92 to 52.36)</td>
</tr>
<tr>
<td></td>
<td>Single-leg balance test (1 min after)</td>
<td>RM*30s</td>
<td>-0.63 (-2.07 to 0.82)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ST</td>
<td>-0.80 (-2.65 to 1.05)</td>
</tr>
<tr>
<td></td>
<td>Single-leg balance test (10 min after)</td>
<td>RM*30s</td>
<td>-0.53 (-1.95 to 0.89)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ST</td>
<td>-0.35 (-2.34 to 1.64)</td>
</tr>
<tr>
<td><strong>Sullivan, et al., 2013</strong></td>
<td>Maximal isometric force</td>
<td>RM5s×1</td>
<td>-0.24 (-2.46 to 1.98)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RM5s×2</td>
<td>0.22 (-1.96 to 2.39)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RM10s×1</td>
<td>0.13 (-1.63 to 1.90)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RM10s×2</td>
<td>-0.09 (-1.54 to 1.35)</td>
</tr>
<tr>
<td><strong>Arabaci, 2008</strong></td>
<td>Vertical jump</td>
<td>SM15m</td>
<td>-0.34 (-1.85 to 1.17)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ST</td>
<td>-0.22 (-1.87 to 1.43)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RS</td>
<td>-0.03 (-1.84 to 1.76)</td>
</tr>
<tr>
<td></td>
<td>30-metre sprint</td>
<td>SM15m</td>
<td>-0.60 (-0.65 to -0.55)*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ST</td>
<td>-0.42 (-0.47 to -0.37)*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RS</td>
<td>-0.20 (-0.24 to -0.16)*</td>
</tr>
</tbody>
</table>

95% CI = 95% confidence interval, RM30s = Self-massage with roller massager (30 sec × 3 sets), RM5s1 = self-massage with roller massager (5 sec × 1 set), RM5s2 = self-massage with roller massager (5 sec × 2 sets), RM10s1 = self-massage with roller massager (10 sec × 1 set), RM10s2 = self-massage with roller massager (10 sec × 2 sets), ST = static stretching, FM6m = Self-massage with foam roller (6 min in total), PL = plank exercises, PM20m = passive massage (20 min in total), SU = sham ultrasound, SM15m = Swedish massage (15 min), RS = rest, PET6m = petrissage (6 min in total), TAP6m = tapotement (6 min in total), CON = control group with placebo massage, * = 95% CI not crossing zero.
Considering the apparently different effects of massage with different timeframes in chosen studies, where the nine-minute duration seemed to be a cut-off point to determine the effects massage on motor outputs, massage for less than nine minutes were defined as short-duration massage, while massage of nine minutes or longer was defined as long-duration for the purposes of this review.

**Effects of pre-performance massage on maximal muscle strength**

Three low-quality studies examined the effects of self- or machine assisted massage with a roller massager or a foam roller.\(^{19,20,22}\) Two studies showed no significant statistical difference between these massage interventions and other interventions, such as plank exercises and no intervention to improve maximal strength or MVC.\(^{20,22}\) The findings in one of these studies corresponded with the additional analysis with effect sizes, being not clinically significant (see Table 4). On the other hand, the most recent article found that self-massage with a roller massager resulted in significantly greater improvement in maximal strength of ankle plantarflexors compared to active 30-second static stretching.\(^{19}\) However, it should be noted that static stretching seemed to decrease maximal strength in this study, which was in line with the current evidence regarding longer-duration static stretching.\(^{27-29}\) In fact, further analysis revealed that effect sizes of the massage intervention used in this paper turned out to be small and not clinically significant (see Table 4). One moderate-quality article compared two different 12-minute passive massage techniques (petrissage and tapotement) and rest (no intervention), and found no significant difference between three groups to increase vertical jump height.\(^{21}\) The other two low-quality papers compared self-massage using a foam roller or the Stick (Intracell Technology, USA) with other interventions, including motor imagery, sham electrical stimulation or plank exercises, and found no statistically significant difference.\(^{3,20}\)

In summary, very limited evidence suggests no better immediate effects of massage using a roller massager or a foam roller on maximal strength compared to plank exercises or no intervention. There is very limited evidence suggesting that self-massage with a roller massager might be more effective than static stretching to improve maximal strength immediately. Limited evidence was also found that 20-minute pre-performance passive massage can lead to less maximal strength of knee extensors in the short term.

**Effects of pre-performance massage on vertical jump**

Four studies with varied methodological qualities investigated the effects of pre-performance massage on vertical jump or drop jump. One high-quality study found that 15-minute Swedish massage significantly compromised vertical jump height compared to no intervention.\(^{23}\) In further analysis, 95% confidence intervals of both interventions overlapped, which meant that the difference of effects is not significant (Table 4). One moderate-quality article compared two different 12-minute passive massage techniques (petrissage and tapotement) and rest (no intervention), and found no significant difference between three groups to increase vertical jump height.\(^{21}\) The other two low-quality papers compared self-massage using a foam roller or the Stick (Intracell Technology, USA) with other interventions, including motor imagery, sham electrical stimulation or plank exercises, and found no statistically significant difference.\(^{3,20}\)

In summary, there is limited evidence which suggests 15-minute Swedish massage can cause a decrease in vertical jump height. Limited evidence also suggests that 12-minute passive massage is not more effective than no intervention. There was very limited evidence which suggests that self-massage with a foam roller or the Stick are no more effective than motor imagery, sham electrical stimulation or plank exercises.

**Effects of pre-performance massage on sprint**

In one high-quality study, both 15-minute Swedish massage and static stretching led to significantly compromised sprint performance compared to rest (no intervention).\(^{23}\) Further analysis implied that 15-minute Swedish massage can have more adverse effects on sprint performance with moderate effect size, compared to static stretching or rest (see Table 4). One low-quality article found no significantly superior effects of 30-minute passive massage compared to no intervention to increase stride length.\(^{28}\) In one low-quality study nine-minute passive massage significantly undermined sprint performance compared to active warm-up exercises.\(^{25}\) Another low-quality paper found that self-massage using the Stick did not have superior effects compared to motor imagery and electrical stimulation.\(^{3}\)
In summary, there is limited evidence which suggests negative immediate effects of passive massage (nine to 15 minutes) on sprint performance. Very limited evidence suggests that 30-minute passive massage or self-massage using the Stick have no effects on sprint performance.

**Effects of pre-performance massage on balance and agility**

Balance function was assessed by only one study using single-leg balance test. This low-quality article found that self-massage with a roller massager did not improve the results of this test compared to active static stretching. Another low-quality study evaluated participants' agility with the 5-10-5-yard shuttle run and found no statistically significant difference between self-massage with foam roller and plank exercises.

In summary, there is no evidence to suggest positive effects of self-massage using a roller massager or a foam roller to improve balance or agility.

**Effects of short-duration passive pre-performance massage**

Only one study examined the effects of short-duration passive massage. In summary, very limited evidence suggests that there is no better immediate effects of passive massage using a roller massager on maximal strength.

**Effects of short-duration active pre-performance massage**

The effects of short-duration active massage were investigated by three studies. In summary, very limited evidence suggests that 30-minute passive massage or self-massage using the Stick have no effects on sprint performance. There is limited evidence that self-massage with a roller massager might be more effective than static stretching to improve maximal strength of plantar flexors immediately. Very limited evidence suggests no superior effects of self-massage using a foam roller to improve balance or agility, compared to plank exercises.

**Effects of long-duration passive pre-performance massage**

In total, five studies investigated the effects of long-duration passive pre-performance massage. In summary, limited evidence also suggests that 12-minute passive massage is not more effective than no intervention to improve vertical jump. There is limited evidence which suggests negative effects of passive massage (nine to 15 minutes) on sprint performance. Limited evidence suggests that 20-minute passive massage can lead to an acute decline in maximal strength of knee extensors.

**DISCUSSION**

The aim of this systematic review was to collect, assess and synthesise the findings of RCTs investigating the immediate effects of pre-performance massage on maximal muscle strength and/or functional performance. To the best of the authors’ knowledge, this paper is the first systematic review addressing this clinical question. The systematic search found nine crossover RCTs examining the effects of various types of massage techniques with varied dosages. Meta-analysis was not appropriate due to the absence of homogeneity of the included studies. Following the descriptive analysis using within-group effect sizes of interventions used in included studies, no evidence was found to support the positive effects of any kinds of massage interventions to enhance maximal strength, vertical jump, sprint, agility and balance performance of young healthy participants. In fact, there appears to be limited evidence which indicates the negative effects of passive manual massage. In particular, longer-duration (> 9 minutes) of passive massage interventions tended to result in negative effects on lower-limb maximal strength, sprint performance and jump height.

Although it is not entirely clear why massage can have negative effects on motor outputs, there are several hypotheses. Massage is thought to decrease stiffness and lengthen muscles. This means that massage can result in increased sarcomere shortening distance, which can decrease force production due to altered force-velocity relationship. Secondly, massage can temporarily increase mechanical threshold, decreasing afferent inputs from cutaneous tissues. This can lead to decreased motor unit activation. Thirdly, nociceptive input during massage is likely to result in reciprocal inhibition in antagonist muscles. This might explain a compromise in a functional performance, which
requires coordinated activations of all muscles. In addition to these peripheral mechanisms, a recent evidence suggests the involvement of central modulation. Massage might inhibit corticospinal excitability, leading to less motor outputs. Lastly, massage-induced increased parasympathetic nervous system activity might explain negative effects of massage as noted in the included studies.

**Source of bias and limitations of included studies**

Six out of nine RCTs had low methodological quality, which compromised the strength of the overall evidence presented in this review. None of the included RCTs blinded therapists or participants. However, blinding might be inherently difficult and impractical due to the nature of massage interventions. Most included papers (78%) failed to blind assessors, which might have caused observer bias. Four studies did not collect baseline data for primary outcome measures, which made it impossible to calculate within-group effect sizes. Failure to ensure the baseline comparability may also have resulted in less statistical precision in their findings. One low-quality study failed to report the sampling method for a control group, which was another source of bias.

**Limitations of this review**

Several limitations should be recognized in this review. The main limitation in this review lies in the fact that the primary outcome measures were restricted to immediate improvements in strength and functional performance. In fact, all studies focused on maximal strength, sprint or jump performances, but not other functional outcome measures, such as endurance. In reality, however, pre-performance massage might be performed for various reasons, such as preventing injuries and fatigue during sports performance, decreasing subjective stiffness and soreness and enhancing athletes' mood and confidence. Therefore, the overall effects of pre-performance massage for each individual athlete should be considered during the clinical decision-making process. This review was potentially biased due to its search strategy, where only studies published in peer-reviewed journals were included. This strategy can be subject to publication bias. This review failed to perform a subgroup analysis according to the types of massage techniques. Since passive manual massage and active self-massage might be different in nature and have different effects, the absence of a subgroup analysis can be another weakness of this review. Due to the lack of meta-analysis, it might have been difficult to achieve sufficient statistical power to overcome potential false negative results in individual studies. Lastly, no study investigating upper-limb strength or functions, such as throwing in baseball or tennis serves, was identified. It is unclear whether the findings achieved in this review are applicable to upper-limb strength and functions or not.

**Implications for Clinical Practice**

Based on the findings of this review, the use of pre-performance massage specifically to improve athletes' strength and functional performance should be reconsidered and challenged. The findings of this review indicate that longer duration (>9 minutes) passive manual massage techniques should not be used for the purposes of immediately enhancing young athletes' lower-limb maximal strength, vertical jump or sprint performance. Although there is no evidence which clearly demonstrates positive effects of any types of short-duration pre-performance massage techniques on strength and functional performance, these interventions might be justifiable to achieve other outcomes, such as increasing range of motion, preventing injuries and fatigue, and enhancing athletes' confidence and motivation, based on athletes' specific demands and clinicians' sound clinical reasoning.

**Implications for future research**

A great variability in the dosage of massage techniques has been identified. Future research needs to investigate potentially time-dependent effects of massage. This systematic review has highlighted prevalent risk of bias in the current research evidence. Since there is a serious lack of good-quality research, all findings in this review were inconclusive. Thus, it is recommended that future research should address the following methodological issues. Firstly, future research need to collect baseline data to allow more statistically accurate analysis. Secondly, blinding for assessors should be ensured.
to avoid observer bias in outcome measurements. Thirdly, future studies should conceal allocation in order to avoid sampling bias. Furthermore, future studies should describe data using exact values for mean, standard deviation, effect size and 95% confidence interval. To use critical appraisal tools, such as PEDro scale in designing research will lead to higher internal validity and a consistency across future RCTs, which may allow data pooling in future systematic reviews. Lastly, future primary or secondary studies are required to examine various outcome measures, including injury prevention, improvement in range of motion and endurance, and psychological benefits to complement the findings of this review and accurately assess the overall effects of pre-performance massage for athletes.

CONCLUSIONS
This study systematically reviewed RCTs investigating the immediate effects of pre-performance massage on strength and functional performance. Based on the narrative synthesis of the findings from nine crossover RCTs, there is limited evidence to suggest no positive immediate effects of any types of pre-performance massage on maximal muscle strength, sprint, jump, balance and agility performance among asymptomatic young subjects. Limited evidence also indicates the negative effects of longer-duration passive manual massage on lower-limb maximal strength, vertical jump and sprint performance. Future research with less methodological flaws are required to strengthen the evidence identified in this review.

REFERENCES


ABSTRACT

Background: A reliable measure of dynamic postural control is needed for inclusion in the sports-related concussion assessment battery. Currently, there is not a clinical gold standard. The Limits of Stability (LOS) test has potential to be a useful tool to collect objective data on important dynamic postural stability variables. Psychometric properties of the LOS test with healthy young adults are yet to be established.

Hypothesis/Purpose: The purpose of this study was to examine the intra-session and test-retest reliability for the LOS on the NeuroCom® VSR Sport when performed by young adults.

Study Design: Reliability study

Methods: Twenty-seven healthy university students completed four trials of the LOS in each of two testing sessions one week apart. Relative reliability was measured within each session with an intraclass correlation coefficient (ICC[3,k]) for Session 1 and Session 2, respectively, on each of the five dependent variables (movement velocity [MVL], directional control [DCL], maximum excursion [MXE], endpoint excursion [EPE], and reaction time [RT]) provided by the Neurocom. Test-retest reliability was assessed using a repeated-measures analysis of variance along with an ICC (3,k) for relative reliability. An ICC value of 0.90 or higher was defined as having a high reliability, moderate reliability for ICC values between 0.80-0.89, and below 0.80 as questionable.

Results: The reliability within each session for LOS composite scores for MVL, DCL, and MXE was moderate to high (ICC[3,k]=0.89-0.95). These same three variables also had high levels of test-retest reliability (ICC[3,k]=0.95-0.96). EPE and RT had moderate reliability over time (ICC[3,k]=0.88) but differences for within session reliability.

Conclusions: LOS provides a reliable measure of dynamic postural control for young adults. Two trials are recommended at baseline with the first being an adaptation trial to ensure accuracy of findings. Care needs to be taken when interpreting EPE and DCL scores on post-injury tests due to a learning effect for those variables.

Level of Evidence: 2c

Key Words: Balance, clinical test, dynamic postural control, reaction time

CORRESPONDING AUTHOR
Monica R. Lininger
Department of Physical Therapy and Athletic Training
Northern Arizona University
PO Box 15094
Flagstaff, AZ 86011
E-mail: monica.lininger@nau.edu

1 Northern Arizona University, Flagstaff, AZ, USA
2 Department of Physical Therapy, Lynchburg College, Lynchburg, VA, USA
3 Department of Athletic Training, Lynchburg College, Lynchburg, VA, USA

The authors have no conflict of interest to disclose.
INTRODUCTION
Postural control is used as part of an assessment battery for diagnosing sports-related concussions (SRC) and making return-to-play decisions for college athletes. The most commonly used tools assess postural steadiness, such as the ability to stand as still as possible under different conditions. Tests such as the Balance Error Scoring System (BESS) are clinically accessible, easy, and inexpensive to perform. However, reliability scores of the BESS have been found to be less than optimal and this test used in isolation may be insufficient for testing the postural control skills needed by athletes. Athletic participation requires complex dynamic postural control and rapid response to changing field conditions putting demands on visual and perceptual motor abilities. Tests of postural steadiness are found to return to baseline performance levels within three to seven days following SRCs; whereas deficits have been found in measures of dynamic postural control for a longer period of time, even after clearance for return to sport participation. It appears that tests of postural steadiness are not sensitive enough to identify subtle deficits and to follow changes throughout the concussion recovery time period. Further, performance on static and dynamic measures have been found to vary independently of each other suggesting that performance on these balance tests are not related. In summary, normal performance on a test of postural steadiness may not indicate that a person is prepared to accurately respond to dynamic demands on the playing field.

Currently, no gold standard exists for assessment of dynamic postural control for the young adult population, especially during on-field examination where sophisticated equipment may be unavailable or cumbersome. Gait studies have provided evidence of impaired dynamic postural control processes following SRCs, but the specialized equipment required for those studies limits clinical applicability. A need exists for a clinically accessible test of postural control that produces consistent, objective information about dynamic postural control variables that can also identify prolonged impairments. The Limits of Stability Test (LOS) performed on the NeuroCom® VSR Sport allows quantifiable variables of dynamic stability to be obtained in a clinically accessible manner due to its portability. Test-retest reliability and the practice effect need to be established as first steps in determining the usefulness of the LOS as part of a SRC management program for college athletes. Limits of stability testing has been studied using a variety of testing techniques resulting in differing reliability scores in healthy adolescents and young adults. To be clinically useful, an assessment must be able to establish a baseline within a few trials due to time constraints when performing pre-season testing with college athletes. Test-retest reliability of all five of the LOS variables was found to be moderate to high when performed on the NeuroCom® VSR Sport by healthy adolescents. However, this testing protocol had subjects perform only two trials so it is unknown if a true baseline was reached.

Establishment of a true baseline (prior to injury) is important for tests included in a pre-season and post-injury SRC management program to determine if change in performance can be attributed to injury rather than to test inconsistency. Further, test psychometrics need to be established for the population of intended use. Therefore, the purpose of this study was to examine the intra-session and test-retest reliability for the LOS on the NeuroCom® VSR Sport when performed by young adults.

METHODS
Participants
Twenty-eight healthy university students (7 men, 21 female; age: 24.4±1.6 years; height: 170.2±9.7 cm) volunteered to participate and completed informed consent approved by the college Institutional Review Board. Participants were recruited by an oral introduction and informed consent documents were left for interested individuals to complete. Participants had to be between 18 and 30 years old, not currently engaged in college sponsored athletics and verbally attest to having no injury, illness or condition that impaired balance or ability to see the computer screen. All participants completed the first testing session, but one was unable to schedule follow-up testing within the seven to ten day time period; therefore 27 participants completed the study. Sample size was estimated at 24 participants with a type I error of a 2-sided test set at 0.05, 80% statistical
power, and an effect size of 0.25 for the test-retest analysis.

Measures

The LOS test required participants to stand in a designated foot position, about hip width apart, on a fixed force plate. The computer screen, placed at eye level in front of the participant, depicted a center box with eight target boxes equally spaced in an elliptical arrangement around the center at the individual’s computer-generated limit of stability based on height. Participants were instructed to shift their weight so that the projection of their COP on the computer screen, indicated by an icon, was in the center box. All trials started with holding steady in the center (Figure 1). Participants were instructed, “When you see the circle jump to the target and hear the tone, shift your weight to move the icon as fast and accurately as you can to the target and hold steady until you hear a second tone.” Participants were free to use whatever movement strategy they chose as long as they did not lift or move their feet. All trials began with shifting to the target in the 12:00 (forward) position and moved sequentially in a clockwise direction.

Performance on five programmed variables set by the NeuroCom® VSR Sport was recorded for each trial in each of the eight directions: reaction time (RT), movement velocity (MVL), directional control (DCL), maximum excursion (MXE) and endpoint excursion (EPE) (Table 1). Reaction time is used as a measure of cognitive efficiency.21,22 For the LOS, the reaction time is recorded as the time from the cue to the time the COP sway exceeds the random range indicating volitional movement has begun.23 Movement velocity is the average speed of the center of gravity (COG) shift toward the target measured in degrees per second. Directional control is the amount of movement in the intended direction minus the amount of off-axis movement given as a percentage. Endpoint excursion is the distance traveled by the COG on the primary attempt to reach the target expressed as a percentage of the LOS. Endpoint excursion is considered to be a measure of an individual’s confidence in approaching their LOS.23 Maximum excursion is the furthest distance traveled.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Reaction Time</td>
<td>Time from the cue to the time the COP sway exceeds the random range indicating volitional movement has begun</td>
</tr>
<tr>
<td>Movement Velocity</td>
<td>Average speed of the COG shift toward the target measured in degrees per second</td>
</tr>
<tr>
<td>Endpoint Excursion</td>
<td>Distance traveled by the COG on the primary attempt to reach the target expressed as a percentage of the LOS</td>
</tr>
<tr>
<td>Maximum Excursion</td>
<td>Furthest distance traveled by the COG in a given trial</td>
</tr>
<tr>
<td>Directional Control</td>
<td>Amount of movement in the intended direction minus the amount of off-axis movement given as a percentage</td>
</tr>
</tbody>
</table>

Figure 1. Limits of Stability Test. The test begins in the center square. The first target is in the forward position and the test proceeds in a clockwise direction.
Composite scores were generated for each of the five variables by averaging the performance across all eight targets within a trial. Composite scores were found to demonstrate better reliability than individual target scores when the LOS was performed by high school students and aligns most closely with the current sample, according to the available literature.

**Procedures**
Participants attended two data collection sessions 7.8 ± 0.8 days apart. On both occasions they performed the LOS four times in a row with a two-minute break between trials to prevent fatigue. Although the number of trials may lead to overestimation of reliability, four trials were necessary in each session to examine practice effects. Demographic information was collected before the first trial on testing day one. Testing was performed on the NeuroCom® VSR Sport (Natus Medical Incorporated, Pleasanton, CA; Figure 2) with bare feet, and all data were sampled at rate of 100Hz. Participants were given a one-minute warm-up to practice shifting their COP in order to move the cursor icon to the target positions depicted on the computer screen. The force plate was calibrated to manufacturer specifications before each testing session. Both testing sessions took place in the same quiet room and participants were questioned to assure no illness or injury occurred between testing sessions that could impact performance.

**Statistical analysis**
Descriptive statistics were used to find means and standard deviations. Normality of data was assessed using the Kolmogorov-Smirnov test and the assumption was met (p > 0.05) for all dependent variables (reaction time, movement velocity, endpoint excursion, directional control, and maximum excursion). The possible presence of systematic error, such as a learning effect, was evaluated using a one-way repeated measure analysis of variance (RM ANOVA) for each of the five different dependent variables with trial as the independent variable (trials 1-4). If the assumption of sphericity was violated, a Greenhouse-Geisser adjustment was implemented. To measure relative reliability within each session, an intraclass correlation coefficient (ICC), specifically an ICC [3,k] model was used. The intra-session reliability was calculated separately for Session 1 and Session 2.

To compare differences between sessions, the four trials within each session were averaged together. Then the test-retest reliability was determined using a RM ANOVA for each of the five dependent variables stated above. A 2-way fixed effects model was used to determine the relative reliability (ICC [3,k]). An ICC value of 0.90 or higher was defined as having a high reliability, moderate reliability for ICC values between 0.80-0.89, and below 0.80 as questionable. Ninety-five percent confidence intervals

![Figure 2. NeuroCom® VSR Sport.](image)
RESULTS

Intra-Session Reliability

More variability was seen in Session 1 compared to Session 2. Differences were seen in reaction time (F_{1,92} = 3.52, p = 0.04) for Session 1, specifically between Trial 2 (0.60 ± 0.10) and Trial 4 (0.68 ± 0.17) (P = 0.02) with Trial 4 having a slower time. Endpoint excursion trials were different (F_{1,75} = 4.67, p < 0.01) for Session 1, only between Trial 1 (86. ± 7.) and Trial 4 (90. ± 5.) (p = 0.03). There were also differences between trials (F_{5,91.94} = 10.54, p < 0.01) for directional control, specifically between Trial 1 (79. ± 6.) and Trial 4 (84. ± 6.) (p < 0.01) and between Trial 2 (81. ± 7.) and Trial 4 (P < 0.01). However, there were no differences between trials for movement velocity (F_{1,66.41.50} = 1.71, p = 0.20) or maximum excursion (F_{3,78} = .89, p = 0.45) suggesting no learning effects for these two variables in Session 1. In Session 2, there were no learning effects as indicated by the lack of statistically significant differences (reaction time: F_{1,75} = 0.13, p = 0.91; movement velocity: F_{3,75} = 0.92, p = 0.44; endpoint excursion: F_{3,75} = 0.89 p = 0.45; and maximum excursion: F_{2.25.56.19} = 1.38, p = 0.26) except for directional control (F_{3,75} = 3.94, p = 0.01) which were different between Trial 5 (83. ± 6.) and Trial 7 (85. ± 4.).

Reliability was high for movement velocity in both Session 1 (ICC [3,k] = 0.92, 95% CI = 0.85-0.96) and Session 2 (ICC [3,k] = 0.95, 95% CI = 0.92-0.98). This was also true for directional control in both Session 1 (ICC [3,k] = 0.92, 95% CI = 0.87-0.96) and Session 2 (ICC [3,k] = 0.93, 95% CI = 0.88-0.97). For maximum excursion, the reliability was high in Session 2 (ICC [3,k] = 0.94, 95% CI = 0.89-0.97) but moderate for Session 1 (ICC [3,k] = 0.89, 95% CI = 0.79-0.94). Reliability was questionable in Session 1 for both reaction time (ICC [3,k] = 0.62, 95% CI = 0.31-0.81) and endpoint excursion (ICC [3,k] = 0.77, 95% CI = 0.59-0.89). Both of these measures, reaction time (ICC [3,k] = 0.88, 95% CI = 0.78-0.94) and endpoint excursion (ICC [3,k] = 0.87, 95% CI = 0.76-0.93) had moderate reliability values in Session 2.

Test-Retest Reliability

There were no significant differences between session averages for reaction time (t_{25} = -1.64, p = 0.11), movement velocity (t_{25} = -0.303, p = 0.765), or maximum excursion (t_{25} = -0.47, p = 0.64). However, there were significant differences between session averages for endpoint excursion (t_{25} = -3.28, p < 0.01) and directional control (t_{25} = -3.12, p < 0.01). The second session average was significantly higher (EPE: 90.29 ± 4.83 and DCL: 83.82 ± 4.56) than the first session (EPE: 87.90 ± 4.51 and DCL: 81.64 ± 5.78). Three of the five variables demonstrated high levels of reliability over time, between Session 1 and Session 2 (movement velocity: ICC [3,k] = 0.96, 95% CI = 0.93-0.98, SEM = 0.35; maximum excursion: ICC [3,k] = 0.95, 95% CI = 0.91-0.97, SEM = 0.64; and directional control: ICC [3,k] = 0.95, 95% CI = 0.91-0.97, SEM = 1.17 as seen in Table 1. Reaction time (ICC [3,k] = 0.88, 95% CI = 0.80-0.94, SEM = 0.04) and endpoint excursion ICC [3,k] = 0.88, 95% CI = 0.80-0.94, SEM = 1.61) had moderate reliability over time.

DISCUSSION

Tests for perceived stability limits have been used as a measure of dynamic postural stability.\textsuperscript{15,18,19} Comparison of reported reliability and learning effects for LOS testing is challenged due to variations in testing protocols, testing equipment and metrics reported. Unidirectional leaning tests from a stable platform have been found to demonstrate larger COP excursions with less variability than circling tests or those with a moving platform.\textsuperscript{18,19} Tompkins et al. hypothesize that circling is more difficult than leaning in the four cardinal directions (forward, backward, side to side) because circling requires control of movement in two directions at once.\textsuperscript{19} LOS testing performed with the NeuroCom® protocol requires the subject to shift center of gravity in eight directions: at a 45 degree diagonal toward each corner as well as in the four cardinal directions. The four corner leans require control in two planes at once, increasing the difficulty of the task and this may potentially provide more challenge than the four-way leaning test.
Reliability

Good test-retest reliability (ICC \([3,k]=0.88-0.96\)), and little practice effect, were found for five variables both within and between testing sessions in this study when the LOS was performed by young adults using the portable NeuroCom® VSR Sport, a stable platform system. Our findings are higher than the reliability reported by Pickerill and Harter (ICC \([2,k]=0.69-0.88\)) when they tested LOS with young adults.\(^1\) Differences in methodology may contribute to the difference in findings for the three variables they reported (DCL, MVL, EPE). Pickerill and Harter\(^1\) had subjects perform the LOS assessments on two different pieces of equipment during both of their testing sessions. The NeuroCom® Smart Balance Master® utilized a short, stable force plate and visual surround whereas the Biodex® DLOS test had subjects standing on an unstable platform.\(^1\) Different postural control demands are created under the two different conditions potentially causing interference in test performance and reducing reliability for both testing protocols. It is also possible that four trials in each of the testing sessions may have led to overestimation of reliability. However, the current findings are similar to others\(^1,15\) who used fewer trials when testing with the NeuroCom® VSR Sport. Alsalaheen et al.\(^15\) had adolescent subjects perform one practice trial and one testing trial in each of two sessions, one week apart. They reported test-retest reliability as ICC\([2,1]=0.81-0.96\) for RT, MXE, MVL and EPE.\(^15\) They also had subjects perform assessments other than LOS during the testing sessions, but in their study the other assessments examined postural steadiness.\(^15\) It seems the steadiness tests did not interfere with consistency of LOS performance since their reliability scores are quite good. Both the Pickerill and Alsalaheen studies reported the lowest reliability (0.69 and 0.73, respectively) and the widest confidence interval for DCL.\(^15,18\) This conflicts with the present findings in which DCL demonstrated excellent reliability (0.95) and a narrow confidence interval (95% \(\text{CI}=0.91-0.97\)) indicating good test precision. The subjects in this study were allowed to move however they naturally would, so long as they kept feet down in place on the force plate. In the other studies subjects were constrained to keep their arms crossed on their chest,\(^19,20\) palms on their thighs,\(^15\) and/or their body rigid without flexing knees or hips.\(^18\) Constraining individual movement strategy may impact consistency of performance and therefore lower reliability findings for directional control. There was a

| Table 2. Test-Retest Reliability Measures, presented as means +/- SD's. |
|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
|                        | Session 1              | Session 2              | ICC (95% CI)           | SEM                    |
| **Time**               |                        |                        |                        |                        |
| Reaction               | 0.64±0.10              | 0.61±0.10              | 0.66±0.15              | 0.67±0.16              | 0.67±0.18              | 0.88                    | (0.80, 0.94)           |
| Movement               | 6.1±1.5                | 6.7±1.9                | 6.5±2.3                | 6.4±1.9                | 6.7±1.8                | 6.7±1.9                | 6.6±2.1                |
| Velocity**             |                        |                        |                        |                        |                        | 0.96                    | (0.93, 0.98)           |
| Endpoint†              | 85±7                   | 89±5                   | 90±5                   | 91±5                   | 90±7                   | 0.88                    | (0.80, 0.94)           |
| Maximum†               | 96±5                   | 95±5                   | 95±4                   | 95±5                   | 96±4                   | 0.95                    | (0.91, 0.97)           |
| Directional Control‡   | 80±6                   | 82±7                   | 82±7                   | 84±6                   | 83±5                   | 0.95                    | (0.91, 0.97)           |

*measured in seconds
**measured in degrees per second
†measured as percent of projected 100% LOS
‡measured as percent of movement in the right direction compared to off target trajectory
learning effect for DCL when scores were examined for differences within and between testing sessions. Learning effects were not addressed in the previous studies, but could contribute to the lower DCL reliability scores reported by other authors.\(^\text{15,18}\)

**Learning effects**

Four trials in each testing session were necessary to examine practice effect in this study. Three variables, RT, MVL, and MXE, reached baseline by the second trial. Two variables, EPE and DCL, demonstrated a small practice effect beyond the second trial. Improvement in EPE in the first testing session occurred primarily between Trials 1 and 2 with no significant difference seen between consecutive trials in either testing session after the second trial. However, when scores for all four trials in each testing session were averaged, scores were slightly higher in the second testing session for both EPE and DCL. Directional control scores persisted with small improvements in consecutive within session trials indicating that a clear baseline was never established. Healthy young adults continue to show small improvements in EPE and DCL, so any decrement in post-testing performance may be considered an abnormal response. Directional control could be clinically important in the prevention of further injuries, for example, in soccer, when two players go up to head the ball at the same time, inaccuracy in directional control, of even a few degrees, could cause a player to connect with another player's head instead of with the ball. Therefore, careful consideration must be taken by clinicians in interpretation of post-test scores for directional control.

Clinicians and researchers provide acclimation time and practice trials to mitigate the impact of learning in an attempt to obtain true ability scores when testing. The number of trials suggested when performing tests of stability limits varies from two to eight depending on testing methods.\(^\text{15,18,19}\) Thomsen et al. suggest performing eight trials when using the four-way leaning test, since they found a learning effect up to the eighth trial.\(^\text{19}\) The high number of trials reduces clinical usefulness due to time factors, especially since the only metric obtained is excursion distance. Both Alsalaheen et al. and Pickerill and Harter provided three to five minutes of acclimation and had subjects perform two trials of the LOS using the NeuroCom® protocol.\(^\text{15,18}\) The current findings support the use of two trials, using the first as practice, unless a firm baseline is required for directional control. One-minute acclimation time appears to be sufficient for young adults according to the good reliability estimates found in this work, or better than studies providing longer times.

**Limitations and Future Directions**

Although this study is an important step in determining if the LOS test is reliable, the authors concede that only healthy volunteers were used as the purpose was to determine reliability for baseline concussion testing. Future studies are needed to determine the reliability across a sport season and to determine baseline testing modifiers, such as lower extremity injury, fatigue, or testing session, that could alter results and cause invalid scores. Determining the sensitivity and specificity to identify concussion injury and to monitor recovery is a vital next step in determining the clinical usefulness of LOS testing using the NeuroCom® VSR Sport. Future studies should aim to measure these metrics as well as others such as odds-likelihood ratios. Finally, the authors caution against broad generalizations in the direct application of the data as they were collected from a small, convenience sample of college aged individuals.

**CONCLUSIONS**

Composite scores from all five variables obtained with LOS testing performed by young adults on the NeuroCom® VSR Sport show moderate to high test-retest reliability. Two trials are recommended to establish a baseline for MXE, RT and MVL. Caution is advised in interpreting EPE and DCL results since a practice effect was found for those variables. The LOS on the NeuroCom® VSR Sport is a reliable test of dynamic postural stability for young adults which may offer more challenge than tests of steadiness.

**REFERENCES**


ABSTRACT

Background: Oculomotor function is impaired when an individual has a concussion and as such, it is important to identify tests that are able to assess oculomotor impairment. The King-Devick (K-D) test assesses horizontal saccadic eye movement and attention. The Developmental Eye Movement (DEM) test is designed to identify oculomotor dysfunction in children. It measures both horizontal and vertical saccades. The K-D test shows promise as a concussion-screening tool and part of a multifactorial assessment. The DEM has not been tested as a concussion assessment tool, but the neuroanatomical control of horizontal and vertical saccades originates from different areas of the brain, so one might expect to see differences in performance on the K-D and DEM tests when administered to concussed patients. First, it is important to determine if performance on the DEM and K-D tests, particularly with respect to the measurement of vertical and horizontal saccades, is similar in a healthy population.

Hypothesis/Purpose: The primary purpose was to evaluate the relationship between horizontal and vertical saccade tests over repeated trials in normal, healthy subjects. A secondary purpose of this study was to determine the number of trials needed to reach a performance plateau for both the DEM and K-D tests.

Study Design: This study used a prospective cohort research design

Methods: Forty-two healthy non-concussed participants (22 males, 20 females; mean age, 24.2 ± 2.92 years) completed six repeated trials of both the DEM, and then six trials of the K-D test in a single testing session. Trials within each test were performed in random order and participants were offered short rest breaks as needed between test administrations.

Results: Results indicated strong correlations, r = .67, or greater, between measurements of horizontal and vertical saccades. Performance plateaued on the K-D at trial three and on the DEM at trial two for both horizontal and vertical saccades.

Conclusion: It appears that the DEM and K-D tests measure similar constructs in healthy individuals and that no additional information is provided by assessment of vertical saccades. Additional studies are required to investigate the usefulness of the DEM in concussed individuals.

Level of Evidence: 3: Laboratory study with repeated measures.

Key words: Concussion baseline testing, ocular motor dysfunction, saccades

1 Northern Arizona University, Program in Physical Therapy, Flagstaff, AZ, USA
2 Department of Interdisciplinary Health Sciences, A.T. Still University, Mesa, AZ, USA
3 Athletic Training Programs and School of Osteopathic Medicine in Arizona, A.T. Still University, Mesa, AZ, USA

The authors have no financial disclosures or conflict of interests to report. The authors have no commercial or proprietary interest in the Developmental Eye Movement test or the King-Devick test.

CORRESPONDING AUTHOR

John D. Heick, PT, PhD, DPT
Northern Arizona University
PO Box 15105, Flagstaff, Arizona 86011
Telephone: 928-523-8394
Fax: 928-523-9289
E-mail: John.Heick@nau.edu
INTRODUCTION

Sport-related concussions are considered a public health issue\(^1\) because of the number of athletes who sustain concussions and the potential for cumulative effects following repeated injuries. Evaluation of the visual or oculomotor system has been incorporated into concussion assessment and continues to be investigated.\(^2\,4\) Ocular motor dysfunction following a concussion may include disruptions to convergence, accommodation, and smooth pursuit with or without disruptions to saccades or saccadic fixation,\(^4\) so evaluating oculomotor function may be beneficial. Currently, the King-Devick (K-D) test shows promise as an assessment of horizontal saccades, within a multifactorial concussion assessment battery.\(^2\,7\) The K-D test was created in 1976, as a modification of the Pierce Saccadic test,\(^8\) to assess the association of oculomotor dysfunction and learning disabilities.\(^9\) The K-D test was initially designed to mimic a child’s ability to read.\(^6\) As individuals quickly scan numbers on test cards, they are replicating the horizontal ocular motion that occurs when reading with abrupt, rapid, discrete jumps from number to number.\(^6\) The pause that occurs as individuals interpret the number is known as a saccadic fixation and requires gaze stability.\(^6\)

The Developmental Eye Movement (DEM) test was developed in 1990 and is similar to the K-D test, but in addition to assessing horizontal saccades it also incorporates two subtests of vertical saccades.\(^10\,11\) Research on the DEM has been limited to its use as an oculomotor function test for children. Similar to the K-D test, when an individual scans numbers on the vertical and horizontal cards, the eyes make abrupt, discrete jumps from one number to the next. Unlike the K-D test, the DEM assesses horizontal and vertical saccades.\(^6\,10\,12\) In one study investigating children, Garzia et al\(^12\) found excellent test-retest reliability for both the vertical (\(r = 0.89\)) and horizontal (\(r = 0.89\)) saccade times. However, these results were not replicated in a separate study\(^10\) that found third-grade children read the DEM vertical cards faster than the horizontal card. Lower reliability was also noted for both vertical (ICC = 0.60 (95% CI 0.32, 0.79)) and horizontal saccade tests, ICC = 0.55 (95% CI 0.25, 0.76).\(^10\) Interestingly, the majority of studies dealing with saccadic eye movements focus on horizontal saccades,\(^13\,17\) but it is important to investigate both horizontal and vertical saccades because the neuroanatomical control of these eye motions originates from different areas of the brain.\(^18\,21\) Specifically, horizontal saccades originating from the pons and vertical saccades involve the rostral mesencephalon.\(^22\,23\) Different neuroanatomical regions of the brain may be affected by a concussion and result in differential changes in saccade reaction times. Further, the saccadic fixation that occurs while the individual interprets the number is slower for horizontal than vertical saccades.\(^8\,10\,12\) The DEM test may provide additional information to concussion assessment since it measures both horizontal and vertical saccades.

During preseason baseline concussion assessment, the recommended procedure requires performing the K-D test twice. The lowest of the two trials, or fastest, is then used to determine the athlete’s baseline K-D composite score.\(^2\,3\,24\) This protocol, however, does not accommodate the potential practice effects associated with repeated administration of a novel test. When using performance tests, practice effects may be reduced by adding trials until a performance plateau occurs.\(^24\) Achieving a performance plateau during baseline concussion testing is important because it provides a stable reference against which performance can be measured following concussion. In a recent study, Heick et al\(^25\) showed that administering the K-D three times, and interpreting only trials 2 and 3 improved the reliability of the K-D test estimate of baseline performance.

The primary purpose of this study was to evaluate the relationship between horizontal and vertical saccade tests over repeated trials in normal, healthy subjects. A secondary purpose was to determine the number of trials needed to reach a performance plateau for both the DEM and K-D tests.

METHODS

The current study employed a prospective research design of a cohort to evaluate the relationship between the DEM and K-D tests across six repeated trials, and to determine the number of trials needed to reach a performance plateau in both tests for 42 healthy adolescents and adults. All experimental
procedures were approved by the A.T. Still University institutional review board.

Participants
Participants in the current study were between the ages of 14 and 35 years and possessed sufficient English skills to complete all tasks. Applicants with a diagnosis of a head injury in the past year and those with vision, vestibular, or balance disorders were excluded. Participants completed a personal/medical history form prior to testing which included questions about current reading levels, attention deficit disorder, learning disorders, and sports participation.

Participants were recruited through flyers distributed to public and private school systems in a metropolitan community. An initial telephone screening was used to ascertain eligibility and potential participants were provided information about the purpose of the study. All participants provided informed consent or the parent/guardian provided permission and the child assented.

Procedures
All testing was administered by the same investigator in a university research laboratory. Participants were permitted to use glasses or contacts, if desired. Standardized instructions were provided before performing the DEM and K-D tests. Participants completed the DEM, and then the K-D test. The six trials of both the DEM and the K-D tests were performed in random order during a single testing session and participants were offered short rest breaks as needed for no more than five minutes between test administrations. To determine the score for both tests, time began and ended when the first and last number was read on each testing card. This procedure was repeated for all test cards for six trials of both tests. To eliminate order effect, participants were randomly assigned the sequence of testing with either DEM or K-D test first.

Instrumentation

DEM Test
The DEM test is a rapid number-naming test that uses visual processing and cognitive demands for both vertical and horizontal saccades. Standardized instructions were used. The DEM test includes one practice card and three test cards. The sum of the time to complete the three test cards constitutes the summary score for the entire test, known as the DEM score. The first two test cards are composed of 40, single-digit numbers arranged in two vertical columns with equally spaced small vertical saccades. The third test card has 16 horizontal rows each with five unevenly spaced digits requiring horizontal saccades in order to read from left to right. The DEM test ratio is the horizontal score (test card three time corrected for any omission or addition errors) divided by the vertical score (time for test card 1 plus card 2). The DEM test ratio is designed to differentiate between an individual having poor saccadic function (assumed to give a better horizontal time and ratio) and poor ability to rapidly name numbers. There is evidence both for and against the use of the DEM test ratio, but the current evidence suggests that the DEM test cards may provide more important information than the DEM test ratio. Therefore, in the current study the DEM test ratio was not used. The six trials of the DEM test in the current study were performed with participants in a seated position and at a self-selected distance for reading. The time for each trial and the average of the three scores from each trial were recorded and used for statistical comparisons. The time required to complete each trial was measured by a stopwatch to the nearest hundredth of a second.

K-D Test
The K-D test is a screening tool that assesses impairment of eye movements, attention, language, and areas of the brain that correlate with suboptimal brain function. The K-D test is based on measurement of the speed of rapid number naming and involves reading aloud a series of single-digit numbers from left to right on three test cards that progressively increase in difficulty. Standardized instructions were used, and the test includes one practice card and three test cards. The sum of the time to complete the three test cards constitutes the summary score for the test, known as the K-D composite score. Each of the three K-D test cards is composed of eight rows with each row having five 20/100 reduced Snellen equivalent numbers (at a recommended 40 cm reading distance). A demonstration card is used to familiarize the participant with the K-D test. Card 1 consists of randomly spaced numbers connected by horizontal lines. Cards 2 and
RESULTS
The demographic characteristics of the 42 participants who completed testing (20 females, 22 males) are provided in Table 1.

### Relationship between Developmental Eye Movement and King-Devick Scores
Correlations between the DEM horizontal and vertical and K-D scores, within trial, were all, $r = .67$, or greater, as noted in Table 2. The correlation coefficients (all $p < 0.001$) increased nominally from Trial 1 to Trial 5, and then decreased on Trial 6. None of the differences between correlations for the horizontal and vertical scores on the DEM Test, within trial, were significantly different, $p > 0.15$.

### Developmental Eye Movement Score
A significant downward linear trend was also noted for the DEM composite score ($p = .021$), (Figure 2). Results of the Helmert contrasts for the DEM are provided in Table 5. Performance did not improve

---

**Table 1. Demographic Characteristics of the Healthy Young Adults (n = 42) included in the Current Study.**

<table>
<thead>
<tr>
<th>Demographic Characteristic</th>
<th>No. (%) or Mean (SD)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>22 (52.4)</td>
</tr>
<tr>
<td>Female</td>
<td>20 (47.6)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>24.3 (2.92)</td>
</tr>
<tr>
<td>Glasses/contacts</td>
<td>15 (35.7)</td>
</tr>
<tr>
<td>Attention deficit disorder</td>
<td>5 (11.9)</td>
</tr>
<tr>
<td>Sports history</td>
<td>42 (100)</td>
</tr>
</tbody>
</table>

*Age is reported as mean (SD).
Abbreviation: SD, standard deviation.

---

**Table 2. Pearson Correlation Coefficients for the King-Devick (K-D) Test and Horizontal and Vertical Developmental Eye Movement (DEM) Test Card Times Within Trial (N = 42)**

<table>
<thead>
<tr>
<th>Trial</th>
<th>Correlation between K-D Test and DEM Horizontal</th>
<th>Correlation between K-D Test and DEM Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.67</td>
<td>0.69</td>
</tr>
<tr>
<td>2</td>
<td>0.84</td>
<td>0.83</td>
</tr>
<tr>
<td>3</td>
<td>0.89</td>
<td>0.84</td>
</tr>
<tr>
<td>4</td>
<td>0.90</td>
<td>0.86</td>
</tr>
<tr>
<td>5</td>
<td>0.91</td>
<td>0.87</td>
</tr>
<tr>
<td>6</td>
<td>0.82</td>
<td>0.79</td>
</tr>
</tbody>
</table>
The reliability of the K-D composite score across the six trials was excellent, (ICC=0.98; 95% CI, 0.97, 0.99).

**DISCUSSION**

In the current study, the K-D and DEM tests appear to be measuring the same, underlying phenomenon, as there were no differences in the correlations between the K-D and DEM tests when the horizontal and vertical components of the DEM test were segregated. Both horizontal and vertical saccades are not independent, and the correlations between the horizontal and vertical components of the DEM test were significant, (ICC=0.98; 95% CI, 0.97, 0.99).
components of the Vestibular Ocular Motor Screening (VOMS) tool and recommended for inclusion in any ocular motor assessment of concussio

Recently, Anzalone et al. showed athletes reported dizziness symptoms primarily during the vertical saccade component and the vertical vestibular ocular reflex component of the VOMS post-concussion. It was also suggested that identification of specific vestibular/ocular motor abnormalities may aid clinicians in management of concussion and allow a targeted vestibular/ocular motor approach to address specific deficits of the athlete. The DEM and K-D

**Table 4. Results of Mean Comparison using Helmert Contrasts with Bonferroni Corrections for the King-Devick Test Across the Six Trials (n = 42).**

<table>
<thead>
<tr>
<th>Helmert Contrast</th>
<th>Contrast Estimate</th>
<th>Standard Error</th>
<th>p-Value (Bonferroni)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1 vs. later trials</td>
<td>2.87</td>
<td>0.60</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Trial 2 vs. later trials</td>
<td>1.54</td>
<td>0.45</td>
<td>0.002*</td>
</tr>
<tr>
<td>Trial 3 vs. later trials</td>
<td>1.62</td>
<td>0.36</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Trial 4 vs. later trials</td>
<td>0.32</td>
<td>0.31</td>
<td>0.52</td>
</tr>
<tr>
<td>Trial 5 vs. last trial</td>
<td>0.34</td>
<td>0.30</td>
<td>0.52</td>
</tr>
</tbody>
</table>

*Denotes statistically significant difference, p<0.05

**Table 5. Results of Mean Comparisons using Helmert Contrasts with Bonferroni corrections for the Horizontal and Vertical Developmental Eye Movement Test Cards Across the Six Trials (n = 42).**

<table>
<thead>
<tr>
<th>Helmert Contrast</th>
<th>Horizontal Contrast Estimate</th>
<th>Horizontal Standard Error</th>
<th>Horizontal p-Value (Bonferroni)</th>
<th>Vertical Contrast Estimate</th>
<th>Vertical Standard Error</th>
<th>Vertical p-Value (Bonferroni)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1 vs. later trials</td>
<td>2.27</td>
<td>0.54</td>
<td>&lt;0.001*</td>
<td>2.27</td>
<td>0.54</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Trial 2 vs. later trials</td>
<td>1.20</td>
<td>0.42</td>
<td>0.02*</td>
<td>1.20</td>
<td>0.42</td>
<td>0.02*</td>
</tr>
<tr>
<td>Trial 3 vs. later trials</td>
<td>0.53</td>
<td>0.53</td>
<td>0.97</td>
<td>0.53</td>
<td>0.53</td>
<td>0.97</td>
</tr>
<tr>
<td>Trial 4 vs. later trials</td>
<td>-0.23</td>
<td>0.63</td>
<td>&gt;0.99</td>
<td>-0.23</td>
<td>0.63</td>
<td>&gt;0.99</td>
</tr>
<tr>
<td>Trial 5 vs. last trial</td>
<td>-0.18</td>
<td>0.88</td>
<td>&gt;0.99</td>
<td>-0.18</td>
<td>0.88</td>
<td>&gt;0.99</td>
</tr>
</tbody>
</table>

*Denotes statistically significant differences, p<0.05
of a multifaceted concussion assessment and may include the DEM or K-D test to provide an objective measure of oculomotor function.

Both saccadic tests were originally designed to assess the association of oculomotor dysfunction and learning disabilities in children. The DEM test has not been evaluated as a potential concussion assessment tool. However, the K-D test has been evaluated in patients with concussion, multiple sclerosis, and Parkinson's disease. The administration of these two saccadic tests is similar in concept but different in format and interpretation.

The tests are also different in the way they assess the function of different neuroanatomical locations. The neuroanatomical correlates of function differ for the horizontal and vertical saccades. The caudal pons is an important neuroanatomical region for initiating horizontal saccades; whereas the rostral mesencephalon is associated with vertical saccades. Burst neurons, responsible for the ballistic movement of a saccade, are present in different neuroanatomical regions for horizontal and vertical saccades. The burst neurons responsible for horizontal saccades are located within the paramedian midbrain column.

**Figure 3.** Means and Standard Deviations of Developmental Eye Movement (DEM) Horizontal Test Scores for the Six Trials of the Healthy Young Adults in the Current Study (N = 42).

*Statistically significant, p < .05
The current study had several limitations. A convenience sample was used of graduate students, employees, and staff associated with a health sciences university as well as participants from local public and private school systems. When the study was initiated, there were two versions of the K-D test available: a spiral-bound version and a computer tablet version. Only the spiral-bound version of the K-D
The International Journal of Sports Physical Therapy | Volume 13, Number 5 | October 2018 | Page 816

Test was investigated in the current study. At present, the computer tablet version is the only version available for purchase. Raynowska et al.\(^{50}\) found good agreement (ICC = 0.92; 95% CI 0.83-0.96) between the two versions of the K-D test. These authors showed that lower scores on both the spiral bound and computer versions of the K-D test are associated with concussion.\(^{50}\) Future studies should examine the test-retest reliability of the computer version of the K-D and the DEM test to evaluate the learning effect of both of these tests. Another limitation was that the test-retest interval was brief, averaging 30 minutes. This interval may have caused some mental fatigue given the volume of rapid number identification over several trials. Future studies should include a longer test-retest time. If a baseline test is done and an athlete does not sustain a concussion until three months later, the test-retest reliability is not known. Finally, all testing was performed in a controlled laboratory environment without noise and distraction, which may not translate well to a real-life clinical assessment environment.

CONCLUSIONS

The results of the current study indicate that performances on both the DEM and K-D are strongly correlated, suggesting that the two tests are measuring similar constructs. In addition, two trials of the DEM were sufficient to achieve a performance plateau. Additional studies should investigate the usefulness of the DEM in concussed individuals.

REFERENCES


ABSTRACT

Hypothesis/Purpose: The purpose of this study was to assess relationships between active trunk rotation range of motion (TROM), upper quarter dynamic stability, and composite and individual item KJOC scores in collegiate baseball pitchers. A secondary purpose was to determine whether differences exist between baseball pitchers with and without an injury history in terms of their performance on TROM, upper quarter dynamic stability, and composite and individual KJOC scores. It was hypothesized that increased TROM and upper quarter dynamic stability are associated with better (higher) KJOC scores and pitchers with an injury history would exhibit lower KJOC scores compared to uninjured pitchers.

Study Design: Cross-sectional Cohort Study

Methods: Thirty-six college pitchers were assessed for TROM, performance on the Upper Quarter Y-Balance Test (YBT-UQ) and they also completed the KJOC. Subjects were grouped based on previous injury history: injured, required surgery, (IS, n = 9), injured, no surgery, (INS, n = 6), and uninjured (UI, n = 21). Pearson's Correlations were used to assess relationships between clinical measurements and the KJOC. One-way ANOVAs were used to assess differences in TROM, YBT-UQ, and KJOC scores between groups (P < 0.05).

Results: No significant relationships were detected between TROM measures and KJOC composite scores (throwing arm: \(r = \frac{.239}{}, p = 0.16\); non-throwing arm: \(r = \frac{.291}{}, p = 0.09\)). A moderate relationship was found between the YBT-UQ and the KJOC scores (throwing arm: \(r = \frac{.413}{}, p = 0.01\); non-throwing arm: \(r = \frac{.380}{}, p = 0.02\)). The mean KJOC scores for item 1 (warm-up limitations) were significantly different between all three groups (IS: 6.7, INS: 9.7, UI: 9.1; p = 0.015). Mean scores on item 5 (strain on relationships with coaches) and item 8 (limitations in competition endurance) were significantly different between the IS and UI groups (Item 5 = IS: 7.8, UI: 9.5, p = 0.02; Item 8 = IS: 6.4, UI: 8.8, p = 0.04).

Conclusion: A positive moderate association was found between upper quarter dynamic stability as measured by the YBT-UQ and the KJOC. Pitchers with no surgical history had better KJOC scores for warm up time, competitive endurance, and impact on team relationships.

Level of Evidence: 3

Key Terms: Baseball, Throwing, Trunk Mobility, Y-Balance Test

Acknowledgements: The authors would like to thank Sophia Ulman, Steven Heer, Justin Losciale, and Jason Shutt PT DPT for help in data collection.

Conflicts of interest: The authors declare that they do not have any conflict of interest with the authorship or publication of this contribution.

CORRESPONDING AUTHOR
Garrett Bullock, PT, DPT
Address: 47 Depot Street Chatham, VA 24531
Phone Number: (434) 432-0028
E-mail: garrettbullock@gmail.com
INTRODUCTION

Baseball is one of the most popular sports around the world and, as “America’s Pastime”, has over 13 million annual participants in the United States alone.\(^1\) Of those, nearly half a million high school students participate in baseball and more than 34,000 will go on to play at the collegiate level.\(^2\) Increasing concern has been raised regarding upper extremity injury, especially in pitchers.\(^3,4\) Posner et al.\(^4\) indicated that over a seven-year period in Major League Baseball, pitchers had a 34% increased injury incidence compared to fielders and that 62% of all disability days were due to injury in pitchers. Similar results were also found by Conte et al.,\(^5\) who concluded that 56.9% of the total disabled-list days were accrued by pitchers. Dick et al.\(^6\) found that in a 16-year period, 59.5% of college baseball injuries involved throwing, with pitching accounting for 73% of those injuries. Despite the high prevalence,\(^4,6\) clinicians continue to lack clear understanding of all the contributing factors.

To better care for baseball players, clinicians often screen and examine various movements in order to identify impairments that may contribute to injury.\(^7\) One common measurement researchers have investigated is active trunk rotation range of motion.\(^8-11\) During pitching there is a force exchange that takes place about the trunk, initiating in the lower extremity and progressing to the upper extremity.\(^11\) Adequate rotational motion is needed in the trunk during pitching to make this transfer of kinetic energy possible.\(^8-10\) In fact, Stodden et al.\(^9\) determined that increased upper trunk rotational momentum correlated to greater pitching velocity.

In addition to trunk rotational motion during pitching,\(^8\) trunk stability during dynamic motion may also play a role.\(^12,13\) Dynamic stability is the capability of an athlete to stabilize the body’s center of mass during distal extremity excursion.\(^14\) One test that incorporates upper quarter dynamic stability is the Upper Quarter Y-Balance Test (YBT-UQ) due to its combination of core and scapular stability demands as the subject reaches as far as possible with one upper extremity while weight bearing on the other, without loss of balance.\(^13\) The YBT-UQ integrates three reach directions: medial (M), inferolateral (IL) and superolateral (SL), in a unilateral three-point plank position.\(^13\) The YBT-UQ has been determined to be reliable for test-retest and inter-rater reliability.\(^12,13,15\) While pitching is considered an open chain movement of the upper extremity, previous authors\(^7,16,17\) have illustrated the importance of closed chain testing to fully examine upper quarter function. Butler et al.\(^7\) revealed no upper quarter dynamic stability differences between throwing and non-throwing upper extremities in uninjured high school baseball and softball players. Garrigues et al.\(^17\) observed that high school and collegiate baseball players performed equally on the YBT-UQ. Thus, closed chain testing appears to be suitable to effectively assess upper quarter dynamic stability.\(^7,17\)

Along with examining trunk rotation and upper quarter dynamic stability, sports medicine clinicians often use patient reported outcome measures to assess their athlete’s attitudes or subjective perceptions. The Kerlan-Jobe Orthopaedic Clinic Overhead Athlete Shoulder and Elbow Score (KJOC) is a 10-item questionnaire focused on the upper extremity in overhead athletes.\(^18-23\) The KJOC has been validated and shown to have reliability as a functional assessment tool in the overhead athlete.\(^19\) The KJOC has also demonstrated greater responsiveness than other outcome forms with regards to overhead athletes.\(^18,19,22\) Alberta et al.\(^19\) compared the KJOC to the Disabilities of the Arm Shoulder and Hand (DASH) and the DASH sports/performing arts module, finding the KJOC to be more responsive to changes in the overhead athlete. In addition to establishing reliability, they found that the KJOC scores correlated with athlete playing status on injury and injury history. As the injured athletes improved over time, so did their KJOC scores. Domb et al.\(^18\) compared the KJOC to both DASH versions and identified the KJOC as the most sensitive outcome measure for detecting subtle changes in throwing athlete performance. Neri et al.\(^22\) found the KJOC to be more accurate than American Shoulder and Elbow Surgeon’s score (ASES) in evaluating overhead athletes with superior labrum anterior to posterior (i.e., SLAP) repairs. In addition to comparing it with other outcome forms, researchers have attempted to establish normative data for the KJOC in baseball players\(^20,21\) and one author has suggested KJOC scores can be used to predict in-season injuries.\(^23\)
Despite being well studied in baseball players,\textsuperscript{18,20,21,23} there is a paucity of literature investigating the KJOC's relationship to clinical measures. This study will give clinical insight into whether or not healthy collegiate pitching populations need further clinical assessment, elucidated through an overhead athlete specific patient reported outcome measure. Further, this study will aid clinicians by offering a better understanding of how upper quarter dynamic stability and trunk rotation relate to patient reported outcomes, which then can be utilized as clinical benchmarks in overhead athlete return to sport criteria. Therefore, the purpose of this study was to assess relationships between active trunk rotation range of motion (TROM), upper quarter dynamic stability, and composite and individual item KJOC scores in collegiate baseball pitchers. A secondary purpose was to determine whether differences exist between baseball pitchers with and without an injury history in terms of their performance on TROM, upper quarter dynamic stability, and composite and individual KJOC scores. It is hypothesized that (1) greater trunk rotation and increased performance with upper quarter dynamic stability are associated with higher composite scores on the KJOC and (2) pitchers with an injury history will exhibit decreased trunk rotation, decreased upper quarter dynamic stability performance, and lower KJOC scores compared to their uninjured counterparts.

**METHODS**

**Participants**
A cohort of thirty-six college baseball pitchers were recruited for this study from three Division I universities. Data were collected prior to routine practices at the pitcher’s respective home practice fields during the pre-season. To avoid bias, subjects were included only if they were fully participating in all practices, training sessions, and pre-season games. Exclusion criteria consisted of a reporting of any current injury or pain while performing the active trunk ROM, the YBT-UQ, or during any baseball activity. Prior to participation, all subjects were informed of the risks and benefits and gave signed consent. Duke University’s Institutional Review Board approved this study. The subjects’ descriptive statistics are presented in Table 1.

**Procedures**

**Kerlan-Jobe Orthopaedic Clinic Overhead Athlete Shoulder and Elbow Score**
The KJOC score is comprised of demographic information and a 10-item questionnaire.\textsuperscript{18} Prior to all other data collection, the KJOC was administered to each subject. As part of the demographic information gathered for the KJOC score, players were asked about their injury and treatment history. This information, not included in the players KJOC score, was used exclusively to classify pitchers into injury groups. The 10-item questionnaire is a patient reported outcome for upper extremity functional performance in the overhead athlete. All 10 questions use a visual analog scale where the player marks an X along a 10-cm line, with the far right indicating higher function (10) and the far left indicating lower function (0). The mark was measured by a single rater to the nearest millimeter to obtain a numerical value for each question. The 10 questions were averaged to compute a composite score out of 100, with higher scores indicating higher function.

Based on the subjects’ responses to the historic injury and treatment questions, the following three groups were identified: pitchers with a previous injury requiring surgery (injured, surgical; IS, n=9), pitchers with a previous injury not requiring surgery (injured, no surgery; INS, n=6), and those with no injury history (uninjured; UI, n=21). All reported injuries were to either the shoulder girdle, shoulder, elbow, or forearm.

**Trunk rotation**
Active trunk rotation was assessed using a protocol studied by Johnson et al.\textsuperscript{24} who found it to be reliable when performed by more than one tester, within healthy active adult populations. This method utilized a standardized backless seat, with

<table>
<thead>
<tr>
<th>Table 1. Variables of interest before and after the low-intensity stiff-leg deadlift in normal and decreased hamstring flexibility groups.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Height (m)</td>
</tr>
<tr>
<td>Mass (kg)</td>
</tr>
<tr>
<td>Age (yrs)</td>
</tr>
</tbody>
</table>
hips and knees flexed to 90 degrees. To facilitate proper hip and knee alignment, the feet were elevated with dense foam pads of varying widths. A test administrator placed a ball (21 cm diameter) between the knees of each athlete and instructed subjects to lightly squeeze the ball. A 48” long dowel rod was placed anterior to the participant, across the middle of the manubrium, with the arms crossed in front of the dowel (Figure 1). The test administrator employed a calibrated electronic goniometer (PT Goniometer, Version 1.1, Copyright © Mark Busman, 2015), positioned parallel to the ground and located between the T1 and T2 spinous process, with C7 and the spine of the scapula utilized for orientation. Subjects were directed to maintain gaze direction at a point at eye level, while rotating to their maximum end range to one side. At rotation end range, the test administrator recorded the measurement. The averages of two trials of right and left trunk rotation were used for analysis.

Upper Quarter Y-Balance Test
The YBT-UQ, using a Y-Balance testing kit (Functional Movement Systems Inc., Chatham, VA, USA), was evaluated prior to warm up and pitching. Test administrators were all trained and certified in the YBT-UQ procedure (Functional Movement Systems Inc., Chatham, VA, USA). Upper extremity limb length was measured with a cloth tape from the seventh cervical vertebral spinous process to the tip of the longest finger on the right arm. Subjects were positioned standing with feet together, upper limbs abducted to 90 degrees, elbows extended and wrists in anatomic position. Subjects’ upper extremity limb length was measured twice for accuracy.

Before upper quarter dynamic stability testing, a test administrator educated each subject on the YBT-UQ protocol. Athletes were positioned in a three-point plank position with feet shoulder width apart. The support hand was placed on the centralized platform with the hand in the proper position according to the test guidelines. Subjects were instructed to adhere to the following standards during each test trial 1) three points of contact, consisting of the patient's two feet and support hand, were to be preserved throughout each trial, 2) to advance the reach indicator, momentum (i.e., a push) was not to be used, 3) only the designated area on the reach indicator was to be applied for progression, 4) increased stability was not to be extended by pushing on the top of the indicator, reach pole or the ground, 5) when returning back to the starting position, balance must be maintained by the reaching arm not touching the ground before coming back to the starting position. Athletes were instructed that if these criteria were not fulfilled, the test would be considered erroneous, and they would have to repeat the trial. In a three-point plank position, each pitcher pushed the reach indicator with most distal aspect of the opposite hand in the M, IL and SL positions (all reach directions are with respect to the stance limb) (Figure 2). All
three reaches were executed per trial. Two practice rounds and three data-collection trials were completed for both left and right limbs. After each trial, the instructor recorded the data and returned each reach indicator to their original positions. During data recording, the athlete volitionally initiated a rest break between trials. The maximum score for each reach direction (M, IL and SL) during successful trials was normalized to the measured limb length and used to compute the composite scores for the throwing and non-throwing arms.

Data Analysis
Unilateral data (i.e., average unilateral trunk rotation, and YBT-UQ composite scores) were organized into throwing and non-throwing arms for analysis. Pearson’s Correlation Coefficients (p < 0.05) were used to assess the relationships between the clinical measurements and the KJOC questionnaire. One correlation was used for each arm (throwing and non-throwing) to evaluate the relationship between unilateral trunk rotation and KJOC composite scores, as well as YBT-UQ composite scores and KJOC composite scores, resulting in a total of four analyses.

To address the second purpose of the study, one-way ANOVAs were used to assess differences in trunk rotation, YBT-UQ scores, and KJOC (composite and individual questions) and scores between the three groups (p < 0.05). Tukey’s Post hoc was used for each of the significant contrasts to determine where differences were observed. Alpha was set at 0.05. Statistical analyses were completed using SPSS 21 (SPSS Inc., IBM, Chicago, Illinois).

RESULTS
No significant relationship was detected between measures of trunk rotation and the KJOC composite scores (throwing arm: r = .239, p = 0.16; non-throwing arm: r = .291, p = 0.09). However, a moderate, positive relationship was found between the YBT-UQ composite scores and the KJOC composite scores (throwing arm: r = .413, p = 0.01; non-throwing arm: r = .380, p = 0.02).

No significant differences were observed between throwing and non-throwing arms across groups in measures of trunk rotation (p= 0.714, P= 0.38) or upper quarter dynamic stability (p = 0.73, p = 0.91) (Table 2).

There was no significant difference in the KJOC composite score (p = 0.08) between the groups. However, the mean score for Item 1 (perceived limitations in warm-up) was different between all three groups, (Item 1 = IS: 6.7, INS: 9.7, UI: 9.1; p = 0.02) with the INS group reporting the greatest function. The mean scores on Item 5 (perceived strain on relationships with coaches) and Item 8 (perceived limitations in competition endurance) were also found to be significantly different between the IS and UI groups (Item 5 = IS: 7.8, UI: 9.5; p = 0.02 and Item 8 = IS: 6.4, UI: 8.8, p = 0.04) (Table 2).
DISCUSSION

Relationships between clinical measurements and patient reported outcome have potential to further the ability to clinically assess baseball pitchers. The two purposes of this study were: (1) to determine if there is a relationship between active trunk rotation, upper quarter dynamic stability, and KJOC questionnaire results, and (2) to determine if there are differences between pitchers with an injury history and those without in terms of their performance on active trunk rotation, upper quarter dynamic stability, and KJOC composite and individual scores. The first hypothesis was partially supported; the results of the current study suggest no association between trunk rotation and KJOC composite scores, but a moderate association exists between measures of upper quarter dynamic stability and KJOC composite scores in collegiate baseball pitchers. Regarding the second hypothesis, there were no differences between pitchers with an injury history and those without in terms of their performance on active trunk rotation, upper quarter dynamic stability, and KJOC composite and individual scores. The current study analyzed active trunk range of motion as a controlled clinical measurement and no correlation was identified between active trunk rotation and the KJOC composite score. This may be due to fact that the KJOC assesses overall throwing function and does not have a specific rotation component to the patient reported outcome when compared to uninjured players, and all three groups differed on one item (Item 1).

### Relationship between trunk rotation, upper quarter dynamic stability, and KJOC scores

There was not a significant relationship between active trunk rotation range of motion and KJOC scores. Laudner et al. assessed active trunk rotation range of motion in baseball players, and they observed decreased active trunk range of motion on both throwing and non-throwing sides (48.8 ± 6.4 deg. vs. 51.9 ± 6.6 deg, respectively) compared to the current study (69.6 deg. vs. 70.7 deg., respectively). Furthermore, other 3D biomechanical studies have measured upper trunk rotation during pitching, and demonstrate active trunk range of motion values very different from our own (52-55 degrees). The current study analyzed active trunk range of motion as a controlled clinical measurement and no correlation was identified between active trunk rotation and the KJOC composite score. This may be due to fact that the KJOC assesses overall throwing function and does not have a specific rotation component to the patient reported outcome when compared to uninjured players, and all three groups differed on one item (Item 1).

### Table 2.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Injured, surgical (IS), n=9</th>
<th>Injured, no surgery (INS), n=6</th>
<th>Uninjured (U), n=21</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk Rotation:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Throwing Side (degrees)</td>
<td>70.1 ± 8.4</td>
<td>66.6 ± 7.6</td>
<td>69.9 ± 9.8</td>
<td>0.71</td>
</tr>
<tr>
<td>Non-throwing Side (deg)</td>
<td>70.4 ± 8.6</td>
<td>75.5 ± 6.8</td>
<td>69.4 ± 10.3</td>
<td>0.38</td>
</tr>
<tr>
<td>YBT-UQ Composite:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Throwing Side</td>
<td>91.0 ± 11.3</td>
<td>94.3 ± 7.1</td>
<td>94.1 ± 10.9</td>
<td>0.73</td>
</tr>
<tr>
<td>Non-throwing Side</td>
<td>93.2 ± 9.1</td>
<td>94.9 ± 6.0</td>
<td>94.7 ± 9.4</td>
<td>0.91</td>
</tr>
<tr>
<td>KJOC Composite</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>74.2 ± 22.6</td>
<td>89.9 ± 9.0</td>
<td>86.8 ± 12.1</td>
<td>0.08</td>
</tr>
<tr>
<td>KJOC Item 1</td>
<td>6.7 ± 3.6</td>
<td>9.7 ± 0.5</td>
<td>9.1 ± 1.6</td>
<td>&lt;0.02*</td>
</tr>
<tr>
<td>KJOC Item 2</td>
<td>8.2 ± 2.3</td>
<td>8.0 ± 2.4</td>
<td>8.3 ± 2.1</td>
<td>0.94</td>
</tr>
<tr>
<td>KJOC Item 3</td>
<td>7.1 ± 2.7</td>
<td>8.6 ± 1.4</td>
<td>7.7 ± 1.7</td>
<td>0.38</td>
</tr>
<tr>
<td>KJOC Item 4</td>
<td>8.0 ± 2.5</td>
<td>9.3 ± 1.6</td>
<td>9.1 ± 1.2</td>
<td>0.25</td>
</tr>
<tr>
<td>KJOC Item 5</td>
<td>7.8 ± 2.8</td>
<td>10.0 ± 0.0</td>
<td>9.5 ± 1.1</td>
<td>0.02†</td>
</tr>
<tr>
<td>KJOC Item 6</td>
<td>7.3 ± 2.8</td>
<td>9.2 ± 1.4</td>
<td>8.5 ± 2.0</td>
<td>0.26</td>
</tr>
<tr>
<td>KJOC Item 7</td>
<td>7.4 ± 3.4</td>
<td>8.6 ± 2.9</td>
<td>8.8 ± 1.7</td>
<td>0.32</td>
</tr>
<tr>
<td>KJOC Item 8</td>
<td>6.4 ± 4.0</td>
<td>9.3 ± 1.3</td>
<td>8.8 ± 1.7</td>
<td>0.04†</td>
</tr>
<tr>
<td>KJOC Item 9</td>
<td>7.8 ± 2.4</td>
<td>9.0 ± 1.8</td>
<td>8.5 ± 1.9</td>
<td>0.54</td>
</tr>
<tr>
<td>KJOC Item 10</td>
<td>7.4 ± 3.3</td>
<td>8.7 ± 1.5</td>
<td>8.0 ± 2.5</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Notes: *= all groups significantly different, †= differences between injured, surgical and uninjured groups YBT-UQ= Upper Quarter Y-Balance Test
measure. A meaningful relationship between the two may provide a clinical advantage, affecting functional outcomes in the rehabilitation setting.

Upper quarter dynamic stability, assessed using the YBT-UQ, provides a composite measure of mobility, strength and stability.12,13 The results of the current study indicate that a moderate, positive relationship exists between YBT-UQ scores and the KJOC composite scores for both the throwing and non-throwing arms. There was no difference in throwing versus non-throwing YBT-UQ composite scores, which is consistent with the literature.7 The overall YBT-UQ composite scores were also similar to previous studies.7,17 As a result, upper quarter dynamic stability testing may be applied as a screen or measurement in return to sport criteria in conjunction with the KJOC. Understanding the relationship between upper quarter dynamic stability and an overhead athlete reported outcome measure may help practitioners better quantify athlete pitching injury susceptibility or acceptability to return to sport following injury.

**Differences in trunk rotation, upper quarter dynamic stability, and KJOC scores between groups**

When pitchers were divided into groups based on their injury histories, no group differences were observed for active trunk rotation or YBT-UQ performance. The YBT-UQ requires trunk rotation, especially during the SL and IL reaches.7 These findings suggest that all pitchers within this sample had the required active trunk rotation range of motion necessary to perform the YBT-UQ.

Several differences were identified between players with various injury histories on individual KJOC item scores. All three groups differed significantly on Item 1 (Question: How difficult is it for you to get loose or warm up prior to competition or practice? Scale: 0-Never feel loose during games or practice, 10-Normal warm-up time).19 Specifically, IS had lower scores compared UI which, surprisingly, also scored lower than INS. Interestingly, pitchers from the INS group reported better ability to warm up compared to their uninjured counterparts. This could be due to INS pitchers having been fully evaluated and treated for all physical impairments. Furthermore, additional skills gained during rehabilitation in which strategic and comprehensive warm-up or stretches were taught could be a factor. This highlights the fact that there may be underlying physical impairments in fully participating and competing pitchers. These insidious impairments may be causing undue stress and strain during throwing and pitching, and thus affecting warm up, among other factors such as recovery between pitching sessions. Administering clinical physical exams to all pitchers, no matter their health status, could be conducive to identifying physical impairments that otherwise would not be recognized until after injury occurrence.

The IS group also had significantly lower scores on Item 5 (Question: How much have arm problems affected your relationship with your coaches, management, and agents? Scale: 0-left team, traded or waived, lost contract or scholarship, 10-not at all) and Item 8 (Question: What limitation do you have in endurance in competition due to your arm? Scale: 0-Significant limitation [became relief pitcher, switched to short races for example], 10-No endurance limitations in competition) compared to the UI group. Franz et al.20 administered the KJOC during three different time points to major league and minor league baseball players over the course of one calendar year. In contrast to this study’s results, they found players with a history of injury, both requiring surgery and not requiring surgery, had significantly lower composite KJOC scores than those without upper extremity injury histories. Furthermore, the mean composite KJOC score in professional baseball pitchers from their study (90.9) differed from the current study’s mean composite KJOC score in college baseball pitchers (82.4). Kraeutler et al.21 identified a mean total KJOC score of 94.8 in 44 professional baseball pitchers, and found that in AAA baseball players scored higher than AA players. Like the current study, Paci et al.22 identified a lower mean total KJOC score (86.9) in college pitchers than that reported by minor league and professional pitchers in the studies by Franz and Kraeutler.20,21 Collectively, these results suggest that higher-level pitchers have better perceptions of their throwing arms than pitchers at lower levels, according to patient reported outcomes.

The KJOC Composite score between the three groups were not different. This is consistent with Alberta et al.19 in which fully participating and healthy overhead
athletes had similar KJOC scores, no matter previous injury history. While there were differences between different individual questions, only the overall composite score has been validated.\textsuperscript{18} The KJOC composite scores may not have the clinical sensitivity to fully detect small variations and decrements in fully participating college baseball pitchers.

There is a need for future research following these findings. There is little understanding between the relationship of active and passive trunk rotation, YBT-UQ, and injuries. Prospective investigations are needed to comprehend if there is a relationship between these clinical assessments and injuries. As previously stated, the use of individual KJOC questions has not been validated. In light of this study’s findings, further research is necessary to understand if each individual KJOC question can be used independently as a patient reported outcome measure, and has the clinical utility to identify pitchers that are more at risk for injury. Lastly, more analysis is required to understand if the composite KJOC score has enough clinical sensitivity to identify pitchers with past injury histories that may still have physical impairments affecting their injury risk.

**Limitations**

As with all studies, there were limitations to this study. A cross-sectional cohort design was utilized for this exploratory analysis. This methodological approach permitted data to be collected at one time point, and pre-season testing was intentionally chosen in an effort to avoid potential confounding effects of overuse or fatigue related injuries. It is possible that the correlations between trunk rotation ROM and the KJOC, and the upper quarter dynamic stability and the KJOC may change throughout a season. As a result, a longitudinal study to understand how these relationships change throughout a competitive season is warranted. This investigation did not include previous training history. Each college program has different practice and training habits that may have affected the data. Understanding this potential selection bias, a variety of college baseball programs were incorporated into the data collection in an effort to make the results more generally applicable to this population. Furthermore, while this study recruited a sufficient number of subjects to potentially discern a difference between groups, overall this study had a low number of subjects. Further studies are needed with higher power to investigate relationships between the KJOC, trunk rotation, and upper quarter dynamic stability. Lastly, this investigation utilized a stationary, seated method to analyze trunk rotation,\textsuperscript{24} while past studies\textsuperscript{26,27} have measured range of motion using 3D biomechanical analysis during pitching. This relationship between a clinical test showing active range of motion and biomechanical measurements of utilized range of motion during pitching should be further evaluated. Research aimed at identifying methods of assessing trunk rotation in pitchers, which do not require expensive motion capture technology, is desirable.

**CONCLUSIONS**

The results of the current study demonstrated no significant relationship between KJOC scores and trunk rotation among collegiate baseball pitchers. However, there was a moderate association between measures of upper quarter dynamic stability and the KJOC composite score in Division I collegiate pitchers. This study found that compared to college baseball pitchers with a surgical history, pitchers without a surgical history had significantly higher KJOC scores for warm up time, competitive endurance, and impact on team relationships. Surprisingly, pitchers with injuries that did not require surgical intervention reported greater perceived function than their uninjured counterparts. Players with a surgical history reported decreased relationship with coaches and throwing endurance when compared to those without an injury history. Future studies should continue to investigate the important relationship between functional and patient reported outcome measures to inform clinical practice regarding the examination of the throwing shoulder.

**REFERENCES**


ABSTRACT

Background/Purpose: Physical preparation in golf is now considered a key component of the game. With players becoming more athletic, warm-up has become an important area in a player's preparation for practice and competition. Much of the research to date has focused on the adult golfer, showing potential for improvements in clubhead speed, driving distance and shot quality, as well as reductions in injury risk. However, there is currently no work specifically investigating the impacts of warm-up in youth golf. The aim of this study was to examine the impact of a club only warm-up and a dynamic exercise routine followed by a club warm-up on club head speed and self-reported shot quality.

Methods: Using a counterbalanced repeated measures design, eight male and 13 female youth golfers completed a control (no warm-up), club only warm-up and an exercise based dynamic warm-up followed by club warm-up on three non-consecutive days. In each session, players were required to hit 10 maximal effort shots with a driver and clubhead speed (CHS) was recorded using a launch monitor alongside self-reported shot quality scores.

Results: Statistically significant improvements in clubhead speed and self-reported shot quality were seen in the dynamic warm-up combined with club warm-up. No significant differences were seen in the club-warm up only or control groups for either clubhead speed or self-reported shot quality.

Conclusion: A combined dynamic physical warm-up and club warm-up improves clubhead speed and self-reported shot quality in youth golfers. However, a club warm-up alone does not seem to be sufficient in eliciting these same improvements.

Level of Evidence: 3

Key words: Clubhead speed, golf, warm-up, performance, youth

CORRESPONDING AUTHOR

Mr. Daniel Coughlan
School of Sport, Rehabilitation and Exercise Sciences
University of Essex
Wivenhoe Park, Colchester
Essex, CO4 3SQ
E-Mail: d.coughlan@essex.ac.uk
Telephone Number: +44 (0)1206 873265

1 School of Sport, Rehabilitation and Exercise Sciences, University of Essex, Colchester, UK

The authors declare that we have no conflicting or competing interests in relation to this article.
INTRODUCTION
Golf is commonly thought of as a technical sport focussing on strategy and skill,\(^1\) however there is a growing recognition of the physical requirements of the game and a clear increase in the focus on physical preparation.\(^2\) Past research has demonstrated strong relationships between clubhead speed (CHS) and proficiency in the sport,\(^3,4\) with higher driving distance, as well as CHS showing strong associations with many athletic physical characteristics.\(^5,6\) Thus, physical preparation, for purposes of maximizing driver ball distance is now an essential component of the modern golfer’s routine.\(^7\)

Carrying out a full physical warm-up is a commonly accepted process for enhancing performance and mitigating injury risk across a range of sports.\(^8-10\) As such, golfers are employing these practices at the elite level, however there is currently no literature exploring the impact of warm-up on the youth golfer. In adult golfers, completing a warm-up in the form of preparatory dynamic exercises prior to competition has been shown as performance enhancing through demonstrable improvements in CHS.\(^11,12\) Moreover, a golf warm-up has been shown to improve driving distance,\(^12,13\) shot quality,\(^11,12\) flexibility\(^13\) and power,\(^13\) as well as having a potential conditioning effect when completed regularly,\(^14\) demonstrating the importance of these practices in golf. However, despite the evidence showing positive effects of warm-up in adult golfers, behaviors are often less than desirable, with many golfers completing inadequate warm-ups.\(^15,16\)

Researchers have demonstrated a need for dynamic rather than static based stretching as part of the warm-up routine. Significant decreases in CHS, driving distance and shot quality have been shown as possible consequences of static stretching immediately prior to golf.\(^11,17,18\) These findings are in line with those of other sports, where static stretching has been shown to acutely reduce explosive muscular performance.\(^19,20\) Use of bodyweight exercises, bands, weights, whole-body vibration and club specific warm-ups have all be shown to have positive effects on golf performance.\(^11,13,17,18\) Read et al\(^21\) also suggest post activation potentiation (PAP) through the use of explosive jumps can have a positive impact on CHS and there may be use in incorporating these techniques prior to particularly long shots whilst on the course.

The completion of a warm-up in golf may also have potential benefits in terms of injury risk reduction.\(^22\) Therefore, encouraging a player to successfully carry out a sufficient, well planned warm-up seems to be a desirable goal of any coach or therapist.

The effects of warm-up on youth athletes outside of golf is an area which has been researched extensively, often demonstrating positive effects on relevant performance measures\(^23-25\) and a reduction in injury rates.\(^26\) This clearly outlines a need for the inclusion of youth specific warm-up research within the sport of golf. Moreover, with evidence demonstrating poor warm-up habits in adult golfers,\(^15,16\) the inclusion of appropriate warm-ups within a youth golfer’s routine could be essential in creating positive behaviors related to warm-up at a young age. This could allow the golfer to enjoy all the proven benefits associated with this behavior when they progress to adulthood. Of note, many studies to date have required use of additional equipment for a warm-up,\(^12,13,17\) which may be off-putting or impractical for the youth golfer and reduce compliance. Creation of an evidence base for the youth golfer, especially with regards to warm-up, is essential to inform youth development programs, coaches, therapists and other associated professionals, so they can best support these aspiring young athletes. Given the lack of research into warm-up in the youth golfer, the aim of this study was to examine the impact of a club only warm-up and a dynamic exercise routine followed by a club warm-up on CHS and self-reported shot quality.

METHODS
Subjects
Eight male and 13 female youth golfers (handicap (HCP) 1.8 ± 2.8 strokes, age 16.6 ± 1.7 years) were recruited to take part in this study. At the time of testing, no golfers were suffering with injuries which impacted their ability to participate in golf. The players and guardians gave informed consent to take part in the study. They were also given a participant information sheet outlining the goals of the work. Ethical approval was granted by the University Ethics Committee.

Study Method
A counterbalanced repeated measures design was used, with subjects randomly assigned to
initial groups of either control, club only warm-up, dynamic and club warm-up. Testing was completed outdoors at several locations, using available driving range facilities. Each testing protocol was completed on separate, non-consecutive days. To obtain CHS values a TrackMan (ISG Company, Denmark) launch monitor was used. The system was calibrated per manufacturer instructions. On the control testing day, golfers were instructed to complete 10 maximal drives measured on the TrackMan system. Golfers could complete a self-defined number of practice swings and between maximal efforts golfers were required to take a one-minute rest. Golfers used their own drivers, and were blinded to their clubhead speed and other values from the launch monitor. Range balls were used for testing, in a variety of locations, and so only clubhead speeds were noted, and other metrics, such as ball speed, accuracy and driving distance were not considered due to the likely lack of reliability across testing locations. Clubhead speed was determined to be a more robust measure in varying conditions as it was less likely to be impacted upon by ball quality/type and weather conditions. On intervention days, golfers were required to complete either a club warm-up only or an exercise based dynamic warm-up which was immediately followed by the club warm-up (Table 1). Once the appropriate interventions had

<table>
<thead>
<tr>
<th>Dynamic Warm-up</th>
<th>Start position</th>
<th>End position</th>
<th>Club Warm-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>10x overhead squats</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td>4x shots for 3 different self-selected pitching distances</td>
</tr>
<tr>
<td>10x squat to overhead reach</td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
<td>4x full-swing shots with 8 iron</td>
</tr>
<tr>
<td>10x (5 on each leg) lunge and side bend</td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
<td>4x full-swing shots with 6 iron</td>
</tr>
<tr>
<td>10x (5 on each leg) lunge and rotate</td>
<td><img src="image7" alt="Image" /></td>
<td><img src="image8" alt="Image" /></td>
<td>4x full-swing shots with 4 iron</td>
</tr>
<tr>
<td>10x (5 on each leg) standing internal hip rotation</td>
<td><img src="image9" alt="Image" /></td>
<td><img src="image10" alt="Image" /></td>
<td>4x full-swing shots with 3 iron</td>
</tr>
<tr>
<td>10x (5 on each leg) single leg land and rotate</td>
<td><img src="image11" alt="Image" /></td>
<td><img src="image12" alt="Image" /></td>
<td>4x full-swing shots with rescue</td>
</tr>
<tr>
<td>10x (5 on each leg) lateral bound</td>
<td><img src="image13" alt="Image" /></td>
<td><img src="image14" alt="Image" /></td>
<td>4x full-swing shots with 3 wood</td>
</tr>
<tr>
<td>Complete all the above twice</td>
<td><img src="image15" alt="Image" /></td>
<td><img src="image16" alt="Image" /></td>
<td>4x full-swing shots with driver</td>
</tr>
</tbody>
</table>
been completed, the golfers were required to take 10 maximal effort shots, measured on the ball launch monitor as per control testing. Mean scores of the 10 shots were used when analysing the data. During all measured shots, golfers were also required to give a self-reported shot quality score (0-10), where 0 represented the golfers worst possible shot and 10 was representative of their best possible shot. Both warm-up conditions were developed through modification of previous literature in consultation with experienced national level golf coaches. The warm-up variations were also developed with no equipment beyond standard golf clubs to enhance the relevance to youth golfers.

### STATISTICAL METHODS

Statistical analysis was performed using SPSS 23.0 software. A repeated measures ANOVA test using the three sets of mean CHS scores were used to look for differences between interventions for CHS values. For the shot quality scores, the Friedman test and Kendall’s W test were carried out on three sets of median scores. These were then followed by a Wilcoxon signed ranks test.

### RESULTS

The repeated measures ANOVA revealed statistically significant improvements in CHS (p<0.001) following a dynamic warm-up combined with a club warm-up, showing a 1.1% increase when compared with control and 0.6% compared to club only warmup. No significant differences existed between the control and club only warm-up for CHS (p=0.877) despite a 0.5% increase in CHS, nor between the club only warm-up and dynamic warm-up combined with a club warm-up for CHS (p=0.385) despite increases of 0.6%. The Friedman test and subsequent Wilcoxon signed ranks test revealed significant improvements (p<0.001) in shot quality scores for the dynamic warm-up combined with a club warm-up when compared with both club only warm-up and control, showing 40% improvements in scores, with no significant differences (p=0.46) between club only and control. Effect size calculations showed moderate

### Table 2. Clubhead speed and self-reported shot quality following warm-up interventions.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean (mph)</th>
<th>Median Shot Quality (/10)</th>
<th>Effect size</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>92.9±7.9</td>
<td>5</td>
<td>0.63</td>
<td>0.998</td>
</tr>
<tr>
<td>Club</td>
<td>93.4±7.0</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamic</td>
<td>93.9±7.60**</td>
<td>7**</td>
<td>0.52</td>
<td></td>
</tr>
</tbody>
</table>

**Indicates significant difference (p<0.001)

### Table 3. Mean % difference between different warm-up protocols on dependant variables.

<table>
<thead>
<tr>
<th>Condition</th>
<th>% change</th>
<th>p-value</th>
<th>95% CI for mean lower-upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Club vs. Control</td>
<td>+0.5</td>
<td>0.877</td>
<td>-0.641 to 1.547</td>
</tr>
<tr>
<td>Dynamic vs. Control**</td>
<td>+1.1</td>
<td>&lt;0.001</td>
<td>0.545 to 1.520</td>
</tr>
<tr>
<td>Dynamic vs. Club</td>
<td>+0.6</td>
<td>0.385</td>
<td>-0.375 to 1.535</td>
</tr>
<tr>
<td>Shot Quality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control vs. Club</td>
<td>0</td>
<td>0.460</td>
<td>-</td>
</tr>
<tr>
<td>Dynamic vs. Control**</td>
<td>+40</td>
<td>&lt;0.001</td>
<td>-</td>
</tr>
<tr>
<td>Club vs. Dynamic*</td>
<td>+40</td>
<td>0.002</td>
<td>-</td>
</tr>
</tbody>
</table>

*Indicates significant difference (p<0.05), **Indicates significant difference (p<0.001)
improvements in CHS (0.63) and shot quality (0.52) as a result of the combined club and dynamic warm-up intervention.

**DISCUSSION**

With no current literature available on the impacts of warm-up on youth golfers, this work is an essential step in expanding the knowledge base, and clearly demonstrates the utility of warm-up routines for youth golfers. However, despite statistically significant effects being demonstrated between the dynamic warm-up and control group, the 95% confidence interval was only 0.545 to 1.520mph. While demonstrating positive and non-harmful effects, these improvements in clubhead speed alone are unlikely to elicit meaningful changes in on-course performance. However, when combined with the large observed improvements in self-reported shot quality (40%), meaningful on-course performance improvements are likely.

Given the limited research on golf warm-up and especially in youth, female, skilful and low handicap players, this research makes a valuable contribution to the body of evidence on physical preparation in golf. With evidence already supporting the use of club warm-ups and exercise based dynamic warm-ups in golf, this investigation looked to apply these principles to the youth golfer, using no equipment beyond golf clubs. The investigation specifically aimed to explore the impact of a club only warm-up and a dynamic exercise routine followed by a club warm-up on youth golf performance, demonstrated through changes in CHS and self-reported shot quality. The results showed a significant increase in CHS when golfers completed a dynamic exercise routine followed by a club warm-up against a control, with a moderate effect size improvement. This certainly demonstrates quantifiable improvements in performance, which may have further implications if continued over a longer period of time. Significant improvements were also seen in self-reported shot quality from the dynamic exercise routine followed by a club warm-up when compared against the control and club only warm up. When combined with the improvements in CHS, meaningful real-world performance impacts on driving distance and shot accuracy are highly likely, despite not being directly measured. No significant improvements were seen between the club only warm-up and the control.

The findings from this investigation demonstrate some of the positive impacts of completing a dynamic exercise route prior to any club warm-ups or golf performance in youth golfers. While changes in CHS were low and likely to make minimal improvements to overall performance, there appear to be quite noticeable changes in self-reported shot quality. These improvements in shot quality are likely to result in increased performance confidence and while not measured within this study, may transfer to noticeable improvements in shot outcome. This research also outlines that while club only warm-ups show trends towards improved performance, they are unable to elicit significant CHS and shot quality improvements on their own. This is further supported by previous literature, where dynamic warm-ups have consistently shown enhanced results.

Research in adult gofers has demonstrated a lack of positive warm-up behaviour and reductions in injury risk through golf warm-up. As such, the demonstration of positive and non-harmful warm-up effects in youth golfers should not only encourage them to participate in warm-ups as part of their preparation, but may also have the by-product of supporting positive warm-up behaviours in golfers from early on in their journey. In view of the significant and varied positive outcomes when golfers reach adulthood, and acknowledging current poor warm-up practices in golf, the implementation of warm-up routines in youth golf should be a desirable goal. This research should aid in encouraging warm-up practices and improving attitudes and behaviour to warm-up of youth golfers.

This study was not without limitations. While able to access high level players in ecologically valid environments, the pragmatic nature of this work limited a wider range of dependant variables which may have increased the acquired knowledge from this work. CHS was measured and improved, which, provided there was no reduction in shot quality, would lead to increased driving distance. However, driving was not directly measured due to the outdoor environment and mix of golf balls used. These environmental challenges would have negatively impacted on the reliability of a distance measure. Also, shot quality was taken through subjective questioning, without
quantifiable measurement, and while this method has previously been used, it has not been validated against shot outcome. However, similar to measures of distance, a variable outdoor environment with a mix of golf balls would not have been conducive to direct measures of accuracy or launch monitor shot quality. As such, the resultant improvements in shot quality from this study are only inferences of what performance improvements might result.

Given the relative infancy of youth golf warm-up research, there are many areas which are worthy of future investigation. However, based on the current work, logical next steps should include evaluation ball speed, smash factor (CHS to ball speed ratio) and accuracy measures as a result of appropriate warm-ups. This will aid in determining whether players’ perceptions of shot quality are comparable or consistent with actual shot quality. This was not possible within the current work due to the variable locations and balls used for the investigation. Given the large improvements in perceptions of shot quality within this study, the quantitative evaluation of this is an essential next step. While a golfer’s perception of their performance is important, and likely well informed, it does come with limitations. In golf, the player is measured on their shot outcome in terms of accuracy to a target, and therefore this may be a useful future addition. Moreover, work investigating the most efficient exercises for a warm-up, impacts of warm-up on injury risk reduction and whether regular warm-ups also have a potential conditioning effect for youth golfers would bring the literature more in-line with current adult golf research in preparation for continued expansion.

CONCLUSIONS
The results of this research indicate that significant improvements in CHS and shot quality occurred in youth golfers who participated in an exercise based and club golf warm up program. Therefore, the use of a dynamic exercise-based warm-up followed by a club warm-up may be advisable for youth golfers. This may have performance impacts and may also help to instill positive warm-up behaviors for the future. The program presented herein provides practical warm-up suggestions requiring no additional equipment that can accompany a club warm-up routine, which could be implemented immediately with youth golfers.

REFERENCES


ABSTRACT

Background: Roller massagers are popular devices that are used to improve range of motion (ROM), enhance recovery from muscle soreness, and reduce pain under acute conditions. However, the effects of roller massage training and training frequency are unknown.

Purpose: The objective was to compare two different roller massage training frequencies on muscle performance.

Study Design: Randomized controlled intervention study

Methods: Twenty-three recreationally active university students were randomly allocated to three groups: control (n=8), rolling three (3/W; n=8) and six (6/W; n=7) times per week for four weeks. The roller massage training consisted of unilateral, dominant limb, quadriceps and hamstrings rolling (4 sets x 30 seconds). Both legs of participants were tested pre- and post-training for active and passive hamstrings and quadriceps range of motion (ROM), electromyography (EMG) activity during a lunge movement, unilateral countermovement jumps (CMJ), as well as quadriceps and hamstrings maximum voluntary isometric contraction (MVIC) forces and electromechanical delay. Finally, they were tested for pain pressure threshold at middle and distal segments of their quadriceps and hamstrings.

Results: There were no significant training interactions for any measure with the exception that 3/W group exhibited 6.2% (p=0.03; Effect Size: 0.31) higher CMJ height from pre- (38.6 ± 7.1 cm) to post-testing (40.9 ± 8.1 cm) for the non-dominant limb.

Conclusions: Whereas the literature has demonstrated acute responses to roller massage, the results of the present study demonstrate no consistent significant training-induced changes. The absence of change may highlight a lack of muscle and myofascial morphological or semi-permanent neurophysiological changes with rolling.

Levels of Evidence: 2c

Key Words: self-myofascial release, foam rolling, massage, flexibility, strength,
INTRODUCTION

Foam rollers and roller massagers are recent popular additions to training and recovery routines. Recently, researchers have demonstrated that an acute session of rolling can increase static hip flexors,\(^1\)\(^,\)\(^4\) hip extensors,\(^4\)^\(^,\)\(^7\) and ankle\(^8\)^\(^,\)\(^9\) range of motion (ROM) as well as dynamic hip extensor ROM during a lunge.\(^1\)\(^0\) Su et al.\(^1\)\(^1\) found that an acute bout of foam rolling was more effective than static stretching for increasing hip flexor (modified Thomas test) ROM. The improved flexibility can have global effects since ROM was improved not only in the rolled limb but also the contralateral ankle,\(^1\)\(^2\) as well as bilateral rolling of the soles of the feet improving the ROM of the hamstrings and lumbar spine.\(^1\)\(^3\)

Not all studies demonstrate increases in ROM. Following foam rolling, the mobility of the thoracolumbar fascia significantly increased 1.79 mm (d = 0.756), but there was no significant effect on lumbar flexion.\(^1\)\(^4\) Couture et al.\(^1\)\(^5\) reported no significant improvement in hamstrings ROM with short (2 sets of 10s) and long (4 sets of 30s) durations of hamstrings rolling. Murray\(^1\)\(^6\) indicated that the statistically significant increase in hip flexor (quadriceps) flexibility with 60 seconds of foam rolling was not clinically relevant while Vigotsky et al.\(^1\)\(^7\) did not see an increase in passive hip extension or knee flexion ROM with 2 sets of 60 seconds of anterior thigh foam rolling. Hence, the literature is not consistent regarding the effects of rolling on subsequent measures of ROM. Furthermore, all the aforementioned studies were acute interventions that examined short term or acute outcomes.

There is also evidence that rolling can acutely increase pain pressure thresholds (PPT) by decreasing pain sensitivity\(^1\)\(^8\) in the affected and contralateral limbs.\(^1\)\(^9\)\(^-\)\(^2\)\(^1\) As Magnusson\(^2\)\(^2\) has suggested that stretch (pain) tolerance can be an important factor with ROM improvements, rolling-induced increases in PPT could contribute to the rolling-induced improvements in flexibility for the stretched limb and non-stretched limbs. This decreased pain sensitivity with rolling before exercise might also be related to the improved function following exercise-induced muscle damage (EIMD).\(^2\)\(^3\)\(^,\)\(^2\)\(^4\) Rolling improved recovery of muscle activation and vertical jump performance\(^2\)\(^4\) as well as sprint, power (broad-jump distance), change of direction speed (T-test), and dynamic strength-endurance\(^2\)\(^5\) after EIMD. In contrast, in another study by Casanova et al.,\(^2\)\(^5\) roller massage did not alter the functional impairments, medial gastrocnemius morphology, or oxygenation kinetics after EIMD, however there were increases of ipsilateral (19%) and a trend toward increases in contralateral (p = 0.095) medial gastrocnemius PPT. Once again, the PPT studies are all acute protocols and it is unknown if the changes in PPT are apparent with more chronic rolling application.

Unlike the performance impairments reported with prolonged static stretching,\(^2\)\(^6\)\(^-\)\(^2\)\(^8\) acute bouts of rolling have been reported in some studies not to negatively affect subsequent strength\(^2\)\(^6\)^\(^,\)\(^6\)\(^,\)\(^8\) or power (i.e. vertical jump).\(^2\)\(^9\) In contrast, Bradbury-Squires et al.\(^1\) did find that the neuromuscular efficiency (amount of muscle activation [electromyography] needed to perform an activity) of a lunge was actually improved following rolling. Su\(^1\)\(^1\) reported improved knee extension torques, while Monteiro et al.\(^3\)\(^0\) showed an improvement in the performance of a functional movement screen overhead deep squat. In comparison to a total body dynamic warm-up, foam rolling was more effective at improving power, agility, strength, and speed.\(^3\)\(^1\) On the other hand, whereas Healey et al.\(^3\)\(^2\) reported a decrease in the sensation of post-exercise fatigue, Monteiro\(^3\)\(^3\) countered that the number of knee extension repetitions was impaired when rolling was performed between knee extension sets. Furthermore, an acute session of rolling can also produce force deficits as evidenced by 9.5% - 19.1% decreases in the maximum voluntary isometric contraction (MVIC) force developed in the first 200 ms of the contraction when tested immediately and five minutes after rolling.\(^2\)\(^0\) MacDonald et al.\(^2\)\(^4\) reported that foam rolling negatively affected evoked muscle contractile properties. Furthermore, foam rolling of the quadriceps decreased biceps femoris activation.\(^3\)\(^4\) Once again, the general findings of these acute studies are inconclusive with no roller training studies examining possible chronic training-induced changes in performance.

There is only one training study that involved rolling. Junker and Stoggl\(^3\)\(^5\) reported similar increases in a stand and reach flexibility test for foam rolling and proprioceptive neuromuscular facilitation
(PNF) stretching over a three session per week, four-week training period of healthy adults. Thus, based on the lack of longer term rolling training studies, the objective of this study was to investigate the effects of two weekly frequencies (three versus six days per week) of a four-week roller massage training program on measures of ROM, PPT, voluntary contractile properties, and jump performance.

**METHODS**

**Subjects**

Twenty-three volunteers, including 13 males (25.1 ± 2.9 years, 180.4 ± 7.1 cm, 89.5 ± 16.4 kg) and 10 females (24.9 ± 4.3 years, 171 ± 7.8 cm, 69.1 ± 9.6 kg) were recruited from the university population. One female subject (six day/week group) withdrew from the study due to an unrelated injury. In order to meet entry criteria, subjects were between the ages of 18-35 years, were recreationally trained (participate in physical activity ≥ three times/week), had no experience of lower body injury or history of neurological conditions within the prior six-months, and reported no regular prior usage of roller massagers or foam rollers (defined as ≤ one time/week) within the past six months. After being briefed on study procedures all participants signed a consent form approved by the Health Research Ethics Authority at the University (file #:20180010-HK), in addition to completing the Physical Activity Readiness Questionnaire (Canadian Society for Exercise Physiology 2011). It was asked that participants avoid vigorous physical activity, foam rolling/roller massage, or stretching, and to refrain from alcohol consumption for 24-hours prior to testing sessions.

**Experimental Design**

The research questions were approached with a within subject, repeated measures, intervention design. Participants completed pre- and post-testing separated by a four-week intervention period involving either unilateral, dominant leg roller massage (RM) training (three or six times/week) or no RM training (control) (Table 1). Prior to each testing session, bipolar surface electrodes (Meditrace Pellet Ag/AgCl electrodes; Graphic Controls Ltd, Buffalo, NY) were placed over the midpoint of the participant’s biceps femoris and rectus femoris on both legs. A ground electrode was also placed on the fibular head. The skin covering these areas was carefully shaved with reusable razors and cleansed with isopropyl alcohol swabs. The session then commenced with a dynamic warmup on a cycle ergometer (Monark; Ergomedic 828E; Sweden) at 60-70-rpm with a resistance of 1-kp (70 Watts) for five minutes. Participants then underwent testing measures, which included active and passive ROM, neuromuscular efficiency (as measured by EMG) during a dynamic lunge task, single-leg countermovement jumps (CMJs), maximal voluntary isometric contractions (MVCs) force and EMG for knee flexors

<table>
<thead>
<tr>
<th>Table 1. Experimental Design.</th>
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<tr>
<td><strong>Pre-test measures</strong></td>
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<tr>
<td>Active and passive hip flexion (hamstrings) ROM</td>
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<td>Neuromuscular efficiency during a lunge (EMG)</td>
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<tr>
<td>Single leg CMJ</td>
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<tr>
<td>Knee flexors and extensors MVC</td>
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<tr>
<td>Pain Pressure threshold of biceps femoris and rectus femoris</td>
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ROM: range of motion; EMG: electromyography; CMJ: countermovement jump; MVC: maximum voluntary isometric contraction;
and extensors, and pain-pressure threshold (PPT) at the mid-muscle belly and distal muscle-tendon junction of the biceps femoris and rectus femoris. Electrodes were removed following MVICs to eliminate interference with testing locations for PPT trials. All measurements were performed on both legs, beginning with the dominant side.

**Interventions**

Immediately following their pre-test session, participants were randomly appointed to one of three intervention groups by having them roll a standard six-sided dice. The three (3/Wk: n = 8; when a 1 or 2 was rolled) and six (6/Wk: n = 7; when a 3 or 4 was rolled) RM sessions per week for four weeks consisted of RM over the quadriceps and hamstrings of the dominant leg for four sets of 30-seconds each. CONTROL (n = 8; when a 5 or 6 was rolled) involved no RM for four weeks.

Participants assigned to 3/Wk and 6/Wk groups were provided with a personal RM (TheraBand® Roller TH 11753: Performance Health: Akron Ohio, USA), that was a 24-cm long (plus protruding handles) dense rubber cylinder with longitudinal grooves designed for superficial and deep tissue mobilization. The researchers described and demonstrated proper RM application. Subjects were instructed to assume a seated position on the edge of a chair while resting the foot of their extended dominant leg on another surface of similar height (i.e. another chair). RM was then applied manually by the participant by manipulating the roller over the full length of the quadriceps (by pressing the roller downwards over the top of the thigh) and hamstrings (by pulling the roller up along the bottom of the thigh) without crossing any joints. Participants were asked to maintain an approximate cadence of 60-beats per minute, or one-second intervals rolling from the distal to proximal end and vice versa, while eliciting a perceived pain of 7/10 on a visual analogue scale (VAS-10). RM was performed for the dominant limb only, and each 30-second bout was alternated between the quadriceps and hamstrings until four sets had been completed for each.

All intervention groups were instructed to maintain their existing activity and lifestyle routines for this study; however, 3/Wk and 6/Wk were to add their prescribed RM, while CONTROL was asked to refrain from any RM or foam rolling. Members of 3/Wk and 6/Wk were also given a checklist to monitor diligence for daily RM completion. The checklist required participants to document the date and time of day of each rolling session, and to sign that it had been completed. Weekly email reminders were also sent to 3/Wk and 6/Wk groups to minimize the occurrence of missed training sessions. Post-testing was performed for each participant as close to the final day of their four-week intervention period as possible.

**Measurements**

**Range of motion (ROM)**

A large protractor designed on the wall of the laboratory was used to measure active and passive hip flexion ROM. Subjects were positioned supine on the floor against the wall with their hip joint placed against the centre of the protractor (Figure 1). The contralateral knee and hip were held securely in place by the researcher. Active ROM was assessed by instructing the participant to explosively kick their foot as high as possible, holding the position briefly at the end of the movement. They were urged to contract their quadriceps and maintain a fully extended knee joint. Passive ROM testing was then conducted with the researcher raising the participant’s relaxed limb while preventing knee flexion and sustaining neutral ankle flexion throughout the movement.

**Figure 1.** Measurement of passive hip flexion range of motion. Participant actively raised their own leg to evaluate active hip flexion range of motion.
The subject was asked to indicate when the end of the ROM had been reached, defined as the maximal point of discomfort (POD). The maximum angle of hip flexion was recorded. Reliability intraclass correlation coefficients (ICC) of 0.91-0.93 have been reported from this laboratory for this ROM test. 36

As published from this laboratory and others, 1,31,37,38 active and passive knee flexion was assessed by placing the subject in a lunge position and extending the hip to slide the rear knee as far back as possible, while maintaining a 90° angle in the front knee and hip. A metal frame was provided for the subject to maximize stability during the measurement. A handheld goniometer was used to measure the degree of knee flexion while the subject (for active ROM) or the researcher (passive ROM) raised the rear foot, flexing the knee joint, until the end of the ROM (maximum POD) was reached (Figure 2). The authors’ have previously reported reliability ICC’s of 0.964-0.993 for this test. 37

Neuromuscular efficiency
A lunging task, similar to that previously demonstrated in this laboratory, 1 was used to determine the neuromuscular efficiency of the rectus femoris and biceps femoris during a submaximal dynamic activity. In order to standardize lunge lengths, the

Figure 2. Kneeling lunge position for measurement of passive (researcher assisted shown in figure) and active (no assistance) knee flexion range of motion (ROM).

distance from the participant’s iliac crest to their lateral malleolus was measured, recorded, and marked on the floor using tape. This distance was used to measure lunge length during pre- and post-testing sessions to ensure inter-session consistency. Subjects were instructed to step forward to their individual tape marking with their hands on their hips and gaze fixed forward, and lower their rear knee into a lunge with a cadence of two-seconds down, and two-seconds up. Electromyography (EMG) of the rectus femoris and biceps femoris was monitored throughout, and was analyzed for the concentric portion (two-seconds) of the movement. Following the skin preparation, bipolar Ag/AgCl electrodes (Ag/AgCl; Kendall MediTrace foam electrodes, Holliston, Massachusetts, USA) were placed over the mid-belly (half the distance between the anterior superior iliac spine and the patella) of the rectus femoris. The reference electrode was placed over the head of the radius. The inter-electrode spacing was 20 mm. All the EMG signals were collected by the Biopac data acquisition system (Hardware: Biopac Systems Inc., DA 100, and analog to digital converter MP100WSW; Hilliston, MA., Software: AcqKnowledge III, Biopac System Inc. Holliston MA. USA) at a sample rate of 2000 Hz (impedance = 2 MΩ, common mode rejection ratio >110 dB min (50/60 Hz), noise >5 μV). A bandpass filter (10–500 Hz) was applied prior to digital conversion.

Single-leg countermovement jumps (CMJs)
Unilateral CMJ height was assessed using a Vertec measuring device (Vertec, Sports Imports, Hilliard, OH). 23,24 The height of the device was adjusted until the fingertips of the subject’s dominant arm, extended overhead, brushed against the bottom vane. Subject performed the test using a single-leg stance, leaping as high as possible and reaching with their dominant hand to slap the Vertec at the peak of their jump. Subjects were encouraged to make the task as natural as possible by allowing them to squat down and swing their arms for momentum. Three attempts were granted, and the highest vane displaced (measured in ½” intervals) was recorded as their CMJ height. EMG was also recorded and analyzed for the concentric portion of the task. ICCs for CMJ have exceeded 0.9 in testing from this laboratory. 23,24,38
Maximal voluntary isometric contractions (MVICs)

Similar to a number of other studies from this laboratory,\textsuperscript{6,38-40} participants assumed a seated position on the edge of a table with a backrest adjusted to allow 1” between their popliteal space and the edge of the table. They were strapped securely in position across the shoulders and upper legs. The ankle of the testing leg was then inserted into a padded cuff secured to a Wheatstone bridge configuration strain gauge (Omega Engineering Inc., LCCS 250, Don Mills, Ontario, Canada) by a high-tension wire. Knee joint angles were adjusted to 60° from full knee extension when performing knee flexion and 90° for knee extension MVICs, during which subjects were instructed to contract their quadriceps (knee extension) or hamstrings (knee flexion) as forcefully and rapidly as possible by pushing or pulling against the immobile ankle cuff. Attempts were held for three to five seconds until an appropriate plateau of force had been achieved, and was accompanied by repeated shouts of verbal encouragement. Two attempts were performed (with a third attempt if the second was ≥5% than the first), and the effort with the greatest peak force was used for analysis.

Pain-pressure threshold (PPT)

PPT was incorporated similar to other studies from this laboratory.\textsuperscript{19,20} PPT was evaluated at the mid-muscle belly and distal muscle-tendon junction of the rectus femoris and biceps femoris. A hand-held algometer (Lafayette Manual Muscle Test System\textsuperscript{\textregistered}, Model 01163, Lafayette Instrument Company, Indiana, USA) with a range of 0–136.1 kg was used to apply pressure to the muscle tissue with the subject lying supine (rectus femoris measurements) or prone (biceps femoris measurements). The researcher performed three consecutive tests for each target area by exerting pressure in an incremental manner until the subject verbally indicated that the POD (defined as the onset of pain) had been reached. The mean of the three trials was recorded as the PPT. Prior use of this procedure from our laboratory has provided reliability ICC of 0.93.\textsuperscript{19}

Statistical Analysis

Statistical analyses were computed using SPSS software (Version 23.0, SPSS, Inc., Chicago, IL). Dependent variables underwent assumption of normality (Shapiro-Wilk test) and sphericity (Mauchley test), and if violated, the corrected value for non-sphericity with Greenhouse-Geisser Epsilon was reported. Three-way analyses of variance (ANOVAs) [Three groups (CONTROL, 3/Wk and 6/Wk) × 2 times (pre- and post-training) x 2 legs (dominant and non-dominant) were used to analyze quadriceps and hamstrings MVICs, ROM, unilateral CMJ, CMJ rectus femoris and biceps femoris EMG activity, quadriceps and hamstrings electromechanical delay, lunges, rectus femoris and biceps femoris EMG and PPT at all positions. Post hoc LSD analyses were used to examine main effect pairwise differences with t-tests employed to detect the location of specific significant interactions. Statistical significance was accepted with an alpha level of p = 0.05. Descriptive statistics include means ± standard deviation (SD).

RESULTS

There were no significant training interactions for any measures except for CMJ height, which presented an interaction between group, time and leg. Post-hoc analysis found an interaction between time and leg only for 3/Wk group (p = 0.01), showing that the non-dominant leg pre-test (15.18 ± 2.84 cm) was lower than post-test (16.12 ± 3.24 cm, p = 0.03).

Main effects for time were evident with pre- to post-training decreases in active and passive hamstrings ROM, hamstrings and quadriceps MVIC, CMJ rectus femoris and biceps femoris EMG (Table 2). Main effects for limb dominance were apparent with the dominant leg exceeding the non-dominant leg for hamstrings (approaching a significant difference) and quadriceps passive ROM and quadriceps
electromechanical delay, whereas the non-dominant limb exhibited higher scores for quadriceps MVIC force (Table 3).

DISCUSSION
The major findings in the present study were that four weeks of roller massage training with either three or six sessions per week did not induce physiological (i.e. MVIC force and EMG, electromechanical delay, neuromuscular efficiency with a lunge) or performance (i.e. ROM, CMJ) training adaptations in the rolled or untrained, contralateral limbs with the exception that 3/Wk group exhibited higher CMJ height pre- to post-testing for the contralateral, untrained, non-dominant limb.

Prior publications have demonstrated that the acute implementation of RM has increased static ROM of the hip flexors,1-4,11 hip extensors,4-7 and ankle plantar flexors8,9 as well as dynamic hip extensor ROM during a lunge.10 There has only been one rolling training study, which reported similar increases in a stand and reach flexibility test with foam rolling and PNF stretching after a three session per week, four-week training period of healthy adults.35 There were only minor differences between the Junker and Stoggl training study and the present study. While the frequency and duration (four weeks) of the rolling training was similar as was the duration of rolling repetitions (30 vs. 30-40s), the participants in the present study were on average six years younger.

Table 2. Main Effects for Time

<table>
<thead>
<tr>
<th>Main Effects for Time</th>
<th>Pre-training</th>
<th>Post-training</th>
<th>p-value</th>
<th>ES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamstrings Active ROM (°)</td>
<td>95.66 ± 2.73</td>
<td>91.87 ± 2.47</td>
<td>0.0002</td>
<td>1.43</td>
</tr>
<tr>
<td>Hamstrings Passive ROM (°)</td>
<td>98.92 ± 4.04</td>
<td>92.40 ± 3.36</td>
<td>0.001</td>
<td>1.76</td>
</tr>
<tr>
<td>Hamstrings MVC (kg)</td>
<td>35.73 ± 1.89</td>
<td>33.54 ± 1.64</td>
<td>0.04</td>
<td>1.24</td>
</tr>
<tr>
<td>Quadriceps MVC (kg)</td>
<td>62.07 ± 4.02</td>
<td>57.84 ± 3.73</td>
<td>0.001</td>
<td>1.09</td>
</tr>
<tr>
<td>CMJ Rectus Femoris EMG (mV)</td>
<td>0.69 ± 0.04</td>
<td>0.60 ± 0.03</td>
<td>0.04</td>
<td>2.57</td>
</tr>
<tr>
<td>CMJ Biceps Femoris EMG (mV)</td>
<td>0.43 ± 0.05</td>
<td>0.32 ± 0.03</td>
<td>0.06</td>
<td>2.75</td>
</tr>
</tbody>
</table>

ROM: range of motion in degrees; MVC, maximal voluntary isometric contraction; CMJ: countermovement jump; EMG: electromyography; ES: Effect size
Note: ES descriptor: large magnitude of change = ≥ 0.80

Table 3. Main Effects for Leg Dominance

<table>
<thead>
<tr>
<th>Main Effects for Leg Dominance</th>
<th>Dominant</th>
<th>Non-dominant</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamstrings Passive ROM (°)</td>
<td>97.08 ± 3.69</td>
<td>94.24 ± 3.69</td>
<td>0.1</td>
</tr>
<tr>
<td>Quadriceps Passive ROM (°)</td>
<td>53.29 ± 2.35</td>
<td>45.83 ± 2.06</td>
<td>0.003</td>
</tr>
<tr>
<td>Quadriceps MVC (kg)</td>
<td>57.97 ± 3.53</td>
<td>61.93 ± 4.25</td>
<td>0.008</td>
</tr>
<tr>
<td>Quadriceps EMD (ms)</td>
<td>78.17 ± 3.70</td>
<td>68.87 ± 3.63</td>
<td>0.04</td>
</tr>
</tbody>
</table>

ROM: range of motion in degrees; MVC, maximal voluntary isometric contraction; EMD: electromechanical delay; ES: Effect size
Note: ES descriptors: moderate magnitude of change = 0.5 – 0.79, large magnitude of change = ≥ 0.80
(25 vs 31 years), and used a roller massager rather than a foam roller possibly with different intensities of rolling (7/10 VAS scale vs. body mass load when foam rolling). Furthermore, the ROM test with the Junker and Stoggl study was a stand and reach test whereas the present study used active and passive supine straight leg hip flexion. While the small age difference was probably not a significant factor, the possibility of differing intensity or pressure of rolling should also not have played a role. Grabow et al. reported that acute rolling massage at 4/10, 6/10/ or 8/10 on a VAS scale did not provide significant differences in post-rolling ROM or induce performance decrements. Hence the discrepancy might be attributed to the use of a foam roller versus a roller massage. In the present study, with the 3/Wk and 6/Wk groups combined (n=15), there was actually a significant decrease in ROM after the four weeks of training. Whereas roller massage involves just the upper limbs to move the roller, foam rolling involves the upper limbs to move the body segment over the roller and trunk or core muscle stabilization to maintain proper positioning. It might be possible that the core stabilization efforts with foam rolling strengthened this area allowing the subjects to actively reach farther down during the stand and reach test. If this was the case, then the effect was due more to a core strengthening effect than a change in leg muscle extensibility (compliance). However, as this rationale is speculative, further studies are necessary to delineate the effect of foam roller and roller massage training on ROM.

Whereas the present study also did not show training related changes in PPT, acute rolling studies have reported increased PPT or decreased pain sensitivity in the rolled and non-treated contralateral limbs. The proposed mechanisms for the pain modulation was postulated to be a central pain modulation system such as the gate control theory or diffuse noxious inhibitory control. Similarly, acute rolling-induced improvements in ROM have been attributed to central or neural responses. This central neural response of rolling was highlighted by increased ROM in the contralateral ankle, as well as with the hamstrings and lumbar spine following bilateral rolling of the soles of the feet. Although, contralateral increases in ROM were not evident in the present study, the 3/Wk group exhibited higher CMJ height following training for the non-dominant limb. As there were no significant changes in ROM or PPT in the present study, there was no significant evidence for training-related changes in ROM or PPT-related central neural responses. Young et al. in an acute study reported decreased Hoffman (H) reflex activity during rolling, which returned to baseline immediately upon rolling cessation. Similarly, Aboodarda et al. demonstrated reduced corticospinal excitability as measured with transcranial magnetic stimulation (TMS) during four sets of roller massage, which returned to baseline immediately following the rolling protocol. Hence, the neural effects of rolling may be quite transient.

Furthermore, as Magnusson has suggested that stretch (pain) tolerance can be an important factor with ROM improvements. Improved stretch tolerance has been postulated to underpin ankle plantar flexor’s and hip extensor’s ROM improvements following static stretching training programs with similar treatment volume or duration to the rolling intervention in this study. The lack of rolling-induced increases in PPT and ROM in the present study would suggest that four weeks of roller massage did not significantly impact stretch (pain) tolerance.

The increased CMJ height of the contralateral, non-rolled limb with the 3/Wk group would argue for a training-related neurological adaptation. In light of the lack of any other ipsilateral or contralateral results, it is difficult to postulate a specific neurological adaptation. Single leg CMJ are not a common activity and thus there might have been a learning effect from pre- to post-training tests. Although the 3/Wk group showed a significant improvement, there were non-significant improvements that occurred in the 6/Wk (pre-test: 14.2 to post-test: 14.5 cm) and CONTROL (pre-test: 13.9 to post-test: 14.9 cm) groups. While it could also be a statistical anomaly (random effect), there is the possibility that a learning effect occurred to provide a significant, small effect size magnitude change improvement in CMJ height with the 3/Wk group.

Limitations of the current study included the relatively small sample population.
respectively) and training duration (four weeks). With the exception of one finding (contralateral CMJ height), none of the other statistical interactions were anywhere near significance and thus even substantial increases (i.e. increase from 8 to 12 per group) would probably not be expected to alter the findings. However, similar studies with greater statistical power are always recommended. The four-week training duration has been shown to be effective for significantly increasing ROM with stretch training studies\(^{26-28}\) and thus the present roller training duration demonstrates that rolling is not as effective as stretching for improving ROM over this time period.

Related to this point, there are a few acute studies that have combined rolling with stretching to determine if an additive effect was possible. Mohr et al.\(^3\) reported greater hip flexion ROM improvements following three-minutes of combined foam rolling and static stretching (23.6%) versus three-minutes of either intervention (Foam rolling: 6.9%; static stretch: 12.3%). Similarly, Škarabot et al.\(^9\) found greater ankle dorsiflexion ROM with 90-seconds of foam rolling and static stretching (9.1%) than rolling or stretching in isolation. However, there was no significant additive effect with 30 seconds of roller massage and static stretching.\(^{38}\) As there are no training studies integrating both rolling and stretching, further research could be conducted on this question.

**CONCLUSIONS**

In summary, roller massage training performed either three or six days per week did not improve any of the physiological or performance measures with the rolled or contralateral limbs indicating that previously reported rolling-induced acute improvements may be transient. The increased unilateral CMJ height pre- to post-testing for the contralateral, untrained, limb might be ascribed to a learning effect with an unfamiliar task. Hence, roller massage may be a beneficial tool for increasing ROM and PPT during and soon after a warm-up session but its acute effects may not translate into chronic changes. Hence, the clinical relevance reveals that past and present evidence demonstrate that rolling massage can produce acute increases in ROM and pain pressure threshold, however, chronic rolling does not induce plastic (semi-permanent) adaptations.

**REFERENCES**


ABSTRACT

Background: Tightness of hip flexor muscles has been recognized as a risk factor for various musculoskeletal injuries in the lower extremities.

Purpose: The purpose of this study was to examine the acute effects of two hip flexor stretching techniques (dynamic and hold-relax proprioceptive neuromuscular facilitation, HR-PNF) on hip extension (ROM), knee joint position sense (JPS) and balance in healthy college age students who exhibit tightness in hip flexor muscles.

Study Design: Pretest-posttest randomized experimental groups.

Methods: Thirty-six healthy college age students (mean = 22.37 years) with tight hip flexors participated in this study. Hip extension ROM, knee joint position sense and dynamic balance were tested pre- and post-stretching using a digital inclinometer, an iPod touch and the Y-Balance test, respectively. Subjects were randomly divided into dynamic and HR-PNF stretching groups. Three-way mixed analysis of variance was utilized to explore if an interaction existed between the groups in tested variables.

Results: There was a significant effect of time on hip extension ROM in both groups ($p < 0.001$). There was also a significant effect of stretch type on hip extension ROM ($p = 0.004$) favoring hold-relax over dynamic stretching group. There was a non-significant effect of time on mean knee joint position replication error in both groups. There was a significant main effect of time on the Y-Balance test's mean distance of reach to posteromedial and posterolateral directions ($p < 0.001$). There was also a significant main effect of directions of reach on distances achieved ($p < 0.001$) favoring posterolateral over posteromedial, and the latter over anterior direction.

Conclusions: The results of this study demonstrated the effectiveness of both HR-PNF and dynamic stretching techniques which resulted in a significant acute improvement in hip extension ROM and dynamic balance measures, with HR-PNF being more effective than dynamic stretch. However, there were no significant improvements in knee joint position replication over time in either stretching group.

Level of Evidence: 2b

Key words: Dynamic balance; dynamic stretching; hold-relax proprioceptive neuromuscular facilitation; knee joint position sense; tight hip flexor.
INTRODUCTION

Tightness of hip flexor muscles (i.e. iliopsoas and rectus femoris) evaluated through hip extension ROM measurement, has been recognized as a risk factor for various musculoskeletal injuries (e.g., knee and hamstrings) in the lower extremities. \(^1\)–\(^7\) ROM is defined as the degree of movement within a joint, and it can be active (reached by voluntary skeletal muscles’ contraction) or passive (achieved by external mean such as gravity). \(^8\) Restricted hip flexor mobility has been clinically defined as the inability of the individual to achieve full hip extension during the modified Thomas test position. \(^8\) Tight hip flexors is an impairment that has been found in both symptomatic individuals (individuals with lower quarter or extremity disorders and functional limitations) and those individuals who are asymptomatic. \(^6\), \(^9\) Lack of flexibility may result in early muscle fatigue or altered movement patterns. \(^5\) Therefore, hip flexor muscle tightness is believed to have negative impact on dynamic balance as well as on biomechanics of lower extremities which, in turn, can increase the risk of falls. \(^10\), \(^11\)

Hip flexor muscle tightness has been negatively correlated with dynamic balance performance in junior high school students. \(^10\) Several authors have suggested an association between diminished balance and injury. \(^12\)–\(^16\) Balance and joint position sense (JPS) are proprioceptive parameters that rely on contributions from visual, vestibular and peripheral receptors that are found in skin, joints, muscles and ligaments. \(^17\)–\(^24\) Proprioception provides the body with conscious and subconscious JPS and motion, and is essential for knee joint functioning to maintain optimal control (balance) of lower extremities while performing daily physical activities. \(^25\)–\(^27\) JPS is an aspect of proprioception that plays an important role in functional dynamic stability of joints through the action of the muscles and ligaments around them throughout their ROM. \(^26\), \(^28\)–\(^30\) Reduced contributions from sensory proprioceptive receptors may diminish the protective reflex mechanisms of muscles which, in turn, could predispose individuals to musculoskeletal disorders by altering the control of movement. \(^31\), \(^32\)

Since tightness of hip flexors is associated with balance dysfunction, and because the proprioceptive aspect of JPS is one of the mechanisms that contributes to maintenance of balance, it is reasonable to question if restricted hip flexors have unfavorable effects on the knee’s JPS. The action of rectus femoris muscle on both joints (as hip flexor and knee extensor) provides further support for this notion. \(^33\) Similar to the relationship between tight hip flexors and lower extremity injuries, abnormal knee JPS has also been linked to several orthopedic and musculoskeletal conditions in knee joint. \(^34\)–\(^37\) These factors combined may highlight the role of hip flexor tightness as a key component related to reduced balance, diminished knee JPS and increased risk of lower extremity injury.

In rehabilitation practice, stretching of hip flexor muscles has been acknowledged as effective in addressing limited hip extension ROM. \(^6\), \(^38\) A variety of stretching techniques have been described in the literature including dynamic, static (active or passive), and proprioceptive neuromuscular facilitation (PNF) to address this impairment. \(^6\), \(^38\) Dynamic stretching is a controlled movement that uses the active ROM of the joint while moving without exceeding extensibility limits of the individual. \(^40\) Dynamic stretching incorporates a concomitant active contraction of antagonist muscles which may lead to benefits to those muscles that are not experienced with static stretching. \(^6\) Therefore, and due to its distinct benefits on muscular performance, dynamic stretching may be the preferred stretching technique. \(^41\)–\(^43\) Proprioceptive neuromuscular facilitation (PNF) stretching on the other hand, is considered one of the most effective stretching techniques used to improve ROM, particularly in respect to short-term changes in ROM. \(^44\), \(^45\) PNF type stretching can be defined as a combination of isometric contraction and passive lengthening of the target muscle or group of muscles. \(^46\) There are three known techniques for PNF stretching procedures. These three techniques include contract and relax (CR), hold and relax (HR), and contract-relax with antagonist contraction technique (CR-AC). \(^47\)–\(^49\)

The purpose of this study was to examine the acute effects of two hip flexor stretching techniques (dynamic and HR-PNF) on hip extension ROM, knee JPS and balance in healthy college age students who exhibit tightness in hip flexor muscles. The authors
also aimed to determine which one of these techniques has a greater influence on hip extension ROM, knee JPS and dynamic balance. It was hypothesized that significant differences in hip extension ROM, knee JPS and balance measurements would result between pre and post stretching intervention protocols. Additionally, it was hypothesized that significant differences would occur in these measurements between the two stretching groups at post intervention time point.

METHODS

The study sample consisted of thirty-six college age students (25 males, 11 females). The primary criterion for inclusion to this study was the presence of tightness of hip flexor muscles (THF). THF in the current study was identified as a subject demonstrating a bilateral hip (i.e. unilateral THF was excluded) hip extension angle between +5° to +15° above the horizon during the modified Thomas test. Subjects with lower extremity injuries or pain, orthopedic, neurological, cardiovascular abnormalities, or surgeries, as well as a history of participating in a proprioceptive or balance training programs in the prior six months were excluded from participating in this study. This experiment was approved by the human subject’s review board of Western Washington University. A written informed consent, health history and physical activity questionnaire forms were provided to each participant prior to data collection.

Design of the Study

A pretest-posttest randomized experimental groups design was used for this study. The current study utilized two treatment groups: group A performed a dynamic stretching (DS) protocol while group B underwent HR-PNF stretching protocol. Hip extension ROM, knee JPS (constant error, CE) and dynamic balance (% distance of reach) were the dependent variables measured pre- and post-stretching (immediately-post and after five minutes for hip extension ROM) protocols. Pre- and post-intervention time points, type of stretching technique and side for hip extension ROM, knee angle for JPS and direction for dynamic balance performance were the three independent variables in this study. A general warm up protocol which consisted of five minutes of light jogging on a treadmill at a comfortable self-selected pace was used before stretching in both groups.

Dynamic stretching (DS) protocol

In group A, subjects lay prone with stabilizing strap placed at the posterior inferior iliac spine (PSIS) to stabilize the hips to the massage table. Subjects with lower extremity injuries or pain, orthopedic, neurological, cardiovascular abnormalities, or surgeries, as well as a history of participating in a proprioceptive or balance training programs in the prior six months were excluded from participating in this study. This experiment was approved by the human subject’s review board of Western Washington University. A written informed consent, health history and physical activity questionnaire forms were provided to each participant prior to data collection.

Hold-relax PNF stretching protocol

In group B, subjects lay supine on a treatment table and holding one knee to the chest and letting the

Figure 1. Dynamic stretching technique used for stretching hip flexor muscles.
other leg to extend freely toward the floor at the end of table. This protocol was adapted from a previous study (Figure 2). The hip of interest was moved gently toward the floor (knee flexed at 90°) until a mild stretch sensation was felt. Then, subject performed a sub-maximal voluntary isometric contraction by hip flexor muscles for 10 seconds against an examiner resistance of ≈ 20 lbs. applied by using a microFET2, padded hand-held dynamometer (Hoggan Health Industries Inc., Salt Lake City, UT, USA). The leg was then passively moved by the examiner to the new ROM and held for 20 seconds; repeated six times per limb.

Following completion of the stretching, hip extension ROM, knee JPS and dynamic balance measurements were obtained. The same investigator and co-investigators performed the same tasks throughout the study.

Data Collection Procedures

Instrumentation. A PRO 3600 digital Protractor (Jewell Construction LLC, Manchester, NH, USA) inclinometer and an Apple iPod touch 5th generation device (Apple Inc., Cupertino, CA, USA), integrated with custom-made application software were used to measure hip extension ROM and knee JPS in both experimental groups, respectively. Intra-rater reliability for the hip extension ROM (The modified Thomas test) measurement was assessed by a pilot work prior to the initiation of the study in a sample of 10 subjects. An excellent degree of reliability was found between test and retest measurements (ICC < 0.96). Validity of this test is established by controlling lumbopelvic movement (i.e. pelvic tilt) during testing of the participants. The custom-made application software forms from a 3-axis tri-axial accelerometer and a three-axis gyroscope. The data from the accelerometer was used to calculate the angle of the device with respect to gravity. The accuracy of the measurements within the iPod touch device was reported to be 0.49-0.50°. Intra-rater reliability for the hip extension ROM measurements was assessed by a pilot work prior to the initiation of the study in a sample of 10 subjects. An excellent degree of reliability was found between test and retest measurements (ICC < 0.96). The Y-Balance Test (YBT) using the Y-Balance test kit (Perform Better Inc., West Warwick, RI, USA) was utilized to measure DB. The Y-Balance test kit includes three poles that extend to anterior (ANT), posterolateral (PL), and posteromedial (PM) directions in relation to the stance foot. Participants were instructed to stand on the center of the Y figure during testing and slide the blocks outward into these three directions.

Measurement techniques and procedures. To achieve the required level of randomization during testing procedures, the order of hip extension ROM, knee JPS and DB testing was randomized (via computer software) for all subjects to reduce the learning effects.

Hip Extension ROM. The modified Thomas test was used to measure hip extension ROM. The following steps were used during the test: the participants...
were instructed to sit as close to the edge (i.e. the gluteal folds at the edge) of the table as possible; subjects pulled their knees to their chest and then gently rolled backward on the table; while maintaining this position, one of the lower limbs was released, allowing the hip to extend toward the floor; the free hand was used to help holding the other knee to the chest. This position enabled both the leg and knee of the limb being measured to hang off the edge of the table freely unsupported. While the subject kept a posterior pelvic tilt, the examiner assistant placed one of his hands (four fingers) under the lumbar spine to ensure that the lumbar spine was flat. The examiner observed and palpated the thigh to ensure that it was completely relaxed and positioned the knee joint at about 80-90° of flexion, then placed the digital inclinometer on the middle point of the anterior aspect of the thigh (Figure 3). The middle point on the thigh was identified as the midway between trochanterion and the lateral epicondyle of the femur. During the pre- and immediately-post and five-min-post intervention time points, hip extension ROM was measured three times, and the average was used for statistical analysis. This measurement was taken by the same examiner to improve reliability of measures.

Knee JPS test. Subjects were instructed to sit comfortably on the edge of table with shank hanging 90° from horizontal and including 2cm of space between the table and the popliteal fossa. iPod was strapped to the lateral side of the subject’s dominant leg about 2.4 cm above the lateral malleolus and secured via a Neoprene sleeve with hook and loop Velcro fasteners (Figure 4). Once testing began, the iPod provided all audio feedback to guide the subject through their position-reposition task. The task consisted of three trials to both 30° and 60° of knee extension (total of six trials) which were randomized by the application. Throughout all testing, subjects were asked to wear tight clothes as well as keep their eyes closed in order to eliminate external cues. A customized LabVIEW (National Instruments Corporation, Austin, TX, USA) program was used to calculate the accuracy of the reproduction of each knee.
joint angle. The accuracy of the reproduction of JPS was represented as a constant error. Constant error refers to the calculated value of deviation from the target angle.56

Dynamic balance test. The Y Balance Test (YBT) procedures as used in a previous study conducted by Gribble et al. were utilized to measure and represent dynamic balance performance (DB) during pre- and post-interventions measurements in the current study.57 The participants pushed the moving rectangular pieces using their contralateral legs while maintaining a single-leg stance on the stance foot on the center of piece of the Y figure. Participants pushed these moving pieces to the farthest point possible on each pole with their reaching foot (Figure 5). The distances of reach were recorded to the nearest quarter of centimeter. Next, these distances were normalized to the length of subjects’ legs.57 The sequence of reach directions was randomized using a computer software to evade sequencing effects on the collected data. Participants were given one to two practice trials, then they were instructed to perform three trials in each direction (i.e. ANT, PM and PL) and 15 seconds of rest were given between each trial. The mean value of the three trials during the pre-and post-interventions measurements was used for statistical analysis.

Statistical Analysis
Mean and standard deviation (SD) values for hip extension ROM, knee JPS replication error CE and scores of DB performance during the pre- and post-intervention time points for both groups were calculated. A 3-way mixed analysis of variance (ANOVA) was utilized to test statistically significant differences (SPSS version 21.0). The ANOVA was conducted to compare the group (dynamic stretching vs HR-PNF stretching), time (pre-stretching vs post-stretching), and side of limb (right vs right for hip extension ROM). For the knee JPS, angle (30° vs 60° in knee JPS) was used instead of the side of limb. For the Y-balance test, the direction (ANT vs PM vs PL) substituted the side of limb. If statistical significance with the two-way interaction or main effects existed, then a pairwise comparison was performed, and Bonferroni correction was applied. Additionally, a partial-eta ($\eta^2_p$) squared was calculated to determine the effect size. Statistical significance was set at an alpha level of 0.05.

RESULTS
The study sample consisted of thirty-six college age students (24 males, 11 females, mean age 22.37 ± 1.63 years, height 171.05 ± 9.64 cm, and weight 72 ± 13.70 kg). A statistical power analysis based

![Figure 5. The Y-Balance Test.](image)
on a previous study and calculated using G* power 3.1 software (Heinrich Heine University, Düsseldorf, Germany) revealed that 18 participants per group would result in an estimated power of 0.80 to observe significant differences with the alpha level set to 0.05.6 Due to equipment malfunction of the JPS measuring device (iPod failed to record or save the measurement), the data of one male participant was excluded from statistical analysis.

Pre- and post-stretching values of hip extension ROM are shown in Table 1. There was a significant two-way interaction between the side of limb and stretch type (F[1, 33] = 8.154, p = 0.007, $\eta^2_p = 0.198$) indicating to a greater improvement in hip extension ROM on both left and right sides in HR-PNF group compared to DS group ($p = 0.001$ and $p = 0.035$, respectively) (Figure 6). A significant two-way interaction was found between the time and stretch type (F[2, 66] = 20.870, p < 0.001, $\eta^2_p = 0.387$) indicating a greater improvement in HR-PNF compared to DS group occurred in hip extension ROM during immediately-post stretch and post-five-min-stretch time points ($p < 0.001$ and $p = 0.005$, respectively). In the HR-PNF stretching group, immediately-post stretching values of hip extension ROM were better than pre-stretching and post-5 min stretching ($p < 0.001$). In DS group, both immediately-post and post-five-min stretching values were better than pre-test stretching values ($p < 0.001$).

There was no significant main effect of time on mean JPS replication CE (F[1,33] = 0.003, p = 0.956, $\eta^2$ p < 0.001) (Table 1). The only significant difference was observed in this test was between the angles of 30° and 60° over time in JPS replication error CE (i.e. average of pre- and post-combined values in both stretching groups) (F[1,33] = 51.723, p < 0.001, $\eta^2_p = 0.610$), with a smaller error in mean CE (1.90° versus 5.76°) in 60° than 30° of knee angle, respectively ($p < 0.001$) (Figure 7).

Pre- and post-stretching values for DB are shown in Table 1. There was a significant interaction between

| Table 1. Dependent variables' mean and standard deviation (SD) values at pre- and post-stretching time points. * denotes a significant difference $p < 0.05$. |
|---------------------------------|---------------------------------|---------------------------------|
| Dependent Variable              | Dynamic Stretching Group        | HR-PNF Stretching Group         |
|                                 | n=17 (12 males, 5 females)      | n=18 (12 males, 6 females)      |
| Right hip extension ROM (°)     | (mean ± SD)                     | (mean ± SD)                     |
| Pre-stretch                     | 9.20 ± 2.88                     | 9.54 ± 2.58                     |
| Immediately post-stretch        | 4.46 ± 3.79 *                   | -3.87 ± 6.02                    |
| 5-minutes post-stretch          | 4.57 ± 3.60 *                   | -0.90 ± 6.01                    |
| Left hip extension ROM (°)      | (mean ± SD)                     | (mean ± SD)                     |
| Pre-stretch                     | 8.89 ± 2.29                     | 10.34 ± 3.28                    |
| Immediately post-stretch        | 3.17 ± 4.64 *                   | -2.48 ± 5.19                    |
| 5-minutes post-stretch          | 3.35 ± 4.44 *                   | -0.26 ± 4.52                    |
| Knee JPS flexion CE at 30° (°)  | (mean ± SD)                     | (mean ± SD)                     |
| Pre-stretch                     | 5.99 ± 2.43                     | 6.23 ± 4.91                     |
| Post-stretch                    | 5.57 ± 3.62                     | 5.26 ± 3.63                     |
| Knee JPS flexion CE at 60° (°)  | (mean ± SD)                     | (mean ± SD)                     |
| Pre-stretch                     | 1.03 ± 2.97                     | 2.12 ± 3.28                     |
| Post-stretch                    | 1.78 ± 2.41                     | 2.67 ± 3.87                     |
| Y-test/anterior (%)             | (mean ± SD)                     | (mean ± SD)                     |
| Pre-stretch                     | 64.57 ± 6.66                    | 68.30 ± 5.28                    |
| Post-stretch                    | 65.64 ± 6.09                    | 69.24 ± 5.93                    |
| Y-test/posteromedial (%)        | (mean ± SD)                     | (mean ± SD)                     |
| Pre-stretch                     | 102.47 ± 9.43 *                 | 105.11 ± 11.31 *                |
| Post-stretch                    | 107.83 ± 7.97 *                 | 108.03 ± 12.33 *                |
| Y-test/posterolateral (%)       | (mean ± SD)                     | (mean ± SD)                     |
| Pre-stretch                     | 108.90 ± 9.36 *                 | 112.91 ± 10.52 *                |
| Post-stretch                    | 112.87 ± 8.68 *                 | 114.06 ± 11.03 *                |

* Significant difference at $p < 0.05$.  
time and directions of reach \( (F[2, 66] = 5.653, p = 0.005, \eta^2 p = 0.146) \) (Figure 8). Significantly greater distances were noticed during post-test compared to pre-test time point in distances of reach to PM and PL directions \( (p < 0.001) \). There was a significant main effect of directions of reach on the Y-Balance test values \( (F[1.564, 51.619] = 904.148, p < 0.001, \eta^2 p = 0.965) \). There was also a significant main effect of time on the Y-balance test’s mean distance \( (F[1, 33] = 28.386, p < .001, \eta^2 p = 0.462) \) indicating a greater mean distance of reach during post stretching time point than during pre-stretching time point \( (p < 0.001) \).

**DISCUSSION**

The purpose of this investigation was to examine the acute effects of two hip flexor stretching techniques on hip extension ROM, knee JPS and DB
performance. Results showed significant improvement in hip extension ROM over time in both stretching groups. The results of the current study are consistent with results reported in numerous related studies. In a study conducted by Winters et al., researchers stated that the increase in hip extension ROM observed in their study was as a result of passive and active stretching protocols used. Malai et al. reported significant improvement in both right and left hip extension ROM after applying HR-PNF stretching technique on 10 individuals with tight iliopsoas muscles. In another study, Godges et al. demonstrated the effectiveness of both static and PNF stretching procedures on improving hip extension ROM among seven young males. Several possible reasons could have led to the improvement seen in hip extension ROM in both stretching groups such as increased body and muscle temperature and stimulation of nervous system, improved reciprocal inhibition of the antagonist muscles and autogenic inhibition, alteration in stiffness of musculotendinous unit, and alteration in myotatic or stretch reflex. However, the results of the current study were in disagreement with another study conducted by Rodacki et al. as the values of hip extension ROM immediately-post and post-five-min of stretching in the HR-PNF group was significantly greater than in DS group. PNF stretching technique is considered the most effective stretching technique to produce an immediate and short-term increase in ROM because it includes isometric resistance phase and followed by a static stretching phase in HR-PNF which make it an effective muscle release technique as compared to other stretching techniques. The results of the present study are consistent with a study conducted by Miyahara et al. who found a significant increase in hip flexion ROM after using static and PNF stretching protocols on thirteen healthy young male students. The significant differences in HR-PNF group favoring immediately-post values over pre- and post-5-min stretching values, and post-5 min values over pre-stretching values can be explained by the nature and duration of effects of HR-PNF stretching technique. PNF stretch is a very effective technique for inducing an immediate and short-term increase of ROM. Therefore, differences were evident among these testing time points. In post-five-min time point, the effect of HR-PNF technique started to diminish over time, thus, significant difference were also noticed between immediately-post and post-five-min time points. On the contrary, in DS group, only immediately and post-five-min values were significantly greater than pre-test values. This indicates that even
though DS was not as effective as HR-PNF stretching on increasing hip extension ROM, its effect lasted longer and did not diminish as quickly as after the HR-PNF stretching technique.

The smaller mean of CE at 60° compared to 30° (1.90° versus 5.76°) of knee angle may have occurred as a result of that 60° of knee flexion is closer to a resting position of the knee while sitting (i.e. = 90°), therefore, the body is more familiar with replicating this position as compared to the 30° JPS of the knee.70 Possible reasons behind the insignificant differences noticed in the current study may be due to testing and stretching positions’ variation, the participants were young, healthy and physically active individuals who did not have proprioceptive deficits.71 Furthermore, the two stretching techniques may not have imposed adequate effect on the mechanoreceptors in all acting muscle groups around the knee to make a difference in proprioceptive acuity. Lastly, large values of standard deviations for this measurement may have contributed to nonsignificant differences. The findings of this study are consistent with what have been reported in a number of other similar studies.42,71-74 Moradi et al. reported nonsignificant difference in knee JPS replication accuracy at 45° of knee flexion between pre- and post-static stretching in 30 soccer player (mean age 23.20 ± 1.45 years).42 Larsen and his colleagues stated the use of static stretch regimen had no effect on knee JPS (50° and 70° flexion) in 20 (6 men, 14 women) healthy young volunteers.72 A similar study demonstrated that using acute bout of passive stretch of quadriceps muscle has no effect on knee JPS (30° or 70° flexion) among untrained young males (age = 22.1 ± 2.7 years).73 Ghaffarinejad et al. also reported nonsignificant differences in knee JPS absolute error values in 20° of flexion after stretching quadriceps, hamstrings, hip adductors, gastrocnemius and popliteus muscles.74 However, they stated significant decrease in knee JPS absolute error after statically stretching of quadriceps, hamstrings and hip adductors at 45° of knee flexion.71 The authors suggested stretching may have improved knee JPS by increasing proprioceptive feedback which may indirectly cause an enhancement in sensory imagery.

There were significant differences in distances of reach in both PM (pre = 103.82 %, post = 107.94 %) and PL (pre = 110.96 %, post = 113.48 %) directions over time. The distance of reach during both time points to PL direction was significantly greater than the reach to PM direction which was in turn greater than the reach to ANT direction (pre = 66.49 %, post = 65.64 %). Improved DB performance may have occurred due to the decreased postural instability in those individuals by improving the proprioceptive feedback.71,75 It is also possible that the hold duration during HR-PNF stretching and duration of one set during DS was enough to produce this significant improvement.75 Therefore, moderate hold duration during stretching (i.e. 15-20s) may decrease the possible unfavorable reflex activity decrements.75 The results of the current study are supported by findings of several other similar studies.76-79 Handrakis et al. reported significant effect of an acute static stretching protocol on dynamic balance performance in (six men and four women aged 40-60 years) (p < 0.05).76 In a similar study, Azeem et al. have shown that both static and dynamic stretching resulted in a significant improvement in dynamic balance performance in 30 male recreational soccer players (age 17-25 years) (p < 0.001).77 Chatzopoulos and his colleagues demonstrated the superiority of dynamic over static stretching in improving balance performance using stability platform instrument in 31 female high school athletes (p < 0.05).78 Furthermore, Amiri-Khorasani reported that dynamic and combined (static and dynamic) were significantly more effective than static stretching in improving dynamic and static balance performance in 24 female soccer player (mean ± SD age = 22.08 ± 0.77 years) using the Star Balance Test.79 Contrary to the findings of this study, the results of Lim et al showed no significant difference between static, HR-PNF and no stretching groups in the mediolateral and anteroposterior directions of balance test (p < 0.05).80

The significant improvement noticed in distances of reach to PM and PL directions after stretching in both groups may also be explained by nature of the demands during reaching to these directions. Reaching to PM and PL directions involve lengthening of the hip flexors and active hip extension as compared to the anterior reach direction. It is a fact that the stretched muscles (i.e. iliopsoas and rectus femoris) are located on the anterior parts of
the hips and legs. Therefore, more flexible muscles in these parts of the body would in turn facilitate greater ability to reach to PL direction first and PM second. Further, since concentric action of hip flexors produce hip flexion and external rotation, these muscles are stretched by hip extension and internal rotation movements (i.e. movements occurred during dynamic and HR-PNF in this study). Thus, during PL reach, achieving the farthest distance incorporates extension and internal rotation of the hip. On the other hand, reaching to the ANT direction would not have likely benefitted from stretching these muscles because it does not require the hips to be in an extended position but in a flexed position instead (Figure 5). Additionally, the hip and knee of stance leg is flexed while the free leg is performing the reach thus, positioning the hips behind the stance knee (to maintain balance) practically limits the reach distance to ANT direction.

Another possible explanation for the significant improvement in these two directions could be because of a decreased reciprocal inhibition of the gluteus maximus. It is theorized that shortened and restricted hip flexors may decrease neural drive to hip extensors (i.e. reciprocal inhibition of the gluteus maximus muscle). Improved function of this muscle post stretching may be a possible reason for a greater distance of reach (i.e. the reaching leg) to these directions since it is a major thigh extensor. Further, gluteus maximus contributes to maintaining balance of the body because it is a powerful muscle and most effective when the thigh is flexed (i.e. position of stance leg while reaching). The significant differences observed during the pre- and post-stretching time points between distances of reach to these three directions could be possibly explained by the relationship between hip joint anatomy, ROM of hip, nature of the Y-balance test and directions of reach. This thought is supported by the fact that significant differences between these directions did not change and remained over time during the post-stretching time point too.

This study was not without limitations. The age range of this study was limited to college aged-participants which limits the generalization (i.e. external validity) of its results to other populations. Knee JPS accuracy and ability of DB performance among the participants varied greatly (high standard deviations) during the baseline measurements, which may also have affected the results. In addition, repeating tests within 45-50 minutes could have had a learning effect on the performance during the DB and knee JPS tests despite randomization the order of these tests. Further studies should consider these limitations.

CONCLUSIONS
Tightness of hip flexor muscles may negatively affect dynamic balance performance but not knee joint position replication accuracy among female and male college age students. The results of the current study indicate that performing a single session of hold-relax proprioceptive neuromuscular facilitation and dynamic stretching protocols can significantly improve hip extension ROM (HR-PNF was more effective than dynamic stretch) and dynamic balance performance but are unlikely to aid in knee JPS replication accuracy. Further research is needed to understand how different types of stretching protocols can affect the variables studied in the current study.

REFERENCES


ABSTRACT

Background: Monitoring levels of physical activity, as an outcome or in guiding rehabilitation, is challenging for clinicians. Personal activity monitors are increasing in popularity and provide potential to enhance rehabilitation protocols. However, research to support the validity and reliability of these devices at jogging and running speeds is limited.

Purpose: The purpose of this study was to evaluate the validity of the Fitbit Flex™ and ActiGraph GT3X+ for measuring step count at jogging and running speeds. A secondary purpose was to examine inter-device reliability of the Fitbit Flex™.

Study Design: Cross-sectional study

Methods: Thirty healthy participants aged between 19 and 50 years, completed a treadmill protocol at jogging and running speeds (8 km/h to 16 km/h). Treadmill speed was progressively increased by intervals of 2 km/h. Each interval was four minutes in duration with a two minute rest period between stages. Participants were encouraged to continue through the graded exercise test until they reached the maximum running speed that they felt they could maintain for four minutes. Step count data was collected for Fitbit Flex™ devices and the ActiGraph GT3X+. Video analysis of step count was used as the criterion measure.

Results: At speeds of 8 to 14 km/h Mean Absolute Percentage Errors were ≤1% for the Fitbit Flex™ and the ActiGraph GT3X+ when compared to step count via video analysis. Standard Error of Measurement between the three Fitbit Flex™ devices was ≤7 steps for speeds of 8 to 14 km/h and varied between 9 to 19 steps at 16 km/h. Fitbit Flex™ devices showed good to excellent between device reliability at speeds of 8 to 14 km/h (ICC 0.723 to 0.999; p ≤0.001). Greater variability was evident with the low participant numbers at 16 km/h (ICC 0.527 to 0.896; p ≥ 0.02).

Conclusion: Both the Fitbit Flex™ and the ActiGraph GT3X+ provide a valid account of steps taken at jogging and running speeds up to 14 km/hr, attainable by non-elite runners on a treadmill. Fitbit Flex™ devices provide equivalent step count output to each other, enabling comparison between devices during treadmill jogging and running.

Level of evidence: 2b

Key words: Accelerometer, activity tracker, activity monitor, physical activity, step count

CORRESPONDING AUTHOR

Denise Jones
La Trobe Sport and Exercise Medicine Research Centre (LASEM), School of Allied Health, College of Science, Health and Engineering, La Trobe University, Melbourne, Victoria, Australia

The International Journal of Sports Physical Therapy | Volume 13, Number 5 | October 2018 | Page 860
DOI: 10.26603/ijspt20180860
INTRODUCTION

Physical therapists involvement in enabling and promoting physical activity is well established.\(^1\) Enabling the maintenance, return to or improvement of physical activity levels as a key aim of therapy interventions aligns with the scope of practice descriptors identified by the World Confederation of Physical Therapy (WCPT).\(^2\)

As physical activity is a primary factor associated with maintaining health and wellbeing, particularly when considering all-cause mortality,\(^3,5\) it is undoubtedly an important outcome for athletes and non-athletes alike. Although injury has been shown to have a profound effect on long-term activity, irrespective of ongoing disability,\(^6\) identifying suitable and user-friendly methods for monitoring and guiding physical activity is challenging for individuals, clinicians and researchers.

Step count is frequently used as an indicator of physical activity, the number of steps identifying a volume, rather than intensity of activity. Intensity may be extrapolated from the number of steps taken in a given time. It furnishes clinicians with a simple measure to provide guidelines and encourage behavior change for individuals and communities. This utility assumes that devices are reporting an appropriate account of steps taken. Evidence is currently lacking to substantiate the accuracy of step count output from devices in relation to more athletic populations.

Similarly, step count has been used to monitor post-intervention progress in individuals with a health condition, particularly where weight-bearing activity is a key healthcare outcome.\(^10-12\) For runners, an accurate perception of the number of steps taken per minute may also be of relevance in relation to rehabilitation, such as attempting to increase step rate (cadence) to reduce patellofemoral load.\(^13\) The increasing popularity of personal fitness trackers is indicative of individual enthusiasm for monitoring activity data. In addition, these trackers are serving to take the collection of objective physical activity data beyond the laboratory and into the public domain. The popularity of these devices provides opportunities for measuring physical activity that researchers and healthcare professionals are beginning to exploit. As with all emerging technologies, the purpose-specific utility of these devices needs to be established. Fitbit remains at the forefront of the market in digital fitness devices,\(^14\) the Fitbit Flex\(^{TM}\) being a popular wrist-worn device available at a relatively affordable price (~ USD$60).

Current research focuses on the validity of devices at lower speeds, which may be relevant for populations with chronic conditions that inhibit aerobic activity levels.\(^15-21\) For clinicians working with sporting populations, and communities who are capable of running, these boundaries need to be expanded to evaluate the utility of devices at greater ambulation speeds. Correlation estimates of step count for the Fitbit Flex\(^{TM}\) vary between studies. For speeds between 3 and 8 km/h, Diaz et al.\(^16\) report strong correlations to criterion measure (0.77 to 0.85), conversely, Sushames et al.\(^21\) report intraclass correlations of 0.05 and 0.34 for step count during walking and jogging respectively. Huang et al.\(^18\) reported Mean Absolute Percentage Errors (MAPE’s) of 6.5% and 8.9% for the Fitbit Flex\(^{TM}\) at treadmill speeds of 3.24 and 6.41 km/h, respectively. During combined walking and jogging, Nelson et al.\(^22\) reported a comparable MAPE of 6%. Although study protocols vary, a tendency for the Fitbit Flex\(^{TM}\) to underestimate step count is evident, this effect being more pronounced at slower speeds.\(^15,16,18,21\) Data is limited to substantiate the performance of the Fitbit Flex\(^{TM}\) at speeds above 8 km/h. Therefore, this study investigated the validity of the Fitbit Flex\(^{TM}\) at jogging and running speeds by assessing accuracy of the device output in relation to observed values for step count. Inter-device reliability was assessed by evaluating the precision of output between Fitbit Flex\(^{TM}\) devices over the same range of jogging and running speeds. In comparison to commercially available activity trackers, the ActiGraph GT3X+ is a research grade device which allows access to underlying algorithms and options for the user in converting raw count data to step count and energy expenditure data. It is frequently used as a comparator to commercially available devices in assessing physical activity.\(^23-27\) Simultaneous investigation of the Fitbit and ActiGraph devices was undertaken to provide comparative measures to aid assessment of their relative merits for researchers.
The purpose of this study was to evaluate the validity of the Fitbit Flex™ and ActiGraph GT3X+ for measuring step count at jogging and running speeds. A secondary purpose was to examine inter-device reliability of the Fitbit Flex™. The results of this study provide an objective measure of interest to the running community using the Fitbit Flex™ for personal activity monitoring and guidance for clinicians wishing to utilize these devices within rehabilitation and maintenance programmes, such as implementing graded return from injury or embedding modifications to running step rate to modify joint loading.

METHODS

Participants
Thirty young and middle-aged healthy adults were recruited for this cross-sectional study. Participants were recruited within the university and the wider community via website postings, social media, and word-of-mouth. The study was approved by La Trobe University Human Ethics Committee (Approval number HEC16-082).

Eligibility criteria
The Physical Activity Readiness Questionnaire (PARQ) was used to screen for safe participation. Potential participants were excluded on the basis of acute or chronic health conditions that precluded running activity, being pregnant, breastfeeding, being outside the age range of 18 to 50 years or lacking sufficient English language skills to give informed consent.

Equipment

ActiGraph
The ActiGraph GT3X+ (ActiGraph, Pensacola, FL) is a small (4.6 x 3.3 x 1.5 cm), lightweight (19g) tri-axial accelerometer (Figure 1A). It was worn on an elastic belt below the waist, in line with the right anterior axillary line and did not impede the participants’ ability to run.

Fitbit
The Fitbit Flex™ (Fitbit Inc., San Francisco, CA) is a consumer-wearable activity tracker. The triaxial accelerometer is held within a wristband providing a five-light LED display of activity progress (Figure 1B).

Protocol
Data collection took place in a non-air-conditioned physiology laboratory at La Trobe University, Melbourne, Australia, between December 2016 and February 2017. Prior to undertaking testing, potential participants were offered further information on the study and screened for eligibility. All participants

Figure 1. A. ActiGraph GT3X+ (With permission, Actigraphcorp.com); B. Fitbit FlexTM (With permission, fitbit.com)
gave written, informed consent prior to undertaking the test.

Self-reported measures of body mass (kg) and height (m) were used where recent accurate measures could be offered by participants. Where any queries arose, measurements were confirmed in the testing laboratory using a stadiometer and digital scales. Body mass index (BMI) was calculated from these measures.

Participants were advised to wear suitable sports clothing and footwear for the test and abstain from alcohol, caffeine, and cigarettes for 24 hours prior to the test. Participants were also advised to avoid a large meal for at least three hours prior to testing and avoid vigorous exercise during the 24 hours prior to testing in line with standard recommendations for maximal exercise testing.28

Prior to use by each participant the ActiGraph GT3X+ devices were initialized via the supporting software (Actilife 5.10.0, ActiGraph, Pensacola, FL) inputting: start time; sampling rate (30Hz); device position; date of birth; sex; body mass; height and race of the participant.

Each participant was fitted with three Fitbit Flex™ devices, two on the left wrist (device numbers 1 and 2) and one on the right wrist (device number 3). Each band was securely fitted to the participant's wrist to allow minimal movement during testing without being uncomfortable.

For each Fitbit Flex™ device participants' demographic data (sex, date of birth, height, body mass, walking and running stride length) were entered, via the web Fitbit interface. Fitbit defines a stride as heel strike to heel strike of the opposite foot, more conventionally defined as a step. This was assessed for individual participants with a measured 10-step walk in a straight line over flat ground. The process was repeated at a comfortable running pace, self-selected by the participant. The distance was then divided by a factor of 10 to give an average ‘stride’/step length.

For the purposes of treadmill testing, participants were deemed to be undertaking a standardized activity with relatively symmetrical arm movement. Due to this bilateral equivalence, all the Fitbit Flex™ devices were maintained at the default setting of ‘non-dominant’ throughout all data collection.

To obtain minute level data from the Fitbit Flex™ devices, each device was placed into ‘activity mode’ by tapping the device sharply (1 to 2 sec) until it vibrated. The activity mode was deactivated at the end of each test by repeating this procedure. This allowed for a discrete set of minute-by-minute data to be viewed via the interface.

At the start of each test session, participants were given a warm-up period of five minutes on the treadmill (Cosmed T200, Rome, Italy) to familiarize them with the equipment and ensure that all devices were comfortable and secure. Participants then undertook two further warm-up periods at 4 and 6 km/h for four minutes at each level, separated by two minutes rest, to familiarize them with the treadmill protocol. Participants were advised to maintain their regular arm swing, avoid looking at the devices and to avoid holding on to the treadmill.

The graded exercise test began at 8 km/h, progressing at 2 km/h intervals. Each interval was four minutes in duration with a rest period of two minutes between each interval. Rest periods facilitated transitions and the tracking of data between devices. Intervals were recorded for video analysis of step count. A video camera (Lumix DMC-FZ2000, Panasonic, UK) was placed to capture right and left footfall during each incremental stage of a test. A clearly visible digital clock was placed within the video frame to enable tracking of real time. Data from devices were compared to video observation of step count, which was regarded as the criterion measure.

Participants were encouraged to continue through the graded exercise test until they reached the maximum running speed that they felt they could maintain for four minutes. Each test was terminated either at the participant's request or at a point at which the researchers had concerns for the participant's wellbeing.

Data Processing
Following test sessions, each Fitbit Flex™ was synced to allow the data to be accessed via the product interface. Data from each ActiGraph GT3X+ was downloaded via a universal serial bus (USB) and processed using proprietary software (Actilife 5.10.0, Actigraph Corp. Pensacola, FL). The data
were processed in 60-second epochs to align with the output from the Fitbit Flex™.

Videos were downloaded to a PC and viewed via Windows Media Player. The recordings (30 frames per second) were visually analyzed in slow motion and the number of steps, identified by foot strike, tallied for the middle two minutes of each level completed by the participant. The middle two minutes of each stage was used to minimize inconsistencies related to participants settling into their target pace or becoming fatigued at the termination of later stages. The observed video data provided criterion values for step count at each level of the treadmill test. A proportion (10%) of the step count data was analyzed by two assessors (DJ and SC) to ensure consistency.

Analysis

Sample size
Sample size numbers were determined by procedures described by Walter et al.29 for inter-device reliability. Twenty-two subjects were deemed to be acceptable to judge the difference between two devices with a minimally acceptable level of 0.5, when \( \alpha = 0.05 \) and \( \beta = 0.20 \) (power = 0.08). A sample size of 18 participants was required to assess validity of the devices based on an estimated correlation coefficient of \( r = 0.6 \), 2 tailed test (\( \alpha = 0.05 \)) with a power of 80%.30

Inter-device reliability
Inter-device reliability was determined for the three Fitbit Flex™ devices using intraclass correlation coefficients (ICC 2, 1)30 with 95% confidence intervals (CI). ICC’s were considered to be excellent (0.75 and 1.00); good (0.60 and 0.74); fair (0.40 and 0.59) or poor (≤0.40).31 Paired t-tests (\( \rho = 0.05 \)) were performed on normally distributed data to determine the mean difference (group mean difference) between devices. The standard error of measurement (SEM) was calculated for normally distributed data to determine absolute reliability. This was calculated using the formula SEM = Standard deviation (SD) x \( \sqrt{1-ICC} \).

Validity
Validity was evaluated for the Fitbit Flex™ and ActiGraph GT3X+ for step count, by comparing to observed step count. Correlations between device and criterion measure were judged on the following guidelines for correlation coefficient (r): Little or no relationship (0.00 to 0.25); fair relationship (0.25 to 0.50); moderate to good relationship (0.50 to 0.75) and good to excellent relationship (above 0.75).30

To further investigate device validity, MAPE was used to provide a conservative estimate of individual level error.32 MAPE is calculated with the following formula:

\[
\text{Absolute bias (criterion – device)}
\]

\[
\text{Criterion}
\]

Limits of agreement were used to show the spread of the difference of scores.

The significance criteria for all tests was \( \alpha = 0.05 \) and \( \beta = 0.20 \), thus power = 0.8 (1-\( \beta \)), and confidence intervals were 95% (1-\( \alpha \)).

RESULTS

Participant characteristics
Between November 2016 and February 2017, 54 potential participants responded to notification and advertisement of the study. Figure 2 summarizes the flow of respondents through the study. Thirty healthy adults (18 women, 12 men; mean ± SD: age, 33 ± 8 years; BMI, 24.1 ± 2.5 kg/m²) were included in the study (Table 1).

Findings
All 30 participants completed the protocol to the end of 8 km/h. As the speed increased above 8 km/h, there was a decrease in the sample number (Figure 3). Baseline characteristics of participants completing each level are outlined in Table 2. ActiGraph GT3X+ data were successfully obtained for all 30 participants and minute by minute data were successfully collected for all three of the Fitbit devices worn for 20 participants. For the remaining ten participants, data from two Fitbit Flex™ devices were successfully collected for seven participants. For one participant minute data was successfully collected from only one of the Fitbit devices. Two participants were missing all minute by minute data from the Fitbit Flex™ devices. The missing data was the result of errors in setting the devices to activity.
mode. The successful functioning of this mode for the duration of the test could not conveniently be checked until the data were downloaded and viewed following completion of the trial. For seven participants, errors occurred in video records. A total of eight two-minute intervals were, therefore, missing observed step count analysis. Due to the missing data, sample size varies throughout areas of data analysis and is reported accordingly.

**Observed step count, inter-rater reliability**

When comparing video analysis observed step count, inter-rater reliability between both testers was excellent (ICC = 1.000, 95% CI 0.999 to 1.000).

**Inter-device reliability**

The three Fitbit Flex™ devices demonstrated excellent between device reliability for step count for speeds of 8 to 14 km/h (Table 3), with the exception

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**Table 1. Demographic characteristics of the study cohort.**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Total Mean (SD) range n = 30</th>
<th>Women Mean (SD) range n = 18</th>
<th>Men Mean (SD) range n = 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>33 (8) 19 - 50</td>
<td>34 (7) 19 - 46</td>
<td>32 (8) 23 - 50</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.71 (0.12) 1.47 - 1.95</td>
<td>1.64 (0.07) 1.46 - 1.76</td>
<td>1.82 (0.10) 1.61 - 1.95</td>
</tr>
<tr>
<td>Body Mass (kg)</td>
<td>71 (16) 44 - 128</td>
<td>62 (8) 44 - 74</td>
<td>83 (16) 68 - 128</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.07 (2.51) 19.43 - 33.53</td>
<td>23.19 (1.77) 19.43 - 26.50</td>
<td>24.99 (3.13) 21.83 - 33.53</td>
</tr>
</tbody>
</table>

SD = +/- 1 Standard deviation; n = number of participants; m = meters; kg = kilogram; BMI = body mass index
of Fitbit Flex™ 2 (left arm) and Fitbit Flex™ 3 (right arm) at 12 km/h, for which the intraclass correlation was good (ICC (2,1) 0.723, 95% CI 0.370 to 0.894).

The SEM between the two devices on the same arm did not vary by more than 1% at speeds of 8 to 14 km/h. This error increased to a maximum of 2% between the right and left arm devices for these speeds. Greater errors were evident at 12 km/h. A similar trend is observed at 16 km/h with SEM varying by less than 3%, at both speeds, for devices on the same side and less than 6% for devices on opposite arms.

**Validity**

Due to the close correlation of the output between Fitbit devices, Fitbit Flex™ 1 (left wrist) and the

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>n</th>
<th>Men/Women</th>
<th>Age (Years) Mean (SD)</th>
<th>Height (m) Mean (SD)</th>
<th>Body Mass (kg) Mean (SD)</th>
<th>BMI (kg/m²) Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>30</td>
<td>12/18</td>
<td>34 (8)</td>
<td>1.71 (0.12)</td>
<td>71 (16)</td>
<td>23.80 (7.64)</td>
</tr>
<tr>
<td>10</td>
<td>28</td>
<td>12/17</td>
<td>33 (8)</td>
<td>1.72 (0.12)</td>
<td>71 (15)</td>
<td>23.95 (2.41)</td>
</tr>
<tr>
<td>12</td>
<td>25</td>
<td>11/14</td>
<td>33 (8)</td>
<td>1.72 (0.12)</td>
<td>70 (11)</td>
<td>23.66 (1.59)</td>
</tr>
<tr>
<td>14</td>
<td>13</td>
<td>8/4</td>
<td>34 (8)</td>
<td>1.77 (0.10)</td>
<td>75 (8)</td>
<td>23.83 (1.47)</td>
</tr>
<tr>
<td>16</td>
<td>6</td>
<td>5/1</td>
<td>34 (9)</td>
<td>1.80 (0.09)</td>
<td>77 (9)</td>
<td>23.72 (0.82)</td>
</tr>
</tbody>
</table>

**DISCUSSION**

This study evaluated Fitbit Flex™ inter-device reliability and validity of the Fitbit Flex™ and ActiGraph GT3X+ in a healthy cohort of men and women aged 18 to 50 years. It compared the output from the Fitbit Flex™ and ActiGraph GT3X+ to the criterion measure of observed step count over speeds ranging from 8 to 16 km/h. The results indicate that both the Fitbit Flex™ and the ActiGraph GT3X+ provide a valid assessment of step count with close correlation to observed step count and MAPE values below 1% for speeds of 8 to 14 km/h.

Fitbit Flex™ inter-device reliability was excellent for devices worn on the same arm with closely associated absolute measures at speeds of 8 to 14 km/h. The low SEM between all three Fitbit devices for speeds of 8 to 14 km/h (1 to 4 steps), indicates a high level of confidence that output from the Fitbit Flex™ devices is equivalent. The large confidence intervals observed for mean differences between devices at 16 km/h highlights that participant numbers were
insufficient to draw conclusions regarding reliability of the Fitbit Flex™ devices at this speed. The relatively symmetrical upper limb activity expected with treadmill walking and running was reflected in the similarity of mean differences between devices on opposite sides. Greater variances evident in right/left data at 12 km/h reflect one outlying set of data. With this participant omitted from analysis, ICC's for Fitbit 1 and 3 improve from 0.953 to 0.995 (p < 0.001) and Fitbit 2 and 3 from 0.723 to 0.981 (p < 0.001).

In previous studies of the Fitbit Flex™, MAPE's have varied. Both Diaz et al.16 and Sushames et al.21 reported insufficient to draw conclusions regarding reliability of the Fitbit Flex™ devices at this speed. The relatively symmetrical upper limb activity expected with treadmill walking and running was reflected in the similarity of mean differences between devices on opposite sides. Greater variances evident in right/left data at 12 km/h reflect one outlying set of data. With this participant omitted from analysis, ICC's for Fitbit 1 and 3 improve from 0.953 to 0.995 (p < 0.001) and Fitbit 2 and 3 from 0.723 to 0.981 (p < 0.001).

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a trend of improvement as assessed treadmill speeds increased. Diaz et al.\(^{16}\) reported a MAPE of 16% at 3 km/h improving to 1.8% at 8.4 km/h. Sushames et al.\(^{21}\) observed self-selected walking speeds (between 5 and 6.5 km/h) and jogging speeds (between 8 and 10 km/h) with MAPE decreasing from 14.7% to 2.5% at higher speeds. Conversely, Huang et al.\(^{18}\) reported an increase of 2.4% in MAPE’s between 3.2 and 6.4 km/h. Findings in the current study are reflective of these previously reported figures at 8 to 10 km/h, additionally, the current study highlights that low MAPE’s are also associated with speeds above those previously reported. The excellent correlations between Fitbit Flex\(^{TM}\) 1 and observed step count from video analysis indicate a valid measure. With only five participants, it is inappropriate to draw conclusions regarding the relationship between the devices and criterion measure at 16 km/h.

Despite the ability to use filters to accommodate for slow speeds, studies of the ActiGraph GT3X+ mirror the trends seen in Fitbit Flex\(^{TM}\) data with poor correlation to step count criterion measures at slow speeds, improving as more standard walking speeds are reached.\(^{33,34}\) However, Tudor-Locke et al.\(^{35}\) concluded that steps estimated by a waist-worn ActiGraph GT3X+ were not significantly different from observed step count in speeds ranging from 0.84 km/h to 11.28 km/h. The current study expands the pool of data available for the ActiGraph GT3X+, including previously unreported running speeds above 11 km/h. Correlations to observed step count for jogging and running speeds the current study, ranging from 0.905 to 0.990 (p < 0.001), reflect those reported by Lee et al.\(^{34}\) for average walking speeds. These correlations are markedly different to those reported by Sushames et al.\(^{21}\) for jogging (0.46, p = 0.005). Differences in methodology, such as the self-selection of jogging speed and the 6-minute duration of data collection may account for some of the differences observed.

For research purposes, commercial devices such as the Fitbit Flex\(^{TM}\) potentially have substantial advantages in relation to cost; subjective perceptions of the device, such as being more agreeable to wear, and therefore compliance from participants. Their utility may be compromised by their commercial nature and the speed of change in the market. The Fitbit Flex\(^{TM}\) assessed in this study had now been superseded by the Fitbit Flex2\(^{TM}\). For researchers, this means that the pool of evidence underpinning data collection will remain limited for specific devices and that restricted information sharing from commercial producers will prevent researchers being able to give a full account of algorithms and accuracy when reporting their findings. Small-scale studies such as this can provide a compromise to mitigate some of the uncertainty of using commercial devices. Changes in the commercial market have less impact on clinical utility of devices which maintain the advantages of being accessible, affordable and broadly equivalent to previous incarnations of the same device in relation to the accuracy of basic algorithms such as step count.

**LIMITATIONS**

There are a number of limitations in this study that should be acknowledged. First the convenience sample of participants for this study encompassed a range of athletic abilities across a young and middle-aged cohort of healthy adults. The non-elite nature of the runners participating limited the number able to sustain speeds above 12 km/h. Lower participant numbers at 14 and 16 km/h compromises the validity of the findings at these speeds. A larger pool of participants would reduce the effect of outlying data such as that identified at 12 km/h. Additionally, utilizing laboratory-based measures of height and body mass for all participants would be recommended for future studies to eliminate the possibility of any inaccuracies, particularly in relation to more elite sporting populations. Second, minute by minute data for step count cannot be accessed via the Fitbit user interface unless the device has been put into an activity mode. This resulted in the loss of some data where the activity mode failed to activate or was inadvertently deactivated during the running trials. Third, the two-minute intervals reported provide a limited snap-shot of activity related to controlled treadmill running conditions. The results should be interpreted with caution as they cannot be extrapolated to be indicative of the performance of the devices over the range of running surfaces and physical activity occurring in free-living. Future research in less restrained conditions, using runner specific populations, would be a valuable addition to the current knowledge base.
CONCLUSIONS
Both the Fitbit Flex™ and the ActiGraph GT3X+ provide a valid account of steps taken at jogging and running speeds attainable by non-elite runners on a treadmill. Inter-device reliability for step count at jogging and running speeds indicates that individual users the Fitbit Flex™ can compare outputs between each other's devices for these activities with relative confidence. Users of these devices should be advised to wear the device on the same arm to provide the most reliable comparison of day-to-day data.

REFERENCES


ABSTRACT

Purpose/Background: Bilateral squats are commonly used in lower body strength training programs, while unilateral squats are mainly used as additional or rehabilitative exercises. Little has been reported regarding the kinetics, kinematics and muscle activation in unilateral squats in comparison to bilateral squats. Therefore, the purpose of this study was to compare muscle activity, kinetics, and barbell kinematics between unilateral and bilateral squats with the same external load per leg in experienced resistance-trained participants.

Methods: Fourteen resistance-trained males (age 23±4 years, body mass 80.5±8.5 kg and height 1.81±0.06 m) participated. Barbell kinematics and surface electromyography (EMG) activity of eleven muscles were measured during the descending and ascending phase of each repetition of the squat exercises.

Results: Total lifting time was longer and average and peak velocity were lower for the bilateral squat (p<0.001). Furthermore, higher muscle activity was found in the three quadriceps muscles, biceps femoris (ascending phase) and the erector spinae (ascending phase) in the bilateral squat, while greater activation for the semitendinosus (descending phase) (p=0.003) was observed for the unilateral squat with foot forwards. In the ascending phase, the prime movers showed increased muscle activity with repetition from repetition 1 to 4 (p≤0.034).

Conclusions: Unilateral squats with the same external load per leg produced greater peak vertical ground reaction forces than bilateral squats, as well as higher barbell velocity, which is associated with strength development and rate of force development, respectively. The authors suggest using unilateral rather than bilateral squats for people with low back pain and those enrolled in rehabilitation programs after ACL ruptures, as unilateral squats are performed with small loads (28 vs. 135 kg) but achieve similar magnitude of muscle activity in the hamstring, calf, hip and abdominal muscles and create less load on the spine.

Level of Evidence: 1b

Key words: Ascending phase, descending phase, electromyography, kinematics, single limb squat, two-legged squat

CORRESPONDING AUTHOR
Roland van den Tillaar PhD.
Department of Sports Science and Physical Education
Nord University
Odins veg 23
7603 Levanger
Norway
E-mail: roland.v.tillaar@nord.no
Phone: +47-97662913
Fax: 0047-7411 2001

1 Department of Sports Science and Physical Education, Nord University, Levanger, Norway.
2 Department of Teacher Education and Sport, Sogn og Fjordane University College, Sogndal, Norway

This study was conducted without any funding from companies, manufacturers or outside organizations and the authors report no conflict of interest.
INTRODUCTION
Bilateral exercises, such as snatches, deadlifts and two-legged back squats are frequently implemented as an important part of resistance training programs to improve strength, hypertrophy and power for the lower body.1-3 In recent years, the use of unilateral exercises such as lunges, step-ups and one-legged squats have become popular in strength and conditioning practice.4 However, these unilateral exercises, are regularly included within strength programs as additional exercises to the two-legged back squat to increase volume load or variation.4 Still, little is known regarding the effects of performing these unilateral exercises on muscle recruitment compared with unilateral exercises.

The ability to generate more force in sum performing two unilateral exercises (i.e. one-legged squat) than in a bilateral exercise (i.e. two-legged squat), is referred to as bilateral deficit.5-7 Consequently, including unilateral instead of bilateral exercises in training may be favorable to increase power and strength of the muscles, but the evidence is not conclusive.6,8,9 Furthermore, running, kicking, changing running direction, and jumping are all unilateral movement patterns that are performed in a unilateral weight-bearing phase. Therefore, to improve these performances most effectively, resistance training should closely resemble the mechanics and forces required to perform these necessary skills.10-12

Yet, few studies exist that have compared force output and muscle activity between bilateral and unilateral squats.12-16 In addition, these studies comparing bilateral with unilateral squats have used different protocols for both conditions (split legs and rear foot elevated) and different loads between bilateral and unilateral squats, and neither of these studies compared unilateral squats without any support on the rear leg with bilateral squats. During modified squats (i.e. rear foot on a box) force is produced by the front and rear leg, which is helped by the increase in the base of support.17,18 Thus, in fact they are not truly unilateral squats. Limited studies have performed analysis of single-leg squats, and these studies were focused on unilateral squats without extra load for rehabilitation purposes.19-22 To the authors’ knowledge, no studies have compared heavy weight (>80% of 1 repetition maximum) bilateral squats with unilateral, single-leg squats (with foot forwards or backwards) when the same external load per leg is used. Unilateral squats can be performed with the non-weight bearing foot positioned either forwards or backwards, which could influence weight distribution and thereby muscle activation and kinematics. These facets of single-leg squatting have not been studied before, to the authors knowledge. This information could help researchers, trainers and physiotherapists to gain insight into what happens when performing squatting exercises and thereby could help in designing rehabilitation or strength programs.

Therefore, the purpose of this study was to compare muscle activity, kinetics, and barbell kinematics between unilateral and bilateral squats with the same external load per leg in experienced resistance-trained participants. A secondary purpose was to analyze muscle activity between unilateral squats with the lifted foot forwards vs. backwards. It was hypothesized that force output per leg would be the same between bilateral and unilateral back squats due to the same external load per leg being used. However, greater muscle activity of the leg muscles in the unilateral lifts was expected, which would be affected by an increase balance requirement during single-leg lifts.23 Furthermore, greater gluteus and erector spinae activation during the unilateral lifts with the foot backwards than with the foot forwards was hypothesized due to more flexion of the trunk.

MATERIALS & METHODS
A within-subjects, repeated measures design was used in which each subject performed all three squatting exercises: bilateral, unilateral with foot forwards and unilateral with foot backwards. A four-repetition maximum (4-RM) in bilateral squats was used because it is a typical training load used to increase maximal strength.24,25 The dependent variables were peak vertical force, velocity of the barbell, lifting time, and surface EMG activity of 11 muscles of the lower extremity and trunk during the descending and ascending phase of all four repetitions in each condition.

Subjects
Fourteen resistance-trained males (age 23 ± 4 years, body mass 80.5 ± 8.5 kg, height 1.81 ± 0.06 m)
recruited from sport science education of the university volunteered to participate in this study. Each participant had at least two years of resistance training experience. The participants did not perform any resistance training exercises targeting the lower extremities in the 72 hours before the testing session. Participants without any history of neurological or orthopaedic dysfunction, surgery or pain in the spine and lower extremities, were recruited. All participants signed written informed consent forms containing risk factors and their right to withdraw from the research at any time without stating a reason. The study was approved by the local committee for medical research ethics and complied following the current ethical standards in sports and exercise research.26

Procedures
All participants performed three squats variations: a) bilateral back squat, b) unilateral squat with the non-weightbearing limb forwards, and c) unilateral squat with the non-weightbearing limb backwards (Figure 1). The 4-RM external load in the bilateral back squat was used to equalize the volume load between the squat variations. The equalized volume load that was used in the unilateral squats was calculated by:

\[(\text{Body weight} + \text{external 4-RM load}) / 2\]

This is the load per leg in bilateral squats. The load in unilateral squats was then calculated by:

\[\left(\frac{\text{Body weight} + \text{external 4-RM load}}{2}\right) - \text{Body weight}\]

This is the external load that has to be lifted during unilateral squats.

Thus, when a participant of 80 kg lifting 4-RM of 160 kg in the bilateral squat, the participant had to lift a barbell of 40 kg ((240 kg / 2) − 80 kg) during the unilateral squats. The 4-RM for bilateral squat was 134.8 ± 25.7 kg and for the unilateral squat was 27.9 ± 11.4 kg. This resulted in a total lifted load of 215 ± 30.3 kg and 108 ± 15.1 kg in respectively the bilateral and unilateral squats.

Familiarization sessions
Before the test session, participants were given a two-week familiarization period (two to three training sessions) to establish and train with loads that approached their assumed 4-RM for bilateral squat (descent to 90° knee angle). Furthermore, participants practiced the unilateral squat techniques during these sessions, since they were less familiar with these two techniques with these loads. To reduce the technique and balance requirement while performing 4RM loads, a 90° knee angle during all lifts was used to ensure that the heel was in contact with the

Figure 1. Squat positions. a) Bilateral, b) unilateral with foot backwards, and c) unilateral with foot forwards.
The squat variations were performed on the force plate and during the bilateral squat the participants placed their feet in their preferred position (to avoid extra stress upon the participant and increase the external validity towards training). The position of the feet was measured to maintain the foot position during the exercise (Figure 1a). From this position, the participant placed a barbell on the upper part of the shoulders (consistent with the position of a back squat) and flexed the knees down to a 90° knee angle. This position was found using a protractor. A horizontal rubber band was used to identify this lower position during the tests, which the participants had to touch with their proximal part of hamstring before starting the ascending movement. The participants were instructed to perform the ascending movement at maximal velocity during every repetition in each of the three squat conditions.

**Warm up procedure**
Prior to data collection, participants performed a five-minute jog as a general warm up followed by a specific warm-up protocol consisting of a) 10 repetitions of bilateral squats without extra load, b) 10 repetitions with the barbell (20kg) c) 10 repetitions with 50% of 1-RM d) 6 repetitions with 70% RM. The percentage of RM was estimated based on the self-reported 1-RM of the participants.

**Data collection**
After the warm up sets the assumed 4-RM (based on their previous experience) in bilateral squats was performed. Participants always started with the bilateral squat to ensure that they performed their actual 4-RM in bilateral squats. The load was increased or decreased by 2.5 kg or 5 kg until the actual 4-RM was obtained (1–3 attempts). Between each attempt and between each squat exercise, participants were given five minutes rest between each attempt to provide for an optimal performance. The order of the two unilateral squat variations was randomized and counter balanced to avoid an effect of fatigue. In the unilateral squats, participants started standing with the preferred foot on the force platform. The knee of the preferred foot was fully extended and the opposite knee bent approximately 90 degrees (foot backwards, Figure 1b) or fully extended but slightly elevated (foot forwards, Figure 1c) with a barbell on the shoulders on the back. From this position, the participant flexed the knee controlled and squatted down to a 90° knee angle. When the participants touched the rubber band with their proximal part of hamstring, they could start the ascending movement.

**Measurements**
To assess vertical ground reaction forces (1000 Hz) (kinetics) during each squat, a force plate (Ergotest Technology AS, Porsgrunn, Norway) was used. Average vertical ground reaction force per leg were calculated from the ascending phase together and peak vertical ground reaction force per leg for the descending and ascending phase. A linear encoder (ET-Enc-02, Ergotest Technology AS, Porsgrunn, Norway) connected to the barbell measured the vertical position and velocity (barbell kinematics) during all the squat exercises with a 0.075-mm resolution and counted the pulses with 10 millisecond intervals. Velocity of the barbell was calculated by using a 5-point differential filter with software Musclelab V10.4 (Ergotest technology AS, Porsgrunn, Norway).

Musclelab (Musclelab 6000 system, Ergotest AS Porsgrunn, Norway) was used to measure electromyographic (EMG) activity from eleven muscles: a) vastus medialis, b) vastus lateralis, c) rectus femoris, d) lateral side of gastrocnemius, e) gluteus maximus, f) gluteus medius, g) external abdominal oblique, h) erector spinae at L4-L5, i) semitendinosis, j) the long head of the biceps femoris, k) soleus, according to the recommendations of SENIAM, as in other studies. Before positioning the electrodes over each muscle, the skin was prepared by shaving, abrading, and cleaning with isopropyl alcohol to reduce skin impedance. To strengthen the signal, conductive gel was applied to self-adhesive electrodes (Dri-Stick Silver circular sEMG Electrodes AE-131, NeuroDyne Medical, Cambridge, MA, USA). The electrodes (11 mm contact diameter, 20 mm center-to-center distance) were placed on the participant’s stance side used in the unilateral squats. To minimize noise induced from external sources, the EMG raw signal was amplified and filtered using a preamplifier located as near to the pickup point as possible. The common-mode rejection ratio (CMRR) was 106 dB.
and the input impedance between each electrode pair was > 10^{12} \Omega. The EMG signals were sampled at a rate of 1000 Hz. Signals were band pass (fourth-order Butterworth filter) filtered with a cut off frequency of 20 Hz and 500 Hz, rectified, integrated and converted to root-mean-square (RMS) signals using a hardware circuit network (frequency response 450 kHz, averaging constant 12 ms, total error ± 0.5%)\textsuperscript{25}. To locate possible differences in muscle activity during the squat exercises, the average RMS was calculated for the descending and ascending phases for each four repetitions. The phases were identified with the linear encoder, which was synchronized with the EMG recordings using a Musclelab 6000 system and analyzed using software V10.4 (Ergotest Technology AS).

**Statistical analyses**

To assess the differences in kinetics, barbell kinematics and muscle activity between the three squat exercises, a repeated 2 (phase: descending, ascending) x 3 (exercise: bilateral squat, unilateral squat with foot forwards, unilateral squat with foot backwards) x 4 (repetition) analysis of variance (three-way ANOVA) design was used with Holm-Bonferroni post-hoc tests to identify the differences in barbell kinematics and EMG activity of the 11 muscles. If the sphericity assumption was violated, the Greenhouse–Geisser adjustments of the p-values were reported. All results are presented as mean ± SEM. The level for significance was set at p < 0.05. Effect size was evaluated with \( \eta^2 \) (Eta partial squared) where 0.01 < \( \eta^2 \) < 0.06 constitutes a small effect, a medium effect when 0.06 < \( \eta^2 \) < 0.14 and a large effect when \( \eta^2 > 0.14 \).\textsuperscript{33} Statistical analyses were performed in SPSS version 22.0 (SPSS, Inc., Chicago IL, USA).

**RESULTS**

There was no significant difference in average force per leg (p = 0.14) between the bi- and unilateral lifts. However, the peak vertical ground reaction forces per leg, and peak vertical ground reaction force was significantly greater in both unilateral squats compared with the bilateral squat and the peak vertical ground reaction force during the descending phase of the unilateral squat with the foot backwards was significantly greater than with the foot forwards (F = 47.6, p < 0.001, \( \eta^2 = 0.86 \)). Furthermore, a significantly greater peak vertical ground reaction force per leg during the ascending phase was observed compared with the descending phase in all lifts (F = 15.63, p = 0.004, \( \eta^2 = 0.66 \), Figure 2). No significant effect of the peak vertical ground reaction force between repetitions was found among squats (F = 1.4, p = 0.257, \( \eta^2 = 0.11 \), Figure 2).

The lifting time differed significantly among the three exercises in both the descending (F = 23.2, p < 0.001, \( \eta^2 = 0.74 \)) and ascending phase (F = 95.6, p < 0.001, \( \eta^2 = 0.89 \)) with no significant effect for repetition (F ≤ 1.6, p ≥ 0.207, \( \eta^2 ≥ 0.17 \)). Furthermore, the peak velocity was significantly different among the three exercises during both the descending (F = 3.8, p = 0.045, \( \eta^2 = 0.32 \)) and ascending phases (F = 20.5, p < 0.001, \( \eta^2 = 0.63 \)) as well as for the factor repetition (F ≥ 8.8, p < 0.001, \( \eta^2 ≥ 0.42 \), Figure 3). Furthermore, a significant interaction was found in the ascending phase (F = 3.8, p = 0.003, \( \eta^2 = 0.24 \)). Post hoc comparisons revealed that in both phases, the lifting times were longer during the bilateral lifts compared with the unilateral lifts (17% in descending and 39% in ascending phase) and that in the ascending phase, the lifting phase during repetition two to four the lifting time was significantly shorter (8%) during the unilateral lifts with the foot backwards compared to the lifts with the foot forwards (p = 0.002, Figures 2 and 3). Peak velocity was 31% higher in the unilateral squats in the ascending phase (p < 0.001) and 17% lower in the last two repetitions in the descending phase (p ≤ 0.014) than the bilateral squats (Figure 3). Furthermore, peak velocity increased (faster down and upwards) in the unilateral squats from repetition one to two and repetition two to four with the foot backwards and from repetition one to three and repetition one to four with the foot forwards. In the ascending phase the peak velocity increased from repetition one to three (p ≤ 0.018) for the unilateral squats with the foot backwards and peak velocity in repetition four was significantly higher than all other repetitions for the unilateral squats with the foot forwards (p ≤ 0.012, Figure 3). No significant differences in peak velocity per repetition was found in the bilateral squats (p ≥ 0.49).

Mean RMS EMG activity between the three exercises was significantly different for all three quadriceps
muscles, biceps femoris and the erector spinae ($F \geq 6.7, p \leq 0.026, \eta^2 \geq 0.46$), but not for both gluteal muscles, soleus, gastrocnemius, and semitendinosus muscles ($F \leq 0.98, p \geq 0.398, \eta^2 \leq 0.11$). A comparison of the ascending phase to the descending phase revealed significantly greater EMG activity in all muscles except for the gastrocnemius and oblique external muscles ($F \geq 6.5, p \leq 0.034, \eta^2 \geq 0.47$, Table 1). An effect of repetition was found for the three quadriceps muscles, both gluteus muscles, semitendinosis, biceps femoris and erector spinae ($F \geq 3.6, p \leq 0.028, \eta^2 \geq 0.31$, Table 1). In addition, an interaction between lifting phase-repetition for all quadriceps muscles and erector spinae ($F \geq 3.7, p \leq 0.039, \eta^2 \geq 0.32$), an interaction between exercise-phase for the rectus femoris, erector spinae and semitendinosis ($F \geq 3.7, p \leq 0.047, \eta^2 \geq 0.32$) and an interaction between exercise-phase-repetition for the semitendinosis ($F = 2.35, p = 0.045, \eta^2 = 0.23$) were found. Post hoc comparison revealed that muscle activation

Figure 2. Mean (SEM) peak vertical ground reaction force and lifting time for each repetition in the descending and ascending phases of the three squats.
* indicates a significant difference with the other exercises in this repetition on a $p < 0.05$ level.
† indicates a significant difference between the descending and ascending phase on a $p < 0.05$ level.

Figure 3. Mean (SEM) velocity of barbell for each repetition in the descending and ascending phases of the three squats.
* indicates a significant difference with the other exercises on a $P < 0.05$ level.
† indicates a significant difference between this repetition and all right from the sign on a $p < 0.05$ level.
‡ indicates a significant difference between this repetition and all left from the sign on a $p < 0.05$ level.
during the bilateral squats was significantly greater for the rectus femoris (22%, p≤0.003), erector spinae (47%, ps0.018) in the descending phase, medial vastus in all the repetitions in the descending phase (18%, p≤0.011) and the lateral vastus in the descending phase and the ascending phase in the first three repetitions (17%, p=0.017) compared with the unilateral squats. Furthermore, significantly greater EMG activity of the semitendinosus with unilateral squats with the foot forwards in the descending phase (30%, p<0.01) was found compared with the other two exercises, while during the descending phase of the unilateral squat with the foot backwards EMG activity of the biceps femoris was significantly lower (26%, p<0.01) than the other two exercises (Table 1). Post hoc comparison also revealed that EMG activity increased in the ascending phase from repetition one with mostly repetition three and four for most exercises for all quadriceps muscles, gluteus medius, and the biceps femoris (Table 1).

### DISCUSSION

The purpose of this study was to compare muscle activity, kinetics and barbell kinematics between unilateral with the lifted foot forwards vs. backwards and bilateral squats with the same external load per leg in experienced, resistance-trained participants. The main findings were a lower peak barbell velocity and a longer lifting time for the bilateral squat compared to the unilateral squats. Greater activation of the rectus femoris, vastus medialis, vastus lateralis, biceps femoris and erector spinae occurred during the bilateral squat compared to the unilateral squats. In addition, for the unilateral squat with foot

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**Table 1.** Mean RMS (SEM) EMG activity of the eleven muscles for each repetition in the descending and ascending phase of the three squats. All results are presented in μV as means +/- SD.

<table>
<thead>
<tr>
<th>Muscle (μV)</th>
<th>Repetition</th>
<th>Descending phase</th>
<th>Ascending phase</th>
<th>Significant between repetitions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Rectus Femoris</td>
<td>Bilateral</td>
<td>212±29*</td>
<td>210±34*</td>
<td>216±28*</td>
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<tr>
<td>Unilateral</td>
<td>128±18</td>
<td>138±24</td>
<td>149±26</td>
<td>142±24</td>
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<tr>
<td></td>
<td>Unilateral</td>
<td>157±24</td>
<td>152±24</td>
<td>154±25</td>
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<td>Vastus medialis</td>
<td>Bilateral</td>
<td>207±36*</td>
<td>224±35*</td>
<td>232±34*</td>
</tr>
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<td>169±32</td>
<td>172±29</td>
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<td></td>
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<td>247±20*</td>
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<td>227±24</td>
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<tr>
<td></td>
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<td></td>
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<tr>
<td>Erector Spinae</td>
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<td>122±22*</td>
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</tr>
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<td>Unilateral</td>
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<td>54±10</td>
<td>46±77</td>
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<td>66±8*</td>
<td>73±9*</td>
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<td>54±18</td>
<td>53±12</td>
<td>51±11</td>
</tr>
</tbody>
</table>

*F.F= non-weighbearing foot held forward, F.B= non-weighbearing foot held backward
*indicates a significant difference with the other exercises for this repetition on a p<0.05 level.
† indicates a significant difference between the descending and ascending phase on a p<0.05 level.
# indicates a significant difference between these two exercises on this repetition on a p<0.05 level.
forward, a greater muscle activation was found for the semitendinosis and vastus medialis and a lower activation of the erector spinae in comparison to the unilateral squat foot backwards.

In the bilateral and unilateral squats, the same external load per leg was used, determined by equations (see methods). In the unilateral squats, the participants could produce greater peak vertical ground reaction forces than during the bilateral squats (Figure 2). This resulted in a higher peak velocity and shorter lifting time in the descending and ascending phase during these lifts (Figures 2 and 3). These differences in velocity are likely due to the fact that the unilateral squats were performed at a lower percentage of 1-RM than the 4-RM load in the bilateral squats.\(^\text{34}\) Furthermore, it was shown that the peak velocities during the unilateral squats increased in both phases during the set of repetitions (Figure 3), while no difference in peak velocity was found during the set of repetitions of the bilateral squats. Probably due to the small base of support, the participants were more cautious about their movement velocity to avoid an imbalance especially while performing the first repetition in unilateral squats. After the first repetition, which is more about familiarization, they increased their movement velocity. Similar development has been reported in previous studies on squatting in which after the first repetition, the peak velocity increases.\(^\text{28,32}\)

It was expected that muscle activity of the leg muscles would be greater in the unilateral lifts than in the bilateral back squats.\(^\text{23}\) Yet, the EMG activity of the rectus femoris, vastus medialis and vastus lateralis was greater in the bilateral squat compared to the unilateral squats except for vastus medialis in the unilateral squat foot forwards (ascending phase, Table 1). The reason for these unexpected findings (not supporting the initial hypothesis) was probably body positioning over the feet during the lifts. During bilateral squats, feet can be positioned wider than during unilateral squats. Even when the depth was the same with the same knee angle, hip and ankle joint angles could be different to maintain balance. Thereby, more force can be delivered by the quadriceps during bilateral squats. This is also visible in lesser EMG activity of the vastus medialis during the ascending phase in the unilateral squats with the foot backwards. The speculation is supported by previous studies\(^\text{15,35}\) examining the effects of greater stability requirement (i.e. reduced base of support or unstable surfaces). Performing unilateral instead of bilateral squats represent a greater stability requirement to maintain equilibrium and position and could explain the findings. In comparison, McCurdy, et al.\(^\text{16}\) also found greater quadriceps activity in bilateral squats compared with modified single-leg squats. They also reported greater hamstring and gluteus activity during the modified single-leg squats, which contrasts with the findings presented here.

As indicated before, even with the same external load per leg, unilateral squats were probably performed at a lower percentage of 1-RM than the 4-RM load in the bilateral squats as shown by greater vertical ground reaction forces and velocities during unilateral as compared to bilateral squats. Using a lower percentage of 1-RM this would result in a lower activation of the quadriceps, thereby explaining the difference in muscle activation between bilateral and unilateral squats.

Performing the unilateral squat with the foot forwards resulted in greater muscle activation of the semitendinosis in the descending phase compared to the two other squat variations. However, performing the unilateral squat with foot backwards resulted in lower biceps femoris activation. Placing the foot forwards, the center of mass would shift forward. The participant probably had to reposition the weight by less hip external rotation and more knee abduction at the deepest knee angle than in the other two lifts.\(^\text{29}\) The speculation was supported by Khuu, et al.\(^\text{20}\) who showed that unloaded unilateral squats caused a greater internal knee adductor moment during the lifts with the foot forwards than unilateral squats with the foot backwards. To control these knee adductor moment and joint angles during the descending movement, the semitendinosis and vastus medialis in the unilateral squat with the foot forwards have to be more active. Hence, this type of unilateral squats could target the semitendinosis and vastus medialis more than the other lifts which is of importance for avoiding ACL injuries.\(^\text{36,37}\)

The lower muscle activity of the biceps femoris during the unilateral squat with the foot backwards was
surprising. With the foot backwards, the trunk would likely compensate by leaning forwards\textsuperscript{20} which would cause an increase in hamstrings activity as Kulas et al.\textsuperscript{22} found. Furthermore, DeForest et al.\textsuperscript{14} found increased biceps femoris activity during unilateral squats with the rear leg elevated compared with bilateral squats. However, this discrepancy can be explained by the difference in loads used in the present study and in DeForest et al.\textsuperscript{14} The external weight DeForest et al.\textsuperscript{14} used in the unilateral squats in was half of the weight of the bilateral squats. However, they did not account for the body weight that had to be lifted which resulted in a heavier load lifted during the unilateral squats compared to the bilateral squats. Nevertheless, a lower biceps femoris activity during lifts is not necessarily negative. If a person targets the biceps femoris and quadriceps (lateral vastus) muscles too much, this could increase the chance for ACL ruptures.\textsuperscript{36,37}

Similar activity in the gluteus maximus and medius among the three lifts was surprising. It was expected that the unilateral squats would result in an increased internal hip abduction moment which would cause a greater gluteus activity as McCurdy et al.\textsuperscript{16} found. Still, McCurdy et al.\textsuperscript{16} used a heavier intensity (3-RM) than the present study in both bilateral and unilateral squats which would cause a greater demand on these gluteal muscles in the unilateral squats. However, in the present study the total average load per leg was controlled between the bilateral and unilateral squats and therefore this could have resulted in the same gluteal activity. Furthermore, McCurdy et al.\textsuperscript{16} used a modified unilateral squat with an elevated box to rest the other foot. That procedure likely increased the base of support and decreased the stability requirement which may have resulted in a greater force generating condition and thereby possible activation of the gluteus. Previous studies have demonstrated decreased prime mover activations if the muscle or muscle groups have both to stabilize and maximize force production compared to more stable exercises.\textsuperscript{15,35} Finally, McCurdy et al.\textsuperscript{16} used females in contrast to present study.

The erector spinae activity during the descending phase was significantly greater in the bilateral squats compared with the unilateral squats. The results were not surprising since the external weight on the spine was much greater during these lifts compared with the unilateral squats (134.8±25.7 vs. 27.9±11.4). These results have clinical importance, as participants with lower back pain can train by performing unilateral squats that induce similar levels of muscle activity in the hamstring, calf, hip, and abdominal muscles, with reduced load on the spine. Furthermore, with these relatively smaller loads, greater activation of semitendinosus and lower activation of quadriceps muscles was found which is an advantage against possible chances of ACL strains.\textsuperscript{36,37} In addition, since the weight used in the unilateral squats was probably lower than the 4-RM load for the unilateral squats it would be easy to increase the weights to the intensity (3-RM) used in the studies of McCurdy and colleagues\textsuperscript{13,16,38} to enhance gluteal muscle activation.

There are some limitations in the study. Firstly, no 2D or 3D kinematic analysis of the lower extremities or trunk was performed due the limitations of the equipment that could examine these outcomes. An analysis of the angles during various lifts would give more accurate answers for the difference in the muscle activation and kinematic parameters. Secondly, the adaptation period of learning the unilateral squats with weights could be longer to avoid a possible learning effect during testing as indicated by the increasing peak velocity during the sets. A longer adaptation period would probably result in a higher peak velocity at the first repetition during the unilateral squats. Thirdly, the participants were resistance trained and 90° knee flexion depth was used. The results may therefore not be generalized to other populations and squat depths.

**CONCLUSIONS**

The results of the current study indicate that unilateral squats with the same external load per leg produces significantly greater peak vertical ground reaction forces than bilateral squats as well as significantly higher barbell velocity. However, there is significantly greater activation of the rectus femoris, vastus medialis, vastus lateralis, biceps femoris and erector spinae during a bilateral squat in comparison to a unilateral squat. Furthermore, performing unilateral squats with the foot forward results in significantly greater activation of the semitendinosis...
and reduced activation of the other quadriceps muscles. The authors suggest using unilateral rather than bilateral squats for people with low back pain and those enrolled in rehabilitation programs after ACL ruptures may be beneficial, as unilateral squats are performed with small loads (28 vs. 135 kg) but achieve similar levels of muscle activity in the hamstring, calf, hip and abdominal muscles and create less load on the spine.

REFERENCES


ABSTRACT

Background and Purpose: Knee muscle strength deficits have been reported in individuals who have undergone anterior cruciate ligament reconstruction (ACLR). Isokinetic testing is a valid way to assess muscle strength. Some isokinetic variables, including the range of motion in the phases to attain a specific velocity, load range (sustained specific velocity), time to achieve deceleration, and qualitative analysis of the torque-angle velocity relationship, may contribute to understanding recovery of these individuals after surgery. Thus, the purpose of this study was to compare the load range (LR), time to attain velocity (TTAV), deceleration time (DT) phases, total range of motion (ROM), peak torque/body mass (PT/BM), angle of peak torque (AngPT) during LR and torque-angle-velocity relationships (TAV3D) between post ACLR and matched control subjects.

Study design: Case-control.

Methods: Seven men who underwent ACLR and seven matched controls were evaluated from four to six months after surgery. Testing was performed on a Biodex System 4 isokinetic dynamometer in concentric mode at 60, 120 and 300 °/s, for knee flexion and extension.

Results: Statistically significant differences were seen for extension ROM at 60 °/s where ROM was greater in the control group. PT/BM for extensors was also significantly greater in controls by 20 % compared to ACLR at 60 and 120 °/s. PT/BM for flexors was significantly greater for controls at 60 °/s (~15 %). TAV3D showed differences in torque and, specifically, the control group sustained knee flexion torque for a greater range of motion when compared to the ACLR group.

Conclusion: The ACL group presented with lower ROM and PT/BM, therefore exhibiting worse muscle performance in comparison to the control group.

Level of Evidence: 3

Keywords: Anterior cruciate ligament reconstruction, isokinetic dynamometer, torque.
INTRODUCTION

The most common knee injury in young adults is anterior cruciate ligament (ACL) tears. \(^1,2\) Around 200,000 ACL injuries occur each year in the United States, and approximately 65% of these injuries are treated with reconstructive surgery. \(^3\) This procedure aims to correct functional instability of the knee and allow the patient to return to sport activities. \(^4\) Different operative techniques may be employed with the most widely used being bone patellar tendon bone (BPTB) or hamstring tendon (HT) grafts. \(^5,6\)

After ACL reconstruction (ACLR), muscle weakness is often observed, with lower strength in the extensor muscles when BPTB is used and in flexor muscles when HT is the choice. \(^7,8\) Torque is often measured isokinetically to assess performance of the knee muscles after ACLR. Researchers have evaluated patients between five and six months after reconstruction. During this period, the torque deficit for extensors in the injured leg may be more than 10% and last two years post ACLR. \(^8,10-12\)

Different measurements of muscle performance are important for return to sports and physical activity after ACLR. The most common measure of strength obtained from an isokinetic dynamometer is peak torque and can be represented as a percentage normalized to body mass. \(^13\) Peak torque is a good indicator of joint function and relative muscle strength in comparison to other individuals. \(^14,15\) Another variable is angle of peak torque that is a measure of the torque as a function of knee joint angle produced when the muscle is maximally activated during isovelocity shortening and may be a useful for planning training or rehabilitative programs. \(^16\)

Another way to explore isokinetic results is to divide range of motion into three sections. The first is time to attain velocity (TTAV), the second is load range (LR) wherein specific velocity defined is sustained and finally deceleration time (DT) phases, total range of motion (ROM), peak torque/body mass (PT/BM), angle of peak torque (AngPT) during LR and torque-angle-velocity relationships (TAV\(_{3D}\)) between post ACLR and matched control subjects.

METHODS

Seven males post ACLR using hamstring tendon autograft of their dominant limb participated. Four were professional soccer players while the others were physically active, including participating in amateur soccer. Patients were excluded if they had suffered more than one ACL injury in the same knee or the contralateral limb. The matched control group was comprised of seven healthy males with no prior injuries or surgeries of their lower limbs. Five control participants were professional soccer players while the others were physically active including participation in amateur soccer. All participants read and signed an informed consent prior to testing. The Universidade Estadual de Londrina Ethics Committee approved this study and all procedures (#055/2012).

One investigator performed all isokinetic testing using the Biodex System 4® Dynamometer (Biodex Medical System Inc., Shirley, NY). Testing was performed in the concentric isokinetic mode at 60, 120 and 300 °/s, for knee flexion/extension with a sampling frequency of 100 Hz. Participants were instructed to not perform any physical activities on the day of testing. Warm-up consisted of stationary cycling for ten minutes at a speed of 30 km/h with no resistance. Subjects were then positioned on the seat of the dynamometer, and stabilized by belts around their trunk, pelvis and thighs. Hip flexion was set at 85 ° and the dynamometer axis was aligned with the lateral femoral epicondyle. The ankle pad was positioned just above the medial malleolus. \(^21\) All calibration and gravity correction procedures followed manufacturers' guidelines. \(^22\)
Range of motion (ROM) was limited to between 90° of flexion and 0° of extension. Extension ROM for each participant was defined in accordance with their individual limits. Three practice repetitions at each velocity were performed to ensure compliance with testing procedures. Isokinetic testing consisted of one set of five repetitions at each velocity, in random order, with a rest time of 90 seconds between sets. Participants were instructed to perform at maximal effort during all repetitions while verbal encouragement and visual feedback were provided. For reliability purposes, a coefficient of variation less than 10%, for each set, was considered acceptable.

The raw data were extracted in the Biodex software, and additional processing was performed with specific Matlab® algorithms. Mean values from the five repetitions were calculated for all variables at each velocity. The percentages of each phase (TTAV, LR, and DT) were calculated in relation to the total ROM, as peak torque is achieved in the LR phase. PT/BM and AngPT were also calculated only during the LR phase.

To create the TAV3D surface maps, the surf mathematical function from Matlab® was used. All five repetitions of each velocity were interpolated according to phase duration. The algorithm estimated the intrinsic geometry by considering torque (z-axis), joint angle (x-axis) and velocity (y-axis) in the same time frame. The z axis defined the map height in relation to strength intensity while the x and y axes shaped boundaries of the surface. The qualitative analysis with a TAV3D surface maps improve the interpretation of the test results, it is possible to observe the interaction between torque, velocity and the range of motion. This interpretation may add to the other isokinetic test results, like the evaluation of the movement or the functional activity could add to decision making for the treatment. Given the fact that all participants in the ACL group injured their dominant leg, comparisons were performed between the dominant leg of the control group and injured leg of the ACL group.

For comparisons of the isokinetic variables, multiple two-way analysis of variance (ANOVA) by group and velocity were used, after verification of the equality of variance errors (Levene test). Interactions were also verified. If the F test was statistically significant, multiple comparison post-hoc tests using Bonferroni correction were performed through a specific syntax. Significance was stipulated at 5% and all analyses were performed with SPSS version 22.0 (IBM SPSS®, Armonk, NY, USA).

RESULTS
Anthropometric characteristics are presented in Table 1, and there were no differences between groups.

ISOKINETIC PERFORMANCE
Statistically significant differences were found in extension at 60°/s, where the control group ROM was approximately 7.1% greater (p = 0.007) than the ACL group (Table 2). PT/BM values in the control group were significantly greater for the extensor muscles at 60 and 120°/s, by 18.4% (p = 0.037) and 21.4% (p = 0.023) respectively. For flexion, PT/BM was significantly greater for controls at 60°/s, by 15.3% (p = 0.007) (Table 3). The other variables were not statistically significantly different.

SURFACE MAPS
TAV3D of the control group demonstrated higher torque, in vertical axes, when compared to the post ACLR group (color intensity is proportional to each surface throughout the ROM, with light grey/blue

<table>
<thead>
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<th>Table 1. Anthropometric characteristics</th>
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<td><strong>Mdn (25-75%)</strong></td>
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<td>Height (cm)</td>
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<td>Body mass index (kg/m²)</td>
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<td>Post-operative period (months)</td>
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Md= Median
representing lower torque). For flexion, the difference in the format of figure was lower between groups and the changes in torque were lower during the ROM (Figures 1 and 2).

DISCUSSION
This study evaluated isokinetic variables of post ACLR subjects compared to matched controls; the results indicate that extension PT/BM was lower in the ACLR group at 60 and 120 °/s. This deficit is in accordance with those reported by Hart et al. 24 who also found persistent quadriceps weakness in post ACLR subjects.

The results of the present study demonstrate that a deficit greater than 15% existed in the ACLR group for extensor PT/BM compared to controls, primarily at 60 °/s and the acceptable deficiency in isokinetic muscle strength should be ~15%. 25 A systematic review found strength deficits occur in the both the extensors of the knee (more pronounced after patellar tendon bone reconstructions) and the flexors of knee (more pronounced after hamstring autografts). 26 The authors recommended isokinetic examination of the knee as one criteria to decide if an athlete should be allowed to return to unrestricted sporting activities. 26

| Table 2. Range of motion for each isokinetic phase, between the groups. |
|---------------------------|-----------------------------|-----------------------------|
| Involved                  | ACL Group Mean (95% CI)     | Control Group Mean (95% CI) |
|                          | TTAV (%)                    | LR (%)                      |
| Extension 60°/s           | 7.15 (3.45,10.86)           | 89.47 (83.66,95.08)         |
| Flexion 60°/s             | 3.36 (6.46,6.08)            | 81.44* (77.22,85.66)        |
|                          | 6.21 (2.51,9.92)            | 90.65 (84.84,96.06)         |
|                          | 3.40 (6.86,12)              | 87.71* (83.49,91.93)        |
| 120°/s                   | 12.29 (8.59,16.00)          | 79.09 (73.47,84.70)         |
| Flexion 120°/s           | 8.61 (5.89,11.32)           | 82.32 (78.10,86.55)         |
|                          | 10.58 (6.88,14.29)          | 81.83 (76.21,87.44)         |
|                          | 7.58 (4.86,10.30)           | 83.07 (91.52)               |
| 300°/s                   | 31.37 (27.67,35.08)         | 44.65 (39.04,50.26)         |
| Flexion 300°/s           | 23.97 (21.25,26.69)         | 81.65 (77.43,85.87)         |
|                          | 33.19 (29.48,36.89)         | 41.49 (39.04,55.88)         |
|                          | 25.31 (22.59,28.03)         | 85.00 (80.77,89.22)         |

Bold and *: The mean difference is significant at the p < 0.05 between groups, °/s: degrees per second, TTAV: time to attain velocity, LR: load range, DT: deceleration time, %: percentage of each phase in relation to total range of motion, ROM: range of motion, deg: degrees.

| Table 3. Peak torque and angle of peak torque at different velocities. |
|---------------------------|-----------------------------|-----------------------------|
| Involved                  | ACL Group Mean (95% CI)     | Control Group Mean (95% CI) |
|                          | PT/BM (N.m/kg)              | AngPT (deg)                 |
| Extension 60°/s           | 2.80 (2.49;3.12)            | 65.50 (61.14;69.87)         |
| Flexion 60°/s             | 3.43* (3.12;3.75)           | 67.23 (62.87;71.60)         |
|                          | 120°/s                      | 2.31* (1.99;2.62)           |
|                          | 55.74 (51.38;60.11)         | 3.94 (2.62;3.26)            |
|                          | 59.35 (54.98;63.72)         | 59.21 (54.84;63.58)         |
| 300°/s                   | 1.22 (0.91;1.54)            | 57.40 (53.03;61.76)         |
| Flexion 300°/s           | 1.27 (0.95;1.58)            | 59.21 (54.84;63.58)         |
|                          | 59.21 (54.84;63.58)         |

Bold and *: The mean difference is significant at the p < 0.05 between groups, °/s: degrees per second, PT/BM: peak torque/body mass, AngPT: angle of peak torque, N.m/kg: Newton meter/kilogram, deg: degrees.
Thomas et al. evaluated patients before and six-months post ACLR compared to controls and showed a deficit in PT/BM of 33% for extension and 10% for flexion. In a review of ACLR graft choice (hamstring vs. bone patellar tendon) after two years, an average muscle deficit of 10% in the flexors and extensors was observed in both grafts. However, for the flexor muscles, residual deficits were significantly higher in the hamstring group. It is important to consider that weakness post-surgery may be associated with detraining, incomplete rehabilitation, a combination of crossover inhibition of motor activation, or inadequate reconditioning post ACLR. Similarly, the results of Anderson et al. showed that the ACLR group had some PT deficits, even after six months post-surgery. According to Hiemstra et al., deficits in extensor torque have been shown to be as much as 25% one-year post ACLR.

Regarding ROM at 60 °/s, the differences occurred only for extension. Both groups were allowed to move between full extension (zero degrees) and 90°.
degrees of flexion, however, the control group extension ROM was greater by approximately six degrees (they more closely approached full extension). This could be related to quadriceps weakness, crepitus at terminal knee extension, or persistent mild joint stiffness that contributes to a loss of full extension after ACLR.\textsuperscript{31,32}

The ACLR group had difficulty accelerating at all three velocities, indicated by greater TTAV values when compared to control group. These differences may be related to the injury, since control of movement during acceleration could be affected, and the ability to attain the specific isokinetic velocity at a given range of motion may also be impaired.\textsuperscript{30} Moreover, the TAV\textsubscript{3D}, which provides a qualitative evaluation, demonstrated that the control group was able to maintain higher torques at higher velocities. In flexor and extensor muscles, the range of motion and the distribution of the torque during the range can change in post ACLR patients.\textsuperscript{30} Hence, a lower extensor torque was demonstrated when compared to controls.

The TAV\textsubscript{3D} for both groups at all velocities in extension demonstrated that the torque was not sustained during the ROM. Analysis of TAV\textsubscript{3D} may contribute to the interpretation of isokinetic results and may be used to characterize muscle performance during the recovery period four to six months post ACLR. For flexion, the ACLR group did show a difference with the control group where the control group was able to sustain torque while in the ACLR group PT was not sustained. The study of Mazuquim et al.\textsuperscript{18} showed that professional soccer players sustained torque across a greater ROM in relation to those who were under 17, therefore showing higher muscle efficiency in more experienced athletes. In this study, it was observed that the ACLR group sustained less torque during the ROM which could be a limitation factor for performance of functional activities, mainly for high demand sports.

The limitations of this study include the low number of subjects and the lack of evaluation of eccentric muscle actions. However, isokinetic phase measurement could be a valuable way to evaluate patients post ACLR.\textsuperscript{34,35} Future studies that perform post ACLR testing should include isokinetic muscle performance for both concentric and eccentric actions. Isokinetic results should continue to be compared to performance-based outcome measures for better understanding of the post-reconstruction patient.\textsuperscript{34-36}

CONCLUSION

The findings of the present study demonstrate statistically significant PT/BM deficits for the knee extensors at 60 and 120°/s and for the knee flexors at 60°/s in the injured knee of the ACL group compared to uninjured controls. Extension ROM was also less for the ACL group at 60°/s. TAV\textsubscript{3D} may offer additional information when analyzing isokinetic outcomes post ACLR.

REFERENCES


ABSTRACT

Background: Decreased hamstring flexibility and the angle of peak torque (APT) occurring at a shorter muscle length are considered risk factors for hamstring strain injury. Subjects with decreased hamstring flexibility have an APT that occurs at a shorter muscle length; hence, the susceptibility to hamstring strain injury could be associated with the APT occurring at a shorter muscle length. Low-intensity eccentric exercise (ECC-Ex) may reduce hamstring strain injury risk in the subjects with decreased hamstring flexibility by allowing the APT to occur a longer muscle length. However, the acute effect of low-intensity ECC-Ex on the subjects with decreased hamstring flexibility has not been established.

Hypothesis/Purpose: The purpose of this study was to investigate the acute effect of low-intensity ECC-Ex on the peak torque, APT, and hip flexion angle in the subjects with decreased hamstring flexibility. The authors hypothesized that low-intensity ECC-Ex would shift the APT, allowing it to occur at a longer muscle length with a minimum decrease of peak torque and hip flexion angle in the subjects with decreased hamstring flexibility.

Study design: Case-control study

Methods: Twelve male college students were categorized into normal group [n = 6 (12 legs)] and decreased hamstring flexibility group [n = 6 (12 legs)] based on the median value of the baseline hip flexion angle (i.e., 80.8°) measured by passive straight leg raise test. Peak torque and APT during maximal voluntary eccentric knee flexion (via isokinetic dynamometer) and hip flexion angle were evaluated before and after the low-intensity ECC-Ex in both groups.

Results: Low-intensity ECC-Ex shifted the APT, causing it to occur at a longer muscle length in the decreased hamstring flexibility group. Low-intensity ECC-Ex increased the hip flexion angle and did not change the peak torque in both groups.

Conclusion: The results of the present study demonstrated that low-intensity ECC-Ex shifts the APT to occur at a longer muscle length and increases the hip flexion angle without a decrease in peak torque in the subjects with the decreased hamstring flexibility.

Level of Evidence: 3b

Keywords: Angle of peak torque, flexibility, hamstring strain injury, low-intensity eccentric exercise
INTRODUCTION
The angle of peak torque (APT) has been identified as a risk factor for hamstring strain injury. APT occurring at a shorter muscle length may be associated with susceptibility to exercise-induced muscle damage, and the APT in an injured hamstring is observed at a shorter muscle length. Accordingly, APT occurring at a shorter muscle length is considered a hamstring strain injury and re-injury risk. Decreased hamstring flexibility (e.g., hip flexion angle) has been suggested to contribute to increased incidence of hamstring strain injury. The subjects with decreased hamstring flexibility have an APT that occurs at a shorter muscle length; therefore, shifting the APT to occur at a longer muscle length could be a significant factor for the prevention of hamstring strain injury in the subjects with decreased hamstring flexibility.

A single bout of high-intensity eccentric hamstring exercise (ECC-Ex) (e.g., the repeated Nordic hamstring exercise and maximum eccentric leg curl) shifts the APT to occur at a longer muscle length. However, high-intensity ECC-Ex could immediately decrease muscle strength and flexibility. These negative changes immediately after the ECC-Ex depend on the ECC-Ex intensity. Accordingly, low-intensity ECC-Ex could shift the APT to occur at a longer muscle length with a minimal decrease in muscle strength and flexibility. However, the acute effect of low-intensity ECC-Ex on the subjects with decreased hamstring flexibility has not been established.

The purpose of this study was to investigate the acute effect of low-intensity ECC-Ex on the peak torque, APT, and hip flexion angle in the subjects with decreased hamstring flexibility. The authors hypothesized that low-intensity ECC-Ex would shift the APT to occur at a longer muscle length with a minimum decrease in muscle strength and flexibility in the subjects with decreased hamstring flexibility.

METHODS
Participants
Twelve healthy male college students (mean age, 24.4 ± 2.4 years; mean body mass, 66.8 ± 6.9 kg) participated in this study. None of the participants had regularly performed any lower limb resistance training in the past year, and they did not have a previous hamstring strain injury. This study was reviewed and approved by the institutional review board of the University of Tsukuba and was conducted in conformity with the principles of the Declaration of Helsinki. All the study procedures and potential risks were explained to the participants, and they provided written informed consent prior to participation in this study.

Experimental design
Hip flexion angle during the passive straight leg raise (PSLR) test was evaluated in both legs, and participants were categorized into two groups based on the median value of the baseline hip flexion angle (i.e., 80.8°): normal group [range, 81.7°–96.7°; n = 6 (12 legs)] and decreased hamstring flexibility group [range, 66.7°–80.0°; n = 6 (12 legs)].

Three days before the experiment, the participants were familiarized with the measurements for the peak torque, APT and hip flexion angle as well as the low-intensity ECC-Ex procedure. The positioning of the isokinetic dynamometer (Biodex System 4; Biodex Corp., Shirley, NY, USA) (e.g., seat position, lever arm angle, and height) for each participant was determined during the familiarization. Before the experiment, each participant performed a five-minute warm-up using a stationary bike (M3 INDOOR BIKE; Keiser Corp., Fresno, California, USA) at 50 W/60–70 rpm. All variables of interest were measured in both groups before and after the low-intensity ECC-Ex.

PROCEDURES
Hip flexion angle
The PSLR test was performed to measure the hip flexion angle. The participants were in the supine position on an examination bed, and the pelvis and thigh of the non-tested leg were secured using straps. One investigator raised the participant’s leg, with the participant’s knee kept passively extended, until the point at which the participant felt a strong but tolerable stretch, slightly before the occurrence of pain and another investigator measured the hip joint angle at this point by a goniometer. High test-retest reliability of PSLR test (ICC = 0.94) has been reported previously.
Peak torque and angle of peak torque
The test protocol was adopted from a previous study. The participants were placed in the prone position on an isokinetic dynamometer with a neutral hip joint position (flexion angle, 0°), and the upper back region and pelvis were stabilized using Velcro straps. The rotation axis of the dynamometer lever arm was aligned with the lateral epicondyle of the knee. The ROM was set from a flexed position of 90° to 0° (full knee extension). Before the measurement, four submaximal and two maximal eccentric contractions were performed at an angular velocity of 60°/s as a warm-up. After the warm-up, participants performed three maximal voluntary eccentric knee flexion at an angular velocity of 60°/s. The investigator verbally encouraged the participants to generate the maximum force for the whole range of motion. The peak torque and the APT of the trial with the highest value among three trials were used for subsequent statistical analysis.

Low-intensity ECC-Ex
In the present study, the stiff-leg deadlift (SLDL) without any added weight was used as the low-intensity hamstring ECC-Ex. The degree of muscle elongation during the ECC-Ex was a crucial factor for the shift of APT to a longer muscle length following the ECC-Ex. SLDL was performed with slightly flexed knees and flexed torso; hence, SLDL could lengthen the hamstring to a longer muscle length. Therefore, SLDL was adopted as a hamstring ECC-Ex in this study.

To perform the SLDL, the participants grasped a plastic bar with their hands spaced slightly wider than their shoulder width. While maintaining a neutral spine position and slightly flexed knees, the participants flexed their torso as far as possible over five seconds and subsequently returned to the start position over two seconds (Figure 1). The participants performed three sets of eight repetitions of this exercise, with a three-minute rest between sets.

Statistical analyses
Two-way analysis of variance (ANOVA) with repeated measurements was used to identify the time (before or after) × group (normal or decreased hamstring flexibility) interaction. When a significant interaction or main effect was identified, a post hoc t-test with Bonferroni correction was performed. All data were reported as the mean ± standard deviation (SD). Statistical significance was set at $p < 0.05$ and, where possible, Cohen's $d$ was reported for the effect size (ES) of the comparisons, with the levels of effect being deemed small ($d = 0.2$), medium ($d = 0.5$), or large ($d = 0.8$), as recommended by Cohen.

RESULTS
In this study, a small APT indicates that the peak torque occurred at a longer muscle length.
Table 1. Variables of interest before and after the low-intensity stiff-leg deadlift in normal and decreased hamstring flexibility groups.

<table>
<thead>
<tr>
<th></th>
<th>Normal group</th>
<th>Decreased hamstring flexibility group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>Peak torque, Nm</td>
<td>89.5 ± 19.2</td>
<td>82.4 ± 19.2</td>
</tr>
<tr>
<td>Angle of peak torque,°</td>
<td>24.1 ± 10.0</td>
<td>28.4 ± 15.2</td>
</tr>
<tr>
<td>Hip flexion angle,°</td>
<td>89.6 ± 5.9</td>
<td>98.5 ± 4.9*</td>
</tr>
</tbody>
</table>

Data are expressed as mean ± SD. Significant difference vs. before, *p < 0.05.

Figure 2. Angle of peak torque before and immediately after the low-intensity stiff legged dead lift in the normal and decreased hamstring flexibility group. Results are shown as mean ± SD.

Table 1 shows the variables of interest before and after the low-intensity ECC-Ex in both groups. A significant interaction effect (time x group) for APT (F = 5.435, p = 0.03) was observed. The post hoc t-test indicated that low-intensity SLDL shifted the APT to a longer muscle length significantly in the decreased hamstring flexibility group (normal, 24.1 ± 10.0° to 28.4 ± 15.2°, p = 0.35; decreased hamstring flexibility, 32.1 ± 21.0° to 21.6 ± 11.0°, p = 0.03) (Figure 2). No significant interaction or main effect was observed for the peak torque (normal, 89.5 ± 19.2 to 82.4 ± 19.2 Nm; decreased hamstring flexibility, 84.3 ± 29.7 to 78.7 ± 19.1 Nm). No significant interaction effect for hip flexion angle was observed; however, the main effect for the time showed significance (hip flexion angle: F = 57.819, p < 0.01). The post hoc t-test indicated that low-intensity SLDL increased the hip flexion angle significantly in both groups (normal, 89.6 ± 5.9° to 98.5 ± 4.9°, p < 0.01; decreased hamstring flexibility, 71.9 ± 3.9° to 79.2 ± 5.4°, p < 0.01).

**DISCUSSION**

In this study, the acute effects of low-intensity SLDL on the peak torque, APT, and hip flexion angle in the subject with decreased hamstring flexibility were investigated. The main outcomes are summarized as follows: first, low-intensity eccentric exercise (SLDL) shifted the APT to occur at a significantly longer muscle length in the decreased hamstring flexibility group, and second, low-intensity SLDL increased the hip flexion angle significantly (measured by PSLR) but did not change the peak torque in both groups. These results suggest that low-intensity SLDL could improve the APT and hip flexion angle without a decrement in peak torque in the decreased hamstring flexibility group.

To the authors’ knowledge, this is the first study to demonstrate a shift of APT to occur at a longer muscle length following ECC-Ex in the subjects with decreased hamstring flexibility. Decreased hamstring flexibility is considered a risk factor for hamstring strain injury. According to Alonso et al. (2009), the subjects with decreased hamstring flexibility has an APT that occurs at a shorter muscle length. APT occurring at a shorter muscle length could result in severe muscle damage following ECC-Ex; thus, susceptibility of the subjects with decreased hamstring flexibility to hamstring strain injury could be associated with APT occurring at a shorter muscle length. In this study, low-intensity SLDL shifted the APT to a longer muscle length in the subjects with decreased hamstring flexibility.
This result suggests that low-intensity SLDL could be useful in preventing hamstring strain injury in the subjects with decreased hamstring flexibility. However, it should be noted that in the normal group APT shifted to shorter muscle length after the low-intensity SLDL, though the difference was not statistically significant. This result suggests that single bout of low-intensity SLDL might increase the susceptibility of the subjects with normal hamstring flexibility to hamstring strain injury. Accordingly, the impact of hamstring flexibility should be considered when the low-intensity SLDL is conducted prior to exercise.

High-intensity ECC-Ex could result in changes that impart muscle damage, such as decreased muscle strength and flexibility; therefore, high-intensity ECC-Ex may not be suitable to perform before intense physical activity. Moreover, the present study also showed no change in muscle strength in either group and increased flexibility in both groups following the low-intensity SLDL. Thus, low-intensity SLDL could be useful as a warm-up exercise in the athletes with decreased hamstring flexibility before intense physical activity.

Various warm-up exercises are performed to prevent muscular injury before intense physical activity. Static stretching has been used as a warm-up exercise for the prevention of hamstring strain injury by increasing flexibility. However, an acute bout of static stretching could cause the immediate decrease in eccentric muscle strength and does not shift the APT during eccentric contraction to a longer muscle length. By contrast, low-intensity SLDL shifted the APT during eccentric contraction to a longer muscle length and increased the hip flexion angle without a decrease in peak torque during eccentric contraction in the decreased hamstring flexibility group, making it a potentially useful preventive warm-up exercise as compared to static stretching.

**Methodological considerations and limitations**

There are two major techniques to evaluate the hamstring flexibility such as the PSLR test and active knee extension (AKE) test. The AKE test is considered to be superior to the PSLR test to evaluate the flexibility without compensatory movement of the pelvis. However, previous authors have reported that decreased hip flexion angle could be a risk factor for hamstring strain injury. Thus, PSLR test is considered to be related to the hamstring strain injury; therefore, PSLR test was utilized in the present study.

In this study, participants were categorized into normal group and decreased hamstring flexibility group based on the median value of the baseline hip flexion angle. As a result, the average of normal and decreased hamstring flexibility group was 90° and 72°, respectively. Ayala et al. (2013) has reported that based on the value of PSLR test hamstring flexibility was classified as normal hamstring flexibility (≥ 80°), limited hamstring flexibility (< 80°). Considering this classification, categorization of the present study was considered relatively adequate.

In the present study, a standardized ECC-Ex intensity was not adopted and the influence of ECC-Ex intensity difference on the change in peak torque, APT, and hip flexion angle was not investigated. Therefore, the optimal intensity to improve the APT and hip flexion angle without decreasing peak torque was not established in this study. However, SLDL without any added weight was utilized in the present study as this exercise could be easily performed in various clinical fields. This exercise could be useful in improving the APT and hip flexion angle for athletes with decreased hamstring flexibility; thus, the present findings showed clinical relevance.

**CONCLUSION**

The results of the current study indicate that low-intensity SLDL significantly shifted the APT to occur at a longer muscle length and increased flexibility without decreasing the muscle strength in subjects with decreased hamstring flexibility. While warm-up exercises have been used to prepare for and improve performance, recently, prevention program (e.g., FIFA 11+) has been incorporated into the warm-up. Thus, the present findings suggest that low-intensity SLDL might be useful to shift the APT in individuals with decreased hamstring flexibility without disturbing the preparation for performance. Furthermore, low-intensity SLDL was performed using a plastic bar only, thus, low-intensity SLDL could be easily performed by various athletic populations and varied environments.
REFERENCES


ABSTRACT

Background: Muscle strength testing of an injured infraspinatus muscle (IM) is confounded by actions of synergistic muscles such as the posterior deltoid (PD).

Hypothesis/Purpose: The purpose of this study was to describe a condition for testing of the IM that results in less EMG activity of the PD musculature. The researchers hypothesized that greater inhibition of the PD could be achieved through active adduction (AA), creating reciprocal inhibition of the PD.

Study Design: Prospective cohort descriptive study

Methods: Thirty-four (19 females and 15 males) right-handed subjects between the ages of 22-31 (mean 24.2 years +/- 6.2) with no previous history of shoulder surgery or pathology participated. Surface electrodes were placed over the muscle bellies of the IM and PD of the right shoulder along with a ground electrode over the C7 spinous process. EMG activity was recorded during resisted external rotation in four different testing conditions (seated active and passive adduction, and side-lying active and passive adduction). The order of test positions was randomly assigned, and each subject completed all four positions with appropriate rest. During AA conditions, subjects were asked to adduct the humerus against a sphygmomanometer (using 80% maximum force output) while maximal effort external rotation was manually resisted.

Results: PD activity was significantly less during AA than with no AA (p<0.05) in both test positions. No significant difference occurred between IM EMG activity in the various test conditions.

Conclusion: The results of this study suggest that clinicians can reduce activity of the PD without reducing activity of the IM by using AA of the humerus before applying manual resistance to test the IM during manual muscle testing.

Levels of Evidence: 1b.

Key Words: Electromyography, infraspinatus, infraspinatus test, posterior deltoid, manual muscle testing
INTRODUCTION
Shoulder rotator cuff injuries are commonly evaluated by medical and rehabilitation professionals. A high predominance of rotator cuff injuries has caused an increased awareness among healthcare practitioners regarding evaluation, rehabilitation, and prevention of further injury to the muscle group. The infraspinatus muscle (IM) has been suggested to be the primary rotator cuff muscle that moves the glenohumoral joint (GH) through external rotation while the shoulder is abducted at 0°. The infraspinatus manual muscle test is a reproducible test in intra-rater and inter-rater reliability studies. The most common muscle injured in the cuff is the IM, with some authors reporting an incidence of 22%-40% of rotator cuff injuries involving the IM, found through MRI and surgery. A practitioner needs to be able to accurately assess the strength of the IM to determine deficits of the muscle being tested and would prefer to utilize the muscle being tested without a contribution of other synergistic muscles. The most commonly described manual muscle test (MMT) position for the IM involves the patient in a side-lying position with the humerus fully adducted, in neutral rotation, and the elbow maintained in 90° of flexion while resistance is applied to the distal arm toward internal rotation. Some authors suggest this same test can be performed whether in a seated or standing position. During the seated and side-lying testing 0° abducted positions, the posterior deltoid (PD) is activated along with the infraspinatus, which can increase the resisted external rotation torque and thereby change the reported resisted strength of the infraspinatus muscle. The position of prone horizontal abduction with the shoulder fully externally rotated and prone external rotation with shoulder at 90° abduction and elbow at 90° of flexion have also been suggested for strengthening of the infraspinatus but are more often used to try to isolate the infraspinatus during rehabilitation programs. External rotation resisted positions while the shoulder is in abduction and at 90° of elevation, used for testing and treatment of the infraspinatus, lack the ability to reduce or minimize the EMG activity of the deltoid musculature (one of the muscles known to contribute to external rotation torque). Reese, in her muscle testing text, suggests a 90° abducted position with the elbow flexed to 90° to test the external rotators of the glenohumeral joint. This testing position also activates the other external rotators of the shoulder and is not intended to specifically target the IM.

Porter states that when the agonist muscle contracts maximally, the antagonist muscle relaxes maximally, in a process called reciprocal inhibition. This process occurs when motor neurons of the agonist muscle receive excitatory impulses from the afferent nerves and motor neurons that supply the motor antagonist muscles are inhibited by afferent impulses. Thus, contraction of the agonist muscle has been said to elicit relaxation or inhibit the antagonist. The deltoid musculature (as a group) is primarily an abductor of the shoulder, and certain portions of this muscle (the PD) can assist in rotation and stabilization of the glenohumeral joint. The use of an isometric contraction into adduction (the use of reciprocal inhibition) may allow a decrease in electrical activity of the deltoid muscle while allowing continued functional activity of the IM.

The purpose of this study was to describe a condition for testing of the IM that results in less EMG activity of the PD musculature. The authors propose that reciprocal inhibition through the use of a significant adduction force at the shoulder while performing external rotation in the seated and side-lying positions with shoulder at 0° and elbow at 90°, will allow the IM to continue to function while decreasing the EMG activity of the synergistic PD muscle.

METHODS
Subjects
Thirty-four subjects between 22-31 years-of-age (mean 24.2 +/- 6.2; 19 females and 15 males) were included. All subjects had normal shoulder function in the dominant shoulder. Normal shoulder function was defined as asymptomatic with regard to pain and functional limitation within the past year. Exclusion criteria included: any past shoulder surgery, prior history of shoulder injections for shoulder pain, and any injury requiring medication or rehabilitation of the shoulder in the year prior to the study. The study was approved by the Institutional Review Board at the University of Central Arkansas. 

The International Journal of Sports Physical Therapy | Volume 13, Number 5 | October 2018 | Page 897
**Instrumentation**

Surface EMG data were collected using a Biopac MP36 connected to a PC and was analyzed using Biopac BSL 4.0 software (BioPac Systems, Inc. Goleta, CA). The EMG unit consists of a 24-bit A/D board with differential amplifier characteristics of CMRR > 90dB and an input impedance of 2MΩ. The sampling frequency was set at 1,000 Hz. Data were band-pass filtered (30-500Hz) to decrease movement artifact and extraneous noise and then enveloped with Root Mean Square (RMS) processing using a 50ms window. Self-adhering Biopac EL503 Ag/AgCl electrodes were used for both recording and reference electrodes. A blood pressure cuff and aneroid sphygmomanometer was used to provide feedback in order to determine maximum adduction force and also maintain a consistent level of force during testing.

**Procedures:**

All volunteers were required to review and give an informed consent prior to participation. The dominant arm of each of the participants was tested and was defined as the extremity used to eat and write. All the subjects were right-hand dominant. The electrode sites were cleaned with alcohol and two electrodes were placed over the posterior deltoid musculature at the lateral border of the spine of the scapula and obliquely angled toward the upper extremity parallel to the fibers. In addition, two electrodes were placed over the infraspinatus musculature muscle belly 4cm below the spine of the scapula over the infrascapular fossa. The electrodes were placed 70 mm apart within the confines of the muscle as described by Criswell and a reference electrode was placed over the C7 spinous process. This array has been used by various authors who have studied surface EMG of the infraspinatus. The same tester performed all of the resisted testing on all subjects. Data was collected during 1) sitting, and 2) side-lying test positions. For both positions, a rolled blood pressure cuff was placed between the trunk and medial epicondyle just proximal to the medial epicondyle of the dominant humerus and against the ribcage to determine adductor force of the upper arm during external rotation of glenohumeral joint (GHJ). The cuff was inflated to 20 mmHg and subjects were asked to adduct forcefully to find subject's maximal adduction force output (MFO).

Once the MFO was recorded in mmHg, 80% of the individual’s MFO was calculated. Active adduction was defined as 80% or higher of each individual’s MFO. Passive adduction was defined as 60% or less of each individual's MFO. The subjects were randomly assigned by position and active or passive adduction using research randomizer software (Randomizer.org, Urbaniak and Plous, 2013). Both sitting tests and both side-lying tests were performed in conjunction with each other to reduce the movement of the patient and the strain on the EMG electrodes. The four testing conditions are as follows:

**Test A** (seated active adduction): The subject was placed in a seated position on a chair with the dominant shoulder adducted to 0° and elbow flexed at 90°. Stabilization was achieved as shown in Figure 1. The subject was then asked to actively adduct the arm against the inflated cuff to attain 80% of individual's MFO. Resistance was then manually applied to failure while maintaining 80% of MFO. One consistent person monitored the amount of MFO along with the subject and feedback was given continuously to maintain consistent pressure on the gauge. (Figure 2)
Test B (seated passive adduction): The subject was positioned the same as in Test A. The subject was then asked to not apply pressure to the cuff (operationally defined as to not exceed 60% of the individual’s MFO). Resistance was then manually applied to failure while maintaining less than 60% MFO. Again, one consistent person monitored the amount of MFO along with the subject and feedback was given continuously to not increase the pressure on the gauge. (Figure 2)

Test C (side-lying active adduction): The subject lay on their side on their non-dominant arm on a plinth with a pillow under the head. Stabilization was achieved as shown in Figure 3. The dominant shoulder was placed in a position of adduction of 0° and the elbow was flexed to 90° as before. Active arm adduction and maintenance of 80% of individual’s MFO was done as in Test A. (Figure 4)

Test D (side-lying passive adduction): The subject lay on their side and upper extremity positioned as described in Test C. Adduction force was maintained at less than 60% MFO as described in Test B. (Figure 4)

External resistance was applied until failure (as in a “break” manual muscle test). For each test, a five-second isometric external rotation contraction was produced a total of three times with one minute of...
rest provided between each repetition. In order to avoid the artifact during initial activation and the "break", the middle portion of the EMG was used for analysis. The mean RMS of the three trials (over a three second window) was averaged for each muscle and then compared across test conditions.

Standardized instructions were given to each subject prior to testing. Results of the pressure generated by the subject on the cuff, as monitored by the AS gauge, were submitted to the researcher responsible for data entry. The subjects were blinded from the EMG data collected during the study.

DATA ANALYSIS
The SPSS Statistical Package for Windows (version 22; IBM SPSS, Armonk, NY) to analyze differences in the mean RMS of the IM and PD across the four test conditions. The comparison of mean values from EMG for all the test conditions were calculated. Two ANOVAs with repeated measures and a Bonferroni correction for distribution were used with the alpha level set at p<0.05.

RESULTS
The mean EMG values in microvolts (μV) for each for each of the test positions for the PD are presented in Table 1. The mean EMG values for each of the test positions for the IM are presented in Table 2. The statistical comparison of mean EMG values for all test conditions were made using repeated measures ANOVAs. The repeated measures ANOVA for the PD had an F of 7.34 and demonstrated a significant difference (p<0.05) for the PA between the active and passive conditions. The repeated measures ANOVA for the IM had an F value of 0.35 and there were no significant differences were found between measures (p>0.05). The results of this analysis are found in Table 3. Because of these findings, a post hoc analysis was performed on the PD data and reported in Table 4. The PD mean EMG activity was

<table>
<thead>
<tr>
<th>Deltoid Group</th>
<th>Mean (μV)</th>
<th>Std. Deviation (μV)</th>
<th>n</th>
<th>95% CI Lower Bound</th>
<th>95% CI Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>194.57</td>
<td>126.66</td>
<td>34</td>
<td>147.27</td>
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</tr>
<tr>
<td>B</td>
<td>301.07</td>
<td>232.42</td>
<td>34</td>
<td>214.28</td>
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<tr>
<td>C</td>
<td>217.90</td>
<td>139.20</td>
<td>34</td>
<td>165.92</td>
<td>269.88</td>
</tr>
<tr>
<td>D</td>
<td>315.60</td>
<td>202.61</td>
<td>34</td>
<td>239.94</td>
<td>391.26</td>
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</tbody>
</table>

n = number of subjects, CI = Confidence Interval, μV = microvolts
Group A = Seated Active Adduction
Group B = Seated Passive Adduction
Group C = Side-lying Active Adduction
Group D = Side-Lying Passive Adduction

<table>
<thead>
<tr>
<th>Infraspinatus Group</th>
<th>Mean (μV)</th>
<th>Std. Deviation (μV)</th>
<th>n</th>
<th>95% CI Lower Bound</th>
<th>95% CI Upper Bound</th>
</tr>
</thead>
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<td>B</td>
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<tr>
<td>C</td>
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<tr>
<td>D</td>
<td>276.73</td>
<td>205.18</td>
<td>34</td>
<td>200.12</td>
<td>353.35</td>
</tr>
</tbody>
</table>

n = number of subjects, CI = Confidence Interval, μV = microvolts
Group A = Seated Active Adduction
Group B = Seated Passive Adduction
Group C = Side-lying Active Adduction
Group D = Side-Lying Passive Adduction
significantly different between the active adduction groups and the passive adduction groups in both sitting and in side-lying positions (p<0.05). The difference between means from seated passive adduction and side-lying passive adduction of the PD were not significantly different (p>0.05). The mean EMG activity of the PD during both positions and all four testing procedures through post hoc testing is found in Table 4. A post hoc analysis did not reveal any significant difference in the mean EMG activity of the IM between either of the test positions or adduction conditions.

**DISCUSSION**

The intention of this study was to find a clinically applicable method to test the infraspinatus muscle which might reduce the EMG activity and contribution of the deltoid musculature. Jensen et al\(^2^2\) stated the PD is active during external rotation testing in most subjects. Reinold et al\(^1^0\) reported that the best position to reduce deltoid activity while increasing activity of the IM (and teres minor) musculature is in 0° of abduction in a side-lying position. Other authors have suggested other exercises and testing procedures for the IM but none have been found to be a more accurate test for the IM more than the infraspinatus test.\(^2^3\) The current study found the PD contributed greatly during these same tests intended to test the infraspinatus, even in the 0° abducted position. This deltoid activity could easily contribute to the resistance given by a subject and confuse test outcomes, especially when testing an injured

<table>
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<tr>
<th>Table 3. Repeated Measures ANOVA.</th>
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<tr>
<td>Variables</td>
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<tr>
<td>Posterior Deltoid</td>
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<tr>
<td>Infraspinus</td>
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</table>

* The mean difference is significant at the p < .05 level.
df = degrees of freedom

<table>
<thead>
<tr>
<th>Table 4. Post Hoc Comparison of Posterior Deltoid Means</th>
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<tr>
<td>Groups</td>
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<tr>
<td>--------</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>D</td>
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<td>B</td>
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<td>C</td>
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</table>

* The mean difference is significant at the p < .05 level.
µV = microvolts
Group A = Seated Active Adduction
Group B = Seated Passive Adduction
Group C = Side-lying Active Adduction
Group D = Side-Lying Passive Adduction
shoulder. Ha et al\textsuperscript{24} found significant activity of the deltoid in both the side-lying and in the upright positions with resisted external rotation even though the side-lying position elicited the least PD activity compared to four different positions studied. Park et al\textsuperscript{25} suggested shoulders may work differently when the rotator cuff is injured and found increases in PD EMG activity in persons with a rotator cuff injury. Clisby et al\textsuperscript{26} suggest that the rotator cuff and deltoid are imbalanced in patients with rotator cuff injury and the goal of rehabilitation is to reduce the activity of the deltoid and increase the activation of the rotator cuff. These authors also found that, whether the shoulder was elevated or adducted passively, continual activity of the deltoid occurred, especially in those persons with shoulder pathology.\textsuperscript{26} In the present study, the PD was significantly active during traditional IM testing in both the seated and side-lying positions with 0° of abduction in agreement with the authors cited, and could create inaccurate testing results when performing manual muscle testing because of contributions and activity of the PD to assist in countering the resistance.

The results of this study demonstrated less PD EMG activity when performing forceful active adduction during resisted external rotation. When subjects actively adducted during IM testing during both seated and side-lying external rotation with the arm in 0° of abduction, the PD was significantly less active than when the active adduction was not performed during this testing. This suggests that the PD contributed less to the external rotation output during manual muscle testing. However, the IM activity was not significantly different whether the subject was adducting or not adducting. This would suggest the IM remained active and was contracting at a similar level while the PD was contributing less to the action. If the IM had decreased in EMG activity with active adduction, then the action of adduction could be interpreted as reducing the contraction of shoulder musculature that are abductors. Thus, the IM may be more accurately tested in this test position, as the PD was no longer assisting as much in attempting to externally rotate.

A towel roll was not used at the side but the use of an AS for adduction force was utilized during this session. Other authors have suggested a towel roll or other object to be placed between the elbow and the side in the infraspinatus test position to decrease the activity of the deltoid during the testing procedures.\textsuperscript{8,22,27} However, the use of the towel roll was not shown to be as effective at reducing activity of the deltoid after the Reinold et al\textsuperscript{10} study was completed, as these authors found increased activity in supporting muscles during testing, including the teres minor, and continued significant deltoid activity in normal shoulders.

Reciprocal inhibition was used to reduce the contribution of the deltoid during two commonly used testing procedures for the external rotators. This procedure required active adduction be performed while testing the external rotators. The mechanical properties of the posterior deltoid compared with the infraspinatus support the deltoid having a primary torque-producing role rather than the stabilization role of the IM.\textsuperscript{22} The deltoid muscle’s ability and tendency to substitute for the rotator cuff, especially when an injury has occurred, make the evaluation of the amount of strength loss and percentage of damage to the IM difficult.\textsuperscript{26} Reciprocal inhibition has been suggested as a method to reduce the activity of a muscle group.\textsuperscript{28-31} Active adduction during infraspinatus testing in this study allowed no significant change in EMG activity of the IM while significantly reducing the EMG activity of the PD. Active adduction while performing IM testing has not been explored as a method to reduce deltoid activity in any previous study.

**Limitations**

This study has several limitations. First, this study only utilized data from 34 healthy subjects and may differ in those with shoulder pain or pathology. Though the post hoc power analysis was favorable for this number, more numbers would be necessary to establish reliability data for these new test positions. Second, all positions that have been suggested for IM clinical testing or treatment were not tested.\textsuperscript{3,32,33} Other positions have been offered through previous studies, but these other positions have been shown to have increased posterior or middle deltoid activity along with increased IM activity.\textsuperscript{10,11,26,34,35} This study did not attempt to try reciprocal inhibition techniques to quiet PD activity.
in any of these other positions. Third, the manual resistance applied toward external rotation was not quantified using any form of dynamometer. The subjects in this study varied greatly in strength and size and differing resistance was used to reach a point of failure for each individual. Use of a manual dynamometer during the collection of data might help describe differences in levels of resistance and recruitment of deltoid musculature as suggested by another author. Finally, other levels of adduction resistance against the cuff could have been used. In this study, 80% of maximal contraction was utilized. Other levels of adduction might have differing results in the inhibition of the PD musculature. Attempts to find ways to inhibit the PD were not effective using light to moderate adduction pressures (increase of 20-40 mmHg) by this same research lab in previous studies. Eighty percent of maximal contraction was chosen as a means to test effects of resistance in the upper range of adduction activity for subjects.

CONCLUSIONS
In this study, aggressive AA during the testing of the IM (seated and side-lying) resulted in significantly less activity in the PD while not reducing the EMG activity of the IM. The results of this study suggest that clinicians may be able to reduce the activity of the PD by having the subject actively adduct the humerus before applying manual resistance during IM testing. When testing for injury to the IM, either a side-lying or seated position, using 80% or greater adduction pressure, should reduce the contribution of the PD.

REFERENCES


ABSTRACT

Background and Purpose: Frozen shoulder (FS) is a condition of the shoulder that is characterized by gradual loss of passive and active range of motion of the glenohumeral joint. Current treatment recommendations remain unclear due to the elusive etiology of FS and absence of nomenclature in the literature. The purpose of this case report is to describe the effects of treatment guided by the assessment and treatment of a breathing pattern disorder (BPD) coupled with Total Motion Release® (TMR) exercise program on a 17-year high school cheerleader with a diagnosis of frozen shoulder.

Case Description: A 17-year-old female cheerleader reported left anterolateral chest pain after running during cheer practice. The subject continued to experience additional episodes of chest pain and sought out medical care at an emergency department where she was diagnosed with a FS. Clinical findings upon examination included soft tissue muscular irritability, glenohumeral internal and external rotation active range of motion (AROM) loss, and a dysfunctional breathing pattern. Intervention consisted of two types of breathing interventions and a Total Motion Release® (TMR) exercise program. The Numeric Rating Scale (NRS), inclinometer measurements to measure AROM, and breathing assessment outcomes were used to identify patient-reported outcomes and determine treatment effects.

Outcomes: The use of the coupled treatment resulted in a resolution of the patient's primary complaint, an increase in AROM, and an improvement in breathing assessment outcomes. After the first treatment, internal rotation (IR) improved by 27° exceeding a minimal detectable change (MDC) of 8°, and after the second treatment, external rotation (ER) improved by 21° exceeding the MDC of 9°. Equally important, there were improvements in flexion (11°) and abduction (45°) exceeding the MDC of 8° and 4° respectively over the course of treatment. The minimal clinically important difference (MCID) on the NRS was exceeded when the patient returned to activity.

Discussion: In this case report, breathing treatments, coupled with a TMR® exercise program, were beneficial treatments for this patient and provided a clinically meaningful resolution of her condition. Clinicians treating patients who display a similar presentation of frozen shoulder can consider this a possible treatment option.

Levels of Evidence: Level 4; single case report

Key Words: Adhesive capsulitis, breathing pattern disorder, manual therapy

CORRESPONDING AUTHOR
Krystal A. Tyree, DAT, LAT, ATC
Athletic Trainer
19400 W Bellfort St
Richmond, TX 77407
Office: 832-223-3000 ext 3160
E-mail: Katryree10@gmail.com

1 Lamar Consolidated High School, Rosenberg, TX, USA
2 University of Idaho, Moscow, ID, USA
The authors do not have any conflict of interest, financial or otherwise, to report pertaining to this study.
BACKGROUND AND PURPOSE

Frozen shoulder (FS), or adhesive capsulitis, is a common shoulder condition characterized by an insidious onset of pain and loss of active and passive range of motion (ROM) of the glenohumeral (GH) joint. Classification of FS encompasses a primary condition, characterized by idiopathic, progressive painful loss of active and passive ROM of the shoulder; and a secondary condition that has a similar clinical presentation, but results from a known extrinsic or intrinsic source. The characteristics of FS is described by four stages with varying time presentations. (Table 1). A gradual onset of pain and cascade of inflammation and fibrosis causes the individual to limit the use of the affected arm. While specific inflammatory cells have yet to be identified, pain at end range of motion and muscular inhibition results in compensatory movement patterns in order to minimize pain.

Clinicians typically diagnose FS based on patient history and physical examination. Patients report sleep-disturbances at night due to pain, with female patients between the ages of 40 and 65 years of age commonly at risk to develop primary FS. Patients reporting trauma, diabetes, prolonged immobilization, thyroid disease, stroke, heart attack, and the presence of an autoimmune disease are commonly at risk to develop secondary FS. The typical pathological capsular pattern of limitation that occurs with FS is decreasing motions of external shoulder, followed by abduction or shoulder flexion and internal rotation (IR). Classification based on physical examination occurs when there is a greater than 50% reduction as compared to the contralateral shoulder in passive external rotation or less than 30º of external rotation in the affected shoulder.

Many interventions have been examined in the treatment of FS however, the definitive treatment remains unclear. This is partly due to the unknown etiology and absence of a standardized nomenclature for FS, which causes confusion in the literature. Additionally, if FS is classified as secondary FS, systemic, extrinsic, or intrinsic factors must be addressed first. Treatment for FS has traditionally been directed to eliminate pain, decrease inflammation, and stretch surrounding tissue to increase shoulder ROM via the use of NSAIDS, therapeutic modalities, corticosteroid injections, exercise, joint mobilization, manipulation (i.e. under anesthesia forcefully abducting the shoulder by stabilizing the scapula against the thorax, elevating the humerus to release the inferior capsule), and surgery. Yet, little evidence exists to support the use of modalities and when comparing exercise versus manipulation, researchers found no difference in patient outcomes at various follow-ups. A common intervention used

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**Table 1. Stages of Frozen Shoulder (Adhesive Capsulitis)**

<table>
<thead>
<tr>
<th>Stage 1: Freezing Stage</th>
<th>Stage 2: Freezing/Painful Stage</th>
<th>Stage 3: Frozen/Transitional Stage</th>
<th>Stage 4: Thawing Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of symptoms: 0 to 3 months</td>
<td>Duration of symptoms: 3 to 9 months</td>
<td>Duration of symptoms: 9-15 months</td>
<td>Duration of symptom: 15-24 months</td>
</tr>
<tr>
<td>Pain with AROM and PROM</td>
<td>Pains worsens and develops with AROM and PROM</td>
<td>Minimal pain except at end-range PROM and AROM</td>
<td>Minimal pain</td>
</tr>
<tr>
<td>Limitation of active forward flexion, Abd., IR, and ER.</td>
<td>Significant limitation of active and passive forward flexion, Abd., IR, and ER.</td>
<td>Significant limitation of AROM and PROM into forward flexion, Abd., IR, and ER with “rigid” end feel (muscular disuse due to limited arm movement)</td>
<td>Progressive improvement in AROM and PROM</td>
</tr>
<tr>
<td>Characterized by an acute synovitis at the GH joint</td>
<td></td>
<td>Characterized by a fibrotic synovium at the GH joint</td>
<td></td>
</tr>
</tbody>
</table>

Abd = abduction; IR = internal rotation; ER = external rotation; ROM = range of motion; AROM = active range of motion; PROM = passive range of motion

*Note: Stages are in order, but a transition can occur within a stage and thus the next stage begins.*
to address limitations or restrictions of the glenohumeral joint capsule is joint mobilization. However, when treated with joint mobilization and a home exercise program (HEP), outcomes significantly improved at four-week follow-up and were equal to patients treated with corticosteroid injections.4 9 With the potential to exacerbate symptoms (i.e., HEP and/or mobilizations), GH injections have been recommended in the literature in to be performed in the first four to six weeks.4,9-10 To formulate a logical approach to treatment of patients with FS and guide rehabilitation, authors have proposed several classification schemas.4,11 The latest is a four-component model for evaluation and intervention that begins with medical screening and differential diagnosis. Clinical decisions regarding rehabilitation and intervention (component 4) are then made based on patient's tissue irritability status (component 3).11 Nonetheless, while treatment interventions are geared towards the patient's irritability status, applying the incorrect tensile dose (frequency, duration, and intensity) by way of stretching or joint mobilizations can negatively impact patient outcomes.12 Therefore, the limited efficacy of local treatments recommended and utilized in studies supports the exploration of more holistic or regional interdependent (RI) approaches. This often includes assessing and treating multiple body systems and/or body's segments that may be contributing to the patients' condition (e.g., frozen shoulder).

Breathing Pattern Disorders (BPD's)

Breathing Pattern Disorders (BPD's) One potential option for treating patients with FS is the assessment and treatment of breathing patterns disorders (BPD's). A breathing pattern disorder occurs when there is a chronic or recurrent change in breathing mechanics.13-14 During ideal breathing, a synchronized motion of the upper and lower rib cage along with the abdomen is present. Additionally, the muscles of diaphragm, which provide 70-80% of inhalation force and are responsible for postural control, must perform properly.15-16 Improper breathing mechanics happen when the primary muscles become restricted due to biomechanical, biochemical, psychological, physiological and/or unknown factors affecting the body.13-14,16 As a result of this restriction in the primary muscles, there is an insufficient ability of the respiratory system to meet the demands of altered breathing patterns and thus the accessory muscles substitute for the primary respiratory muscle, the diaphragm. Over-activity of the accessory muscles can cause musculoskeletal pain by way of insufficient gas exchange and respiratory distress.13-16 Additionally, restrictions in the respiratory muscles may result in compensating structural changes due to muscular and fascial influences and connections.17

Janda theorized in the case of upper crossed syndrome of imbalances, changes include an altered direction of the axis of the glenoid fossa.18 The pectoralis major, which contributes to shoulder flexion, horizontal adduction, and internal rotation, tightens and shortens. Fibrosis may also develop in these muscles along with myofascial trigger points (TrPs);16-18 a similar presentation that is supported in the literature as the etiology of primary FS.1-3 This theory is supported by authors who have linked improper breathing patterns to pain and limited movement of the arm.19 Breathing pattern disorders have also been found to produce respiratory symptoms (asthma) or non-respiratory symptoms such as neck, shoulder, and/or low-back pain.20-22 The body’s pH can be altered resulting in respiratory alkalosis which can cause breathlessness and mimic angina or chest pain.15-16 Kinnula and Sovijärvi believe the anxiety inducing breathlessness that is attributed to asthma may be due to excessive inflation and physiological outcome from a BPD.23 Once a BPD is identified, the appropriate intervention is aimed at restoring proper breathing mechanics at rest such as resetting the diaphragm.24-25 As it relates to the shoulder complex, this action is theorized to induce a relaxation of the pectorals, which became tightened and shortened as a result of a dysfunctional pattern of the breathing muscles.20 Identification and treatment of biomechanical changes as well as functional status of structures involved in respiration must also be addressed. Rehabilitation protocols should include interventions aimed at improving and correcting biomechanical changes and structural compensation patterns of key respiratory muscles.16

Total Motion Release®

As investigators develop interventions from an RI approach, Total Motion Release® (TMR®) may be
an option to improve biomechanical and functional status of structures involved in respiration. Founded and developed by Tom Dalonzo-Baker, TMR® is an evaluative and treatment tool used to correct asymmetries of the body. A proposed TMR® theory describes the body as an integrated system striving to maintain balance and stability. As such, an individual reporting restriction due to tissue tightness or pain over a long period of time develops a shift in their center of balance. Additionally, due to a natural tendency to place stress on other areas of the body when a body part becomes injured, a person's center of balance is pulled secondarily toward the compensatory dysfunction. This leads to changes in joint alignment, joint integrity, tissue tension, and/or pain. Within the concept of TMR®, movement forces pull the affected joints and/or soft tissue from the contralateral side to correct and re-align the tissue and/or joint into a more normal position, a technique supported by the theory of cross education and neural coupling. Utilization of TMR® has demonstrated a high degree of success in treating mobility deficits (external rotation) in the shoulder as seen in patients with FS.

Given the underlying factors, various classification systems within the literature to guide treatment, transient effectiveness of recommended treatments, and a potential RI manner influencing FS, a broader perspective should be practiced in the evaluation and treatment of patient classified with FS. Successful treatment of FS is not solely based on the restoration of full ROM, but rather, overall patient satisfaction and decrease in symptom(s). Therefore, the purpose of this case report is to describe the effects of treatment guided by the assessment and treatment of a breathing pattern disorder (BPD) coupled with Total Motion Release® on a 17-year high school cheerleader with a diagnosis of frozen shoulder.

CASE DESCRIPTION

Subject Characteristics
The subject, a 17-year-old female cheerleader, reported an acute onset of left anterolateral chest pains following running during cheer practice. The subject removed herself from practice and reported directly to her athletic trainer (AT). She had participated in high school cheer for two years and had a history of asthma. The subject did not report having any chest pain prior to the first episode.

CLINICAL IMPRESSION 1
When the subject initially reported to her AT, she stated that her chest pain was a 10 out of 10 on the Numeric Rating Scale (NRS). The subject reported taking her asthma medication prior to activity as prescribed. The subject denied any serious cardiopulmonary conditions or direct trauma to the upper extremity, chest, neck, or upper back. Physical observation (gross deformity, ecchymosis, edema) revealed a well-appearing, otherwise healthy female in distress. Vital signs (blood pressure, pulse rate, and blood oxygen) were within normal range and a life-threatening-emergency was ruled out. Based on the subject's initial history, evaluation, and current condition, the AT concluded that the subject's condition was systemic in nature and was primarily due to the patient's asthma. The subject's treatment plan included rest, hydration, and her prescribed asthma medication. The subject continued to participate in activity as tolerated and was advised to follow-up with her immunologist. Within 48 hours, the subject reported to her AT again complaining of an acute onset of anterolateral chest pains after running. Follow-up re-examination findings were consistent from initial evaluation across pain and observation; however, vital signs revealed a sustained elevated heart rate (155 bpm). The subject was immediately treated with her asthma medication, rest, and hydration and was referred for further lung function testing. Approximately six to eight hours later, the subject had another occurrence of anterolateral chest pain that lasted an hour and was taken to the Emergency Department (ED) to be evaluated by a physician. The radiograph performed at the ED was negative for an enlarged heart or lung fluid build-up, and the electrocardiogram was normal. The treating physician diagnosed the subject with FS, for which he prescribed cryotherapy and NSAIDS. The physician recommended the subject follow-up with her orthopedic physician for further care of her FS and a cardiologist to rule-out a possible cardiac condition. Differential diagnoses included bursitis, shoulder impingement, and juvenile rheumatoid arthritis.
Prior to ED diagnosis, the subject did not report any shoulder pain or restriction. The subject was actively participating in cheerleading and FS was not a consideration as the subject was in distress during evaluation(s) and a history was not disclosed. Additionally, the typical demographics of FS include females age 40 to 65 years old and with a higher incidence affecting those with diabetes or thyroid disease.\textsuperscript{1-4} The subject's first diagnosis of frozen shoulder happened four years’ prior while participating in softball. The subject was treated with traditional conservative care for four weeks at a physical therapy clinic. The subject's most recent experience with frozen shoulder happened two years prior. The subject did not receive treatment from a healthcare provider and continued with activities of daily living and softball as tolerated. Follow-up physician referrals after the FS diagnosis revealed no cardiac condition or respiratory pathology. The subject decided to deny treatment with a physical therapist as prescribed by her orthopedic physician and sought care of her athletic trainer (AT) for re-evaluation until the end of cheer season (i.e., end of football).

**EXAMINATION**

The subject was re-evaluated by her athletic trainer four days after her ED visit. The subject reported that she had to work over the weekend and had difficulty using her involved shoulder while driving or performing overhead activities. The subject also reported sleep disturbing night pain in her shoulder. Observation and palpation of the bony structures and soft tissues of the shoulder were found to be abnormal. Irritability status reported by Kelley et al. was used to evaluate the subject's tender areas.\textsuperscript{4} Inclinometer measurements were recorded for active range of motion (AROM) in 90° for the GH joint and deficits were noted.\textsuperscript{16-18} Observable signs during internal rotation (IR) revealed extension of the thoracic spine as a compensation.\textsuperscript{21} Considering the subject's history of asthma and physical findings, breathing patterns were further identified with the use of an optimal breath assessment (Table 2). The Hi-Lo assessment was then used to determine respiratory motion (Figure 1).\textsuperscript{16, 24} The AT then determined the patient's breathing patterns, normal or dysfunctional, from the outcome measures and respiratory motion from the Hi-Lo assessment. A summary of the subject's clinical exam can be found in Table 3.

**CLINICAL IMPRESSION 2**

Based on the subject's history, physical examination, inclinometer measurements, and outcomes on the breathing assessment, the AT hypothesized that the subject's condition (glenohumeral joint ROM loss) was associated with a breathing pattern disorder. Breathing treatments and TMR\textsuperscript{®} were deemed ideal treatment paradigms for this subject, addressing the BPD that may have contributed to the subject's

| **Table 2. Optimal Breathing Assessment\textsuperscript{24}** |
|-----------------|-----------------|-----------------|
| **Breath Assessment** | **Description** | **Ranges** |
| Volume Oxygen Uptake (VOU) | Seated or standing, the patient is to inhale fully. Then, while exhaling fully, quietly, but not loud, count fast speaking clear counting as high as possible. *Note:* The patient is cued to be sure to squeeze out the last bit of air while counting. The patient is not allowed to inhale while counting, hold their breath, skip numbers, or whisper.\textsuperscript{24} | 150+ =Excellent, 110-149 = Very Good, 90-109 = Good, 60-89 = Fair, 2-59 = Poor |
| Breathing Rate (bpm) | Standing or seated, the patient breathes in their normal pattern and rate and the practitioner counts complete breaths for one minute.\textsuperscript{24} | 5-6 Excellent, 7-9 = Good, 10-13 = Fair, 14-16= Fair (Normal), 17+= Poor |
| Breathing Pause Extension (BPE) | At the end of an exhalation or natural exhalation, the patient pauses and counts as long as they can before their next inhalation. *Note:* The patient is to count until there is even moderate discomfort, but DO NOT to go so long that the patient passes out, and do not allow patient to exhale more while counting.\textsuperscript{24} | 60+ = Excellent, 45-59 = Good, 30-44 = Fair, 15-29 = Poor, 0-14 = Very Poor |
primary complaint and the biomechanical and structural changes surrounding the GH joint that may have resulted from a BPD. Total Motion Release® is an important concept when restoring range of motion (ROM), because it is an indirect treatment that avoids increasing irritability, thereby fostering patient satisfaction. The Institutional Review Board committee approved this case report and the subject gave assent and written consent prior to care and data collection acknowledging possible publication of their outcomes. The subject’s confidentiality was protected according to the United States’ Health Insurance Portability and Accountability Act (HIPAA).

**INTERVENTION**

**Outcome Scales**

The outcome scales that were used in this case study included the following:(a) the Numeric Rating Scale (NRS), which is a patient-reported outcome measure that is used to assess the subject’s pain intensity level (0 = no pain to 10 = worst pain imaginable). The NRS has been found to be both valid and reliable with the minimal clinically important difference (MCID) value reported as a two point change or 33%;28 (b) GH inclinometer measurements for IR, ER, flexion, extension and abduction AROM (collected at intake and post-treatment), which is a valid and reliable tool used to assess the subject’s active ROM of the GH joint.29 The minimal detectable change (MDC) is regularly reported as an increase of 4º in IR, 5º in

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**Table 3. Summary of Physical Exam Findings**

| Subjective: | 17-year-old female cheerleader reports an acute onset of left anterolateral chest pain, which began after running during cheer practice. Pain experienced approximately 3 times prior to physician consultation. Medical hx of asthma. Physician diagnoses was frozen shoulder. Follow-up physician referral revealed no cardiac condition or respiratory pathology. |
| Observation: | No observable signs of inflammation. Depressed left shoulder, excessive movement of the sternum and shoulder girdles toward the head during inhalation (chest breather), compensation during UE ROM assessment by extension of thoracic spine, respiration=22 bpm (poor), VOU= 38 (poor), and BPE= 24 (fair) |
| Palpation: | TTP teres major, posterior deltoid, levator scapulae, pectoralis major, and pectoralis minor, suggesting high irritability status (≥7)4 |
| Active ROM: | Inclinometer measurements in supine: ER uninvolved 61° involved 38°, IR uninvolved 62° involved 27°, shoulder flexion uninvolved 183° involved 133°, shoulder extension uninvolved 65° involved 48°, shoulder abduction uninvolved 170° involved 106° |

Hx= history; UE= upper extremity; ROM= range of motion; VOU= volume oxygen uptake; bpm= respiratory rate; BPE= Breathing Pause Extension; TTP= tender to palpation; GH= glenohumeral; ER= external rotation; IR= internal rotation 

Note: Shoulder extension, flexion, and abduction measurements were collected on different days. Basic strength testing was not assessed due to patient’s tissue irritability status and significant ROM limitation. Rib mobility was not assessed.
ER, 8º in flexion, and 4º in abduction; optimal breathing assessment (collected at intake and upon the subject returning to activity), which included volume oxygen uptake (VOU), breathing rate (bpm), and breathing pause extension (BPE) (Table 2). The MCID or MDC for the optimal breath assessment outcomes are not available in the literature.

Treatment Procedure
The subject was treated with two breathing treatments and TMR® intervention exercises by a certified athletic trainer. Treatment selection was based on clinician’s clinical experience and treatment indications. At the time of the study, the clinician had over 48 online hours of continuing education in TMR® and had completed up to TMR® Adult – Level 3. To address BPD, the clinician instructed the subject to perform the Clamshell Diaphragm Reset (Figure 2a and 2b) and the Optimal Reflex Triggering Twist and Stretch (ORTTS) (Figure 3a and 3b). The “clamshell” is a modified exercise proposed by the authors from Michael Grant White’s “Optimal Reflex Triggering Ankle Raise”. The exercise elicits the patient’s need to breathe by altering the intra-abdominal pressure at the end of exhalation. The “clamshell” was performed twice. The Optimal Reflex ® Triggering Twist and Stretch (ORTTS) enhances the breathing reflex by way of gentle breathing-wave with full pelvic torso/neck and head integration. The technique was repeated up to 10 times per side. The subject performed this technique for 1x10 each side. To address biomechanical and structural changes, the clinician utilized a TMR® exercise program based on the foundation principles of the TMR® Fab 6; a series of exercises developed by Tom Dalonzo-Baker that allow patients to treat themselves. After a TMR® assessment, the Arm Raise (AR) (Figure 4) and Trunk Twist (TT) were indicated (Figure 5). The clinician instructed the subject to perform an arm raise (AR) raise on the uninvolved side to end range for three sets of ten. For the TT, the clinician instructed the subject...
to perform a seated trunk twist to end range on the “good” side for three sets of ten. The clinician continued with this treatment plan until shoulder ROM normalized overtime (as compared to uninvolved shoulder) and the BPD normalized. Additional exercises within the TMR® system were progressively added and performed to the contralateral shoulder utilizing the foundation principles of TMR® (Table 4, Figures 6 - 11). Exercises were selected based on motion restrictions found in the involved shoulder and neck extensors. During the course of treatment, the subject did not participate in cheerleading activities but continued with activities of daily living. The subject was prescribed a home exercise program (HEP), but she did not follow it consistently.

OUTCOMES
Following the first treatment session, active ROM in IR improved from 27° to 54°. After second treatment session, ER improved from 32° to 59°. Active ER (61°) normalized after the third treatment session compared to the uninvolved side. Considering the improvements that were gained prior in both ER and IR, the clinician then measured and recorded active flexion and extension ROM measurements to further determine efficacy of treatment. After two treatments utilizing the same treatment plan, flexion improved from 133° to 144°. To further improve joint motion, the clinician integrated more complex exercises within the TMR® system (Table 4, Figures 6 - 11). At that point, abduction ROM measurements were recorded. After one treatment session with additional TMR® exercises, abduction improved from 106° to 151°. Upon returning to activity, the subject’s active ER had improved to 90°, IR 58°, flexion 153°, extension 52°, and abduction 150°.

To assess the subject’s primary complaint of chest pain, the clinician incorporated monitored running into the subject’s therapeutic and rehabilitation protocol (Table 4; post-treatment 11). The subject
| Week 1: | 1-3 | Breathing Treatment | 1) Breathing Treatment  
- Clamshell Diaphragm Reset (2x) (Figure 2)  
- Optimal Reflex ® Triggering Twist and Stretch (Figure 3)  
- 10x per side  
2) TMR Exercise  
- Arm Raise (AR) - 3x10 (Figure 4)  
- Trunk Twist (TT) - 3x10 (Figure 5)  
3) IFC 80 – 150 Hz (deltoid) - 15 min |  |
| Week 2: | 4,5 | Breathing Treatment | 1) Breathing Treatment  
- Clamshell Diaphragm Reset (2x)  
- Optimal Reflex ® Triggering Twist and Stretch  
- 10x per side  
2) TMR Exercise  
- Arm Raise (AR) - 3x10  
- Trunk Twist (TT) - 3x10  
3) IFC 80 – 150 Hz (deltoid) - 15 min |  |
| Week 3: | 6-8 | Breathing Treatment | 1) Breathing Treatment  
- Clamshell Diaphragm Reset (2x)  
- Optimal Reflex ® Triggering Twist and Stretch  
- 10x per side  
2) TMR Exercise  
- Arm Raise (AR) - 3x10  
- Trunk Twist (TT) - 2x10  
- Back 2 D Side Out Bent Rotate In AR – .3x10 (Figure 6)  
- Shoulder IR (supine)  
- Back 2 D Side Out Rotate Out AR - 3x10 (Figure 7)  
- Shoulder ER (supine)  
3) IFC 80 – 150 Hz (deltoid) - 15 min |  |
| Week 4: | 9,10 | Breathing Treatment | 1) Breathing Treatment  
- Clamshell Diaphragm Reset (2x)  
- Optimal Reflex ® Triggering Twist and Stretch  
- 10x per side  
2) TMR Exercise  
- Arm Raise (AR) - 3x10  
- Trunk Twist (TT) - 2x10  
- Back 2 D Side Out Bent Rotate In AR – .3x10  
- Shoulder IR (supine)  
- Back 2 D Side Out Rotate Out AR - .3x10  
- Shoulder ER (supine)  
- Cervical Ext - 3x10 (Day 16) (Figure 8)  
- Right Cervical Rotation - 3x10 (Figure 9)  
3) IFC 80 – 150 Hz (deltoid) - 15 min |  |
| Week 5: | 11-14 | Breathing Treatment | 1) Breathing Treatment  
- Clamshell Diaphragm Reset (2x)  
- Optimal Reflex ® Triggering Twist and Stretch  
- 10x per side  
2) TMR Exercise  
- Arm Raise (AR) - 3x10  
- Trunk Twist (TT) - 2x10  
- Back 2 D Side Out Bent Rotate In AR – .3x10  
- Shoulder IR (supine)  
- Back 2 D Side Out Rotate Out AR - .3x10  
- Shoulder ER (supine)  
- Sitting 2 D Straight Side Out Rotate In AR - 3x10 (Figure 10)  
- Shoulder Abd.  
- Right Cervical Rotation - 3x10  
3) Elliptical - 20 min |  |
reported a 0/10 on the NRS for chest pain after running (Figure 12).28 Additionally, the subject reported not complying with asthma medication instructions as she felt her asthma had improved. After six days of treatment with monitored conditioning and no reoccurrence of chest pain, the subject returned cheer practice (post-treatment 16). Prior to returning to cheer practice, the subject did not progress to sport-specific rehabilitation outside of monitored conditioning. The subject was a senior and wanted to be able

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**Table 4. Therapeutic Interventions and Associated Timeline (continued)**

<table>
<thead>
<tr>
<th>Week</th>
<th>Tx number</th>
<th>Intervention(s)</th>
<th>Settings/Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 6:</td>
<td>15, 16</td>
<td>Breathing Treatment TMR® Exercises Running</td>
<td>1) Breathing Treatment - Clamshell Diaphragm Reset (2x) - Optimal Reflex® Triggering Twist and Stretch -10x per side 2) TMR Exercise - Arm Raise (AR) - 3x10 - Trunk Twist (TT) - 2x10 - Back 2 D Side Out Bent Rotate In AR - 3x10 - Shoulder IR (supine) - Back 2 D Side Out Bent Rotate Out AR -3x10 - Shoulder ER (supine) - Sitting 2 D Straight Side Out Rotate In AR -3x10 - Shoulder Abd. - AR Backward - 3x10 (Figure 11) - Shoulder Ext - Right Cervical Rotation - 3x10 3) 1 mile run (4 laps)</td>
</tr>
</tbody>
</table>

---

**Figure 6. Back 2 Dimension Side Out Bent Rotate In Arm Raise (Internal Rotation).** The patient is instructed to perform shoulder internal rotation in supine on the uninvolved side for three sets of ten. When resistance during movement was felt, the patient was cued to go further into end range.26

**Figure 7. Back 2 Dimension Side Out Rotate Out Arm Raise (External Rotation).** The patient is instructed to perform external rotation in supine on the uninvolved side for three sets of ten. When resistance during movement was felt, the patient was cued to go further into end range.26
The subject reported a complete resolution of chest pain on the NRS after cheer practice (day 16 post-treatment) and two days later, the subject cheered a full football game and remained asymptomatic (Figure 12).

The subject was treated a total of 16 times over the course six weeks. The gap in days' treatment was due to subject's schedule and other conflicts. Over the course of treatment, minimal detectable changes (MDC) were reported in AROM for the GH joint; IR, ER, flexion, and abduction (Table 5). A minimal clinically important difference was reported in the NRS (Figure 12) and breath assessment outcomes had improved prior to the subject returning to activity (Table 6).

DISCUSSION

Frozen shoulder is a common shoulder condition of unknown etiology that usually occurs in females...
The subject's symptoms were typical FS symptoms such as pain with AROM, sleep disturbing night pain, high irritability status and limited forward flexion, abduction, IR, and ER. However, the subject also presented symptoms that were atypical of FS suggesting this may not have been a FS, but rather isolated AROM loss(es) due to a breathing pattern disorder. Prior to treatment, the subject had lacked 23 degrees of shoulder ER and 35 degrees of shoulder IR as compared to the uninvolved shoulder, which does not follow the defined capsular pattern of FS. The subject demonstrated significant limitations of active and passive shoulder motion in more than one plane and high irritability consistent with the characteristics of FS however, anterior, posterior and inferior glenohumeral joint glides were not performed to assess for capsular involvement. A more passive accessory joint mobility assessment may have elucidated a reason for the limitation of GH ROM.

Traditional non-operative treatment for FS in patients with high irritability would involve low-grade mobilization and short-duration, pain-free, assisted active range of motion stretching. Alternatively, breathing treatments, coupled with a TMR® exercise program, increased shoulder IR and exceeded the established MDC after the first treatment session. After the 2nd treatment session, shoulder ER increased and exceeded the established MDC. Both of these outcomes exceed those reported with the use of traditional conservative therapy in patients with high irritability. The use of manual therapy and therapeutic exercise for treating FS typically requires more treatment sessions over a longer period of time (i.e. six weeks to three months). The immediate gain after corticosteroid injections is attributed to anesthetic effect of reducing pain and thus limiting muscle guarding. Furthermore, the subject returned to activity within six weeks of...
being diagnosed with FS with symptom reduction and patient satisfaction of improved shoulder function (Table 5). Generally, it is recommended the patient has manipulation under anesthesia if there is unresponsiveness to varying levels of treatment over time between three to six months.4 Time-loss from activity in this subject was lower than the time frames presented in the literature for traditional rehabilitation and/or surgery4, 9-10 however, this could have been the result of a differential diagnosis. After 16 treatments, the patient completed her cheer season without a recurrence of symptoms (chest pain) or the need of wanting further treatment for her shoulder.

In patients who have FS or a history of chronic FS, breathing treatments and a TMR® focused exercise program may be an effective treatment (when indicated) in lieu of, or adjunct to treatment strategies recommended for patients with high irritability. Even though current literature indicates that corticosteroid injections are favored in patients with high irritability or in patients who do not respond in the first three to six weeks of traditional treatment,4 the patient:(a) may only receive a short-term benefit of decreased pain and immediate gain in motion up to six weeks if not coupled with physical therapy (b) must recover from the effects of an invasive treatment, and (c) can experience a delay in symptom relief.4 Furthermore, treatment strategies such as mobilization and short duration stretching exercise have the potential to exacerbate symptoms delaying recovery.12 Therefore, the consideration of the discussed non-invasive RI focused treatment is essential.

The outcomes in this case report provided evidence that utilizing breathing treatments and a TMR® intervention exercise program may assist in improving shoulder ROM in an athlete with a diagnosis of chronic FS. The combined interventions may produce rapid changes in ROM and shoulder function. Despite the positive outcomes in this case report, this study is not without limitations. Further research with a greater number of typical FS subjects (females age 40 to 65) is needed to determine the treatment effects of the combined use of breathing treatments and TMR® in the treatment of FS. It is important to determine if the treatment will produce positive results over a larger population or only on a subgroup of patients (adolescents with ROM restrictions). More research is needed to determine the long-term effects of the intervention(s) as well as the potential for reducing the need for corticosteroid injections in certain patient cases. Additionally, while increases were observed in AROM, future research that includes passive ROM measurements and an accessory motion examination are needed to fully evaluate and determine true capsular pattern

---

**Table 5. Inclinometer Measurements of Active Range of Motion**

<table>
<thead>
<tr>
<th>Joint Motion (L=affected shoulder)</th>
<th>Baseline</th>
<th>Post-Tx 1</th>
<th>Post-Tx 2</th>
<th>Post-Tx 3</th>
<th>Post-Tx 4</th>
<th>Post-Tx 9</th>
<th>Post-Tx 16</th>
<th>R shoulder AROM (unaffected)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER</td>
<td>38°</td>
<td>32°</td>
<td>***59°</td>
<td>61°</td>
<td>61°</td>
<td>61°</td>
<td>90°</td>
<td>61°</td>
</tr>
<tr>
<td>IR</td>
<td>27°</td>
<td>*54°</td>
<td>***58°</td>
<td>49°</td>
<td>54°</td>
<td>81°</td>
<td>58°</td>
<td>62°</td>
</tr>
<tr>
<td>Flexion</td>
<td>133°</td>
<td>133°</td>
<td>***144°</td>
<td>138°</td>
<td>153°</td>
<td>183°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension</td>
<td>59°</td>
<td>48°</td>
<td>52°</td>
<td>47°</td>
<td>52°</td>
<td>65°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>106°</td>
<td>**151°</td>
</tr>
</tbody>
</table>

Tx= treatment; ER= external rotation; IR= internal rotation; AROM = active range of motion
* = MDC exceeded after first treatment
** = MDC exceeded in comparison to baseline
*** = MDC exceeded after second treatment in comparison to baseline and post-tx 1

Note: flexion, extension, and abduction baseline measurements were collected and recorded on corresponding post-treatment days. Patient returned to activity after treatment 16.

---

**Table 6. Breathing Assessment Outcomes**

<table>
<thead>
<tr>
<th>Outcome Measures</th>
<th>VOU</th>
<th>BPM</th>
<th>BPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>38</td>
<td>22</td>
<td>24</td>
</tr>
<tr>
<td>Week 6*</td>
<td>44</td>
<td>20</td>
<td>33</td>
</tr>
</tbody>
</table>

VOU= volume oxygen uptake; BPM= breaths per minute; BPE= breath pause extension
*Note: Patient returned to unrestricted activity at the end of week 6.
of the shoulder. Given the limited risks of the novel interventions used in this patient case, clinicians can utilize the outcomes in this case to consider the inclusion of these techniques into their patient care. However, this case report was a single, short-term patient case, without controlled activity, and should not be generalized amongst the public or athletic population.

**CONCLUSIONS**

The results of the breathing treatments and TMR® focused exercise program used in this case report demonstrate positive immediate results that were maintained or improved over the course of six weeks in a case of a high school cheerleader diagnosed with frozen shoulder. Return to activity was achieved with the interventions. Breathing treatments coupled with a TMR® exercise program could be considered for the short-term treatment of a patient diagnosed with chronic frozen shoulder or glenohumeral ROM limitations, providing the clinician follows the treatment guidelines associated with these interventions.

**REFERENCES**


ABSTRACT

Background: Roller massage (RM) has become a popular intervention prescribed by physical therapy (PT) professionals. While this popularity has stimulated an increase in research and product development, the trends in the use of RM among PT professionals remain undocumented. It is unknown how professionals are using RM and integrating the research into their clinical practice.

Purpose: To survey and document responses in the knowledge, clinical application methods, and use of RM devices among PT professionals in the United States.

Design: Cross-sectional survey study

Methods: A 20-question online survey related to personal and professional demographics, beliefs about RM, preferred RM devices, RM exercise prescription, and client education was emailed to PT members of the Orthopedic and Sports Physical Therapy Sections.

Results: A total of 685 sports and orthopedic PT professionals completed the survey. Most professionals surveyed believe that RM decreases pain (80%), increases mobility (68%), and increases range of motion (ROM) (40%). Fifty-one percent believed moderate density rollers have the greatest effect. Eighty percent of professionals use a foam roller in their practice and 51% recommend to clients. A high proportion of professionals prescribe RM for injury treatment (82%) and for pre and post-exercise interventions (55%). Most professionals recommend rolling daily for 30 seconds to two minutes (55%), per muscle group (64%), at a self-paced cadence (47%). A high proportion of professionals use patient reported outcomes (80%), followed by joint ROM (59%), and movement-based testing (42%) to measure effects of RM. Eighty-seven percent of professionals use live instruction to educate clients and 91% believe there is a gap in the research.

Conclusion: The results of this survey should be considered descriptive and a starting point for future research to establish a consensus on optimal RM programming, devices, and application parameters for different musculoskeletal conditions. The observed responses provide some insight into how PT professionals are using RM in their practice and highlight the existing gap between the research and professional practice. Further research is needed to explore the responses documented in this study.

Key Words: Foam rolling, massage, muscle soreness, myofascial, perceived pain, self-recovery

Level of Evidence: 3

CORRESPONDING AUTHOR
Scott W. Cheatham, Ph.D., DPT, PT, OCS, ATC, CSCS
Associate Professor
California State University Dominguez Hills
1000 E. Victoria Street, Carson, California
90747
E-mail: Scheatham@csudh.edu

1 California State University Dominguez Hills, Carson, CA, USA
2 National Academy of Sports Medicine, Chandler, AZ, USA
3 Fusionetics, Milton, GA, USA
4 California University of Pennsylvania, California, PA, USA

The authors declare no conflicts of interest.
INTRODUCTION
The use of roller massage (RM) also often called “self-myofascial release” (SMR) has become a popular intervention prescribed to clients by physical therapy (PT) professionals. RM has also become popular in many clinical and fitness settings. This popularity has also prompted manufacturers to create various types of RM devices that can be found in many clinical, fitness, and retail settings. This popularity has also stimulated an increase in RM research; however, evidence is still emerging. Currently, there is no consensus on the optimal RM program and parameters such as cadence, technique, amount of force, and type of rolling device for different musculoskeletal conditions. This gap has driven PT professionals and clients to use their own preferred methods of RM due to the lack of scientific guidelines.

The trends in the use of RM among PT professionals remain undocumented. A recent literature search (May 2018) of electronic databases including: PubMed, PEDro, Science Direct, and the EBSCOhost collection revealed no publications documenting such clinical trends. Understanding the current trends in the use of RM devices among PT professionals may help further guide researchers in developing scientific guidelines for application of RM with clients. The purpose of this study was to survey and document responses in the use of RM among PT professionals. This study was considered descriptive and a starting point for future research analyzing such topics.

METHODS
Participants
PT professional members of the Orthopedic and Sports Physical Therapy Sections of the American Physical Therapy Association (APTA) (N = 22,409) were sent an online survey between the months of April to August 2017. Six hundred and eighty-five participants completed the survey which represented a 3.1% response rate. The following sections discuss the findings from the survey. It is important to note that some survey questions allowed participants to choose more than one answer. Tables 1-3 provide detailed results.

Survey Design
The online survey administered via the Survey Monkey platform (SurveyMonkey®, www.surveymonkey.com) included 20 questions that represented three distinct areas: 1) survey participant demographics 2) preferred RM devices, 3) RM prescription, client assessment, and education. For demographics, the goal was to document age, credentials, practice setting, and years in practice. For RM devices and RM prescription, the goal was to document the preferred RM devices respondents use and how they prescribed the intervention to their clients. The survey asked such questions as common devices used, rationale behind exercise prescription, prescribed cadence, and total time of the intervention. For education, the goal was to document the types of client education conducted by PT professionals and if they referred the client to a specific resource to purchase such devices. Appendix A provides the survey questions.

Once survey development was completed, the survey underwent two rounds of pilot testing with 10 independent PT professionals to establish face validity. Based upon the feedback, revisions were made, and a final survey version was confirmed. The final survey was further tested for readability using the Flesch Ease of Reading Test and Flesch-Kincaid Grade level test. The survey’s 20 questions scored 81.0 on the Flesch Ease of Reading Test and 4th grade on the Flesch-Kincaid Grade level test which indicated the English used in the survey was fairly easy.

Data Analysis
Statistical analysis was performed using SPSS version 24.0 (IBM SPSS, Armonk, NY, USA). Descriptive data including response frequencies and percentages were calculated and reported for the 20 questions.

RESULTS
A total of 685 PT professionals (Sports Section: 193/6,721) (Orthopedic Section: 492/15,688) completed the survey which represented a 3.1% response rate. The following sections discuss the findings from the survey. It is important to note that some survey questions allowed participants to choose more than one answer. Tables 1-3 provide detailed results.

Participant Demographics and Beliefs
Forty-eight percent (n = 327) of respondents were men and 52% (n = 358) were women. All respondents
Table 1. **Respondent professional demographics and beliefs about roller massage.**

<table>
<thead>
<tr>
<th>Gender</th>
<th>Frequency % (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>47.74% (327)</td>
</tr>
<tr>
<td>Female</td>
<td>52.26% (358)</td>
</tr>
<tr>
<td>*Credentials</td>
<td></td>
</tr>
<tr>
<td>Physical Therapist</td>
<td>100% (685)</td>
</tr>
<tr>
<td>Chiropractor</td>
<td>.001% (1)</td>
</tr>
<tr>
<td>Certified Athletic Trainer</td>
<td>9.63% (66)</td>
</tr>
<tr>
<td>Fitness Professional</td>
<td>0.99% (29)</td>
</tr>
<tr>
<td>MD, DPM, DO</td>
<td>.003% (2)</td>
</tr>
<tr>
<td>Other certifications and degrees</td>
<td>8.61% (59)</td>
</tr>
<tr>
<td>*Primary practice setting</td>
<td></td>
</tr>
<tr>
<td>Outpatient clinic</td>
<td>87.73% (601)</td>
</tr>
<tr>
<td>Hospital based clinic</td>
<td>16.79% (115)</td>
</tr>
<tr>
<td>University sports medicine or athletic training facility</td>
<td>3.21% (22)</td>
</tr>
<tr>
<td>High school athletic training facility</td>
<td>.006% (4)</td>
</tr>
<tr>
<td>Fitness or wellness facility</td>
<td>1.75% (12)</td>
</tr>
<tr>
<td>Other setting (e.g. home, outdoors)</td>
<td>7.73% (53)</td>
</tr>
<tr>
<td>*Years in practice</td>
<td></td>
</tr>
<tr>
<td>Average years in professional practice</td>
<td>12 years (685)</td>
</tr>
<tr>
<td>*Immediate and lasting changes (&gt; 2 weeks) seen with RM</td>
<td></td>
</tr>
<tr>
<td>Increased joint range of motion</td>
<td>40.14% (275)</td>
</tr>
<tr>
<td>Increased mobility</td>
<td>68.17% (467)</td>
</tr>
<tr>
<td>Decreased pain</td>
<td>80.30% (550)</td>
</tr>
<tr>
<td>No changes</td>
<td>6.71% (46)</td>
</tr>
<tr>
<td>*Type of roller density believed to have greatest effect</td>
<td></td>
</tr>
<tr>
<td>Hard density</td>
<td>30.80% (211)</td>
</tr>
<tr>
<td>Moderate density</td>
<td>50.51% (346)</td>
</tr>
<tr>
<td>Soft density</td>
<td>5.41% (37)</td>
</tr>
<tr>
<td>Other types of roller densities</td>
<td>13.28% (91)</td>
</tr>
<tr>
<td>*Belief there is a gap in the current RM literature</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>91.39% (626)</td>
</tr>
<tr>
<td>No</td>
<td>8.61% (59)</td>
</tr>
</tbody>
</table>

* Respondents chose all options that applied to them; RM: roller massage

Table 2. **Respondent preferences regarding roller massage devices.**

<table>
<thead>
<tr>
<th>*Type of device used most often in practice</th>
<th>Frequency % (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foam roller</td>
<td>80.00% (548)</td>
</tr>
<tr>
<td>Roller massage stick</td>
<td>44.67% (306)</td>
</tr>
<tr>
<td>Massage ball</td>
<td>51.97% (356)</td>
</tr>
<tr>
<td>Other devices</td>
<td>31.82% (218)</td>
</tr>
<tr>
<td>*Type of roller most often recommended to clients</td>
<td></td>
</tr>
<tr>
<td>Foam roller</td>
<td>79.27% (543)</td>
</tr>
<tr>
<td>Roller massage stick</td>
<td>46.00% (315)</td>
</tr>
<tr>
<td>Massage ball</td>
<td>62.63% (429)</td>
</tr>
<tr>
<td>Other devices</td>
<td>21.75% (149)</td>
</tr>
<tr>
<td>Preferred length of roller to use with clients</td>
<td></td>
</tr>
<tr>
<td>Half size (13-15 inches)</td>
<td>18.39% (126)</td>
</tr>
<tr>
<td>Full size (26-36 inches)</td>
<td>50.51% (346)</td>
</tr>
<tr>
<td>Both sizes</td>
<td>19.85% (136)</td>
</tr>
<tr>
<td>I don’t recommend</td>
<td>11.25% (77)</td>
</tr>
<tr>
<td>*Recommended places for clients to purchase devices</td>
<td></td>
</tr>
<tr>
<td>Manufacturer website</td>
<td>25.69% (176)</td>
</tr>
<tr>
<td>Generic website</td>
<td>80.58% (552)</td>
</tr>
<tr>
<td>Store (brick and mortar)</td>
<td>41.31% (283)</td>
</tr>
<tr>
<td>Medical clinic or business</td>
<td>23.06% (158)</td>
</tr>
<tr>
<td>Other</td>
<td>1.00% (69)</td>
</tr>
</tbody>
</table>

*Respondents chose all options that applied to them*
reported being PT professionals and 19% reported having other credentials. A high proportion of respondents reported working in an outpatient clinic (88%, n = 601). The reported average years in practice was 12 years. Regarding immediate and lasting changes (>2 weeks), 80% (n = 550) believe that RM decreases pain, 68% (n = 467) believe that RM increases mobility, and 40% (n = 275) believe that RM increases joint range of motion (ROM). Additionally, 7% believe RM doesn’t produce any changes. Most respondents believed a moderate density roller (51%, n = 346) has the greatest effect on the myofascial system, followed by hard density (31%, n = 211), and soft density (6%, n = 37) rollers. Regarding research, 91% (n = 626) believe there is a gap in the current RM research and further investigation is needed. See Table 1 for a detailed summary of these results.

Preferred Devices
Regarding delivery of RM, 80% (n = 548) of respondents use a foam roller, 52% (n = 356) use a massage ball, and 45% (n = 306) use a roller massage stick in their practice. Respondents recommend either the

<table>
<thead>
<tr>
<th> </th>
<th>Frequency % (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance enhancement</td>
<td>31.39% (215)</td>
</tr>
<tr>
<td>Injury prevention</td>
<td>40.73% (279)</td>
</tr>
<tr>
<td>Treatment of injury</td>
<td>82.04% (562)</td>
</tr>
<tr>
<td>Pre-exercise warm-up and post-exercise treatment</td>
<td>55.18% (378)</td>
</tr>
<tr>
<td>Time prescribed for a pre or post-exercise session (per muscle group)</td>
<td></td>
</tr>
<tr>
<td>30 seconds or less</td>
<td>6.57% (45)</td>
</tr>
<tr>
<td>30 seconds to 1 minute</td>
<td>26.42% (181)</td>
</tr>
<tr>
<td>1 to 2 minutes</td>
<td>37.51% (257)</td>
</tr>
<tr>
<td>2 to 3 minutes</td>
<td>18.98% (130)</td>
</tr>
<tr>
<td>No, I don’t prescribe</td>
<td>10.52% (72)</td>
</tr>
<tr>
<td>Total time prescribed for pre or post-exercise session</td>
<td></td>
</tr>
<tr>
<td>3 to 5 minutes</td>
<td>35.92% (246)</td>
</tr>
<tr>
<td>5 to 10 minutes</td>
<td>37.51% (257)</td>
</tr>
<tr>
<td>10 to 15 minutes</td>
<td>10.08% (69)</td>
</tr>
<tr>
<td>15 to 20 minutes</td>
<td>5.25% (36)</td>
</tr>
<tr>
<td>No, I don’t prescribe</td>
<td>11.24% (77)</td>
</tr>
<tr>
<td>Average cadence (speed) recommended when using an RM device</td>
<td></td>
</tr>
<tr>
<td>1 to 2 seconds</td>
<td>4.96% (34)</td>
</tr>
<tr>
<td>2 to 5 seconds</td>
<td>16.35% (112)</td>
</tr>
<tr>
<td>Self-paced cadence</td>
<td>47.45% (325)</td>
</tr>
<tr>
<td>No cadence taught</td>
<td>20.29% (139)</td>
</tr>
<tr>
<td>Other techniques</td>
<td>10.95% (75)</td>
</tr>
<tr>
<td>Progression of clients through different roller densities (e.g. soft to hard)</td>
<td></td>
</tr>
<tr>
<td>Always</td>
<td>3.79% (26)</td>
</tr>
<tr>
<td>Sometimes</td>
<td>44.68% (306)</td>
</tr>
<tr>
<td>Never</td>
<td>51.53% (353)</td>
</tr>
<tr>
<td>Clinical measures used to assess effects of RM</td>
<td></td>
</tr>
<tr>
<td>Joint range of motion</td>
<td>58.97% (404)</td>
</tr>
<tr>
<td>Pressure pain threshold</td>
<td>16.93% (116)</td>
</tr>
<tr>
<td>Patient reported outcomes (e.g. pain scale)</td>
<td>80.14% (549)</td>
</tr>
<tr>
<td>Movement based testing (e.g. FMS™)</td>
<td>42.48% (291)</td>
</tr>
<tr>
<td>No, I don’t measure</td>
<td>7.44% (51)</td>
</tr>
<tr>
<td>Recommended frequency for clients to use RM devices</td>
<td></td>
</tr>
<tr>
<td>Daily</td>
<td>55.62% (381)</td>
</tr>
<tr>
<td>Weekly</td>
<td>24.63% (168)</td>
</tr>
<tr>
<td>Monthly</td>
<td>19.84% (136)</td>
</tr>
<tr>
<td>Common modes of educating clients about RM</td>
<td></td>
</tr>
<tr>
<td>Live instruction</td>
<td>86.57% (593)</td>
</tr>
<tr>
<td>Video instruction</td>
<td>9.63% (66)</td>
</tr>
<tr>
<td>Self-guided program</td>
<td>21.17% (145)</td>
</tr>
<tr>
<td>Education materials (e.g. handout)</td>
<td>34.16% (234)</td>
</tr>
</tbody>
</table>

*Respondents chose all options that applied to them; RM: roller massage*
full-size foam roller (51%, n = 346) or both the full size (36" long, 6" diameter) and half size (18" long, 6" diameter) roller (20%, n = 136) to their clients. A high proportion of respondents refer their clients to generic websites (e.g. Amazon) (81%, n = 552) or manufacturer websites (26%, n = 176) to purchase RM devices. See Table 2 for a detailed summary of these results.

**RM Prescription, Client Education, and Assessment**

Most respondents prescribe RM for injury treatment (82%, n = 562), pre-exercise warm-up and post-exercise treatment (55%, n = 378), and injury prevention (41%, n = 279). Fifty-five percent (n = 381) of respondents recommend their clients roll daily followed by weekly (25%, n = 168). A high proportion of respondents recommend for clients to roll one to two minutes (38%, n = 257) or 30 seconds to one minute (26%, n = 181) per muscle group. Most respondents either recommend a total rolling time of three to five minutes (36%, n = 246) or five to 10 minutes (38%, n = 257). Forty-seven percent (n = 325) of respondents recommend a self-paced cadence and 20% (n = 139) recommend no cadence. Forty-five percent (n = 306) of respondents reported that they “sometimes” progress their clients through the different densities and 52% (n = 353) report never progressing clients.

A high proportion of respondents use patient reported outcomes (80%, n = 549) followed by joint ROM (59%, n = 404) and movement-based testing (e.g. the FMS™) (42% n = 291) to measure the effects of RM with their clients. Respondents also prefer to use live instruction (87%, n = 593) as the primary means of education. See Table 3 for a detailed summary of these results.

**DISCUSSION**

This descriptive survey study was the first investigation to document responses regarding the use of RM among PT professionals. Several important aspects of RM use emerged from the survey.

For demographics and beliefs, most PT professionals believe that RM decreases pain (80%) and increase mobility (68%) immediately post-intervention and lasts greater than two weeks. The research suggests that RM produces post-intervention increases in joint ROM in the lumbopelvic region, hip, knee, ankle/foot, and shoulder joint. RM has also been shown to increase pressure pain threshold (PPT), decrease evoked pain, reduce spinal excitability, and reduce the effects of delayed onset muscle soreness (DOMS) in healthy individuals. Researchers have also found that RM to the agonist muscle may modulate muscle activity and PPT in the ipsilateral antagonist and the contralateral agonist through a crossover effect. Despite these finding, there are some researchers that have failed to find any significant RM post-intervention results in flexibility, joint ROM, and balance in healthy individuals. This must be considered when interpreting these studies for clinical practice. It is also important to note that the long-term effects of RM have yet to be determined. To the authors’ knowledge, the longest documented RM post-intervention follow-up has been three days; therefore, research on the long-term effects of RM is needed.

More than half (51%) of PT professionals believe a medium density roller provided the greatest benefit. Several investigations have reported that the myofascial system may respond in a similar manner to low, moderate, and high RM pressure. Results of recent research indicate that different roller densities (soft, moderate, hard) may produce the same post-intervention effects on joint ROM and PPT. The majority of respondents (91%) believe there is a gap in the RM research which should encourage researchers to conduct more translational investigations to help bridge the gap between clinical practice and research.

For preferred devices, most respondents (80%) choose to use the full-size foam roller followed by a massage ball (52%) and roller massage stick (45%) with clients. There is evidence that supports the idea that a multilevel surface foam roller may have a greater effect than a smooth surface roller on the myofascial tissues and that the human body may respond in a similar manner to all types of foam roller densities. Furthermore, research suggests that the vibrating foam roller may have a greater effect on joint range of motion, flexibility, neuromodulation, and muscle performance than non-vibrating rollers. There is also evidence supporting the efficacy of other
devices such as roller massage sticks and roller balls as myofascial interventions. However, there are some researchers that have shown insignificant effects of RM on joint ROM, flexibility, balance, and local muscle temperature. Despite these findings, the majority of evidence supports the idea of having a variety of RM tools available to provide clients with options. Further research is needed to investigate which devices clients are more likely to use in their home-care programs.

For exercise prescription, client education, and assessment, most respondents prefer to use RM for injury treatment (82%) followed by injury prevention (41%). To date, there are few studies that have measured the effects of RM in individuals with a diagnosed musculoskeletal pathology or the influence RM has on injury prevention. There is some evidence that suggests RM may have a positive impact on pain, joint ROM, and quality of life for individuals with fibromyalgia and myofascial pain syndrome. Fifty-five percent of the respondents reported using RM pre and post-exercise and recommend that clients roll daily. The highest recommended rolling time for each muscle group ranged between 30 seconds to two minutes (64%) at a self-paced cadence (47%). Currently, there is no consensus on the optimal time parameters for RM. Researchers have investigated rolling durations of less than 30 seconds, 30 seconds, 45 seconds, 60 seconds, greater than 90 seconds, and using predetermined repetitions. The rolling times reported by respondents seem to be consistent with the majority of RM studies which suggests they are following the current RM evidence for rolling time. Respondents sometimes progress clients through the different densities but the majority (52%) never progress their clients. Common assessment tools used for RM included patient related outcomes (80%), joint ROM (59%), and movement-based testing (42%). These reported measures are consistent with research that has used movement based tests, such as the FMS™, to measure the effects of RM. Respondents also reported using live instruction (87%) as the preferred method for client education. One investigation measured the effects of teaching a short bout of RM using live instruction, video, and a self-preferred program. Interestingly, no differences were seen between the three teaching methods. Cheatham et al concluded that perhaps a prescriptive live instruction would be best initially followed by a supportive video or self-guided program.

**Limitations**

Several limitations need to be discussed for this investigation. First, this survey was sent to a sample of PT professionals, who predominantly practiced in an outpatient setting with a 3.1% response rate. A larger sample with a higher response rate may have produced different results. Second, these results can only be generalized to PT professionals. Other allied health and fitness professionals who also use RM may have provided different responses. Third, the survey asked specific questions with discrete answer choices. Different questions or array of responses may have revealed different ideas of how PT professionals use RM devices. The respondents may have interpreted questions differently which influenced their answers. Third, this survey was sent to members of the APTA Orthopedic and Sports sections members. These results may not fully represent the perceptions and practices from other non-member PT professionals or members from other sections. However, the results do provide some insight into responses among PT professionals.

**Practice Implications and Future Research**

The results of this survey should be considered descriptive in nature. The respondent beliefs documented highlight several clinical practices in the physical therapy industry that warrant further investigation. There seems to be a consensus that an increase in the RM research is needed to move towards determining the optimal RM intervention program, application parameters, and device(s) for different musculoskeletal conditions. The published literature on RM seems limited to small sample sizes and short-term assessments.

Future survey research with larger sample sizes and actual patients is needed before correlations or interpretations are made regarding trends in the use of RM devices among sports and orthopedic PT professionals. Future studies should attempt
to correlate such trends with the type of physical therapy setting, professionals' work experience, and client demographics.

**CONCLUSION**

This descriptive survey explored and documented responses in the use of RM among PT professionals. The results of this study should be considered a starting point for future surveys and correlational research. There is a gap between the RM research and professional practice, and it is important to develop scientific guidelines for prescribing the most effective RM interventions for clients.

**REFERENCES**


1) Please indicate if you give consent to participate in this survey
   • I consent to participate in this survey
   • I do not consent

2) Please describe your gender.
   • Male
   • Female
   • Prefer not to answer

3) Please choose all your credentials.
   • Physical Therapist (PT)
   • Chiropractor (DC)
   • Certified Athletic Trainer (ATC)
   • Occupational Therapist (OT)
   • Fitness Professional (Certified Personal Trainer)
   • Medical Doctor, Podiatrist, Doctor of Osteopathy
   • Other certifications or degrees

4) Which roller massage (RM) or self-myofascial release (SMR) devices do you use most often in your practice? Please rank them.
   • Foam roller
   • Roller massage stick
   • Massage ball
   • Other devices

5) What type of devices do you recommend to your clients (or patients)? Choose * all that apply.
   • Foam roller
   • Roller massage stick
   • Massage ball
   • None
   • Other devices

6) Please choose your primary practice setting/s.
   • Outpatient clinic
   • Hospital based clinic
   • University sports medicine clinic or athletic training facility
   • High school athletic training facility
   • Fitness or wellness facility
   • Other setting (e.g. home, outdoors)

7) How many years have you been in professional practice

8) How often do you prescribe RM (SMR) to your clients? Please rank them (e.g. most to least)
   • Daily
   • Weekly
   • Monthly

9) Where do you direct your clients to purchase devices? Choose all that apply.
   • Manufacturer website (e.g. TriggerPoint, Hyperice, OPTP)
   • Generic websites (e.g. Amazon)
   • Store (brick and mortar)
   • Resell in my clinic or business
   • Other (please specify)

10) What length of foam roller do you most commonly use and recommend to your clients?
    • Half size (e.g. 13-15 inches)
    • Full size (e.g. 26-36 inches)
    • Both sizes
    • I don’t recommend

11) What type of roller density do you believe has the greatest effect on the myofascial system?
    • Hard density (rigid) rollers
    • Moderate density rollers
    • Soft density rollers
    • Other types of roller densities

12) Do you progress your clients through the different roller densities (e.g. soft to hard)?
    • Always
    • Sometimes
    • Never

13) What are the reasons you choose RM (SMR) for your clients? Please rank them.
    • Performance enhancement
    • Injury prevention
• Treatment of injury
• Pre-exercise warm-up and post-exercise treatment

14) What is the common time range you prescribe for a pre or post-exercise session per muscle group?
• 30 seconds or less
• 30 seconds to 1 minute
• 1 minute to 2 minutes
• 2 minutes to 3 minutes
• No, I do not prescribe

15) What is the total time you commonly prescribe for a pre or post-exercise session?
• 3 to 5 minutes
• 5 to 10 minutes
• 10 to 15 minutes
• 15 to 20 minutes
• No, I do not prescribe

16) What is the average cadence (speed) you recommend when using a device?
• 1 to 2 seconds along the muscle (up and down)
• 2 to 5 seconds along the muscle (up and down)
• Self-paced cadence
• No cadence taught
• Other techniques

17) What are the common modes of education you use to teach RM (SMR)? Please rank them.
• Live instruction
• Video instruction
• Self-guided program
• Education materials (e.g. handouts with exercises)

18) What type of immediate and lasting (> 2 weeks) changes have you seen? Choose all that apply.
• Increased joint ROM
• Increased mobility
• Decreased pain
• No changes seen

19) What clinical measures do you use to assess the effects? Choose all that apply
• Joint range of motion (e.g. goniometer, inclinometer)
• Pressure pain threshold (e.g. algometer)
• Patient reported outcomes (e.g. NRS, VAS pain scales)
• Movement based testing (e.g. FMS, SFMA)
• No, I do not evaluate

20) There is a lot of emerging research on RM. Do you believe there are still gaps in what we know?
• Yes
• No
PERFORMANCE ENHANCEMENT FOR THE SPORTS PT

NATIONAL INSTITUTE FOR FITNESS AND SPORT

INDIANAPOLIS, INDIANA

OCTOBER 20, 2018

Featuring

Dan Lorenz, PT, DPT, LAT, CSCS
Overland Park and Kansas City, Kansas

Scot Morrison, PT, DPT, OCS, CSCS
Portland, Oregon
Performance Enhancement for the Sports PT is a comprehensive one day seminar that will benefit both the student and early career physical therapist as well as the experienced professional. It is sponsored by the American Academy of Sports Physical Therapy.

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Dan Lorenz, DPT, PT, ATC/L, CSCS
Dan Lorenz is a co-owner and Director of Clinical Operations for Specialists in Sports and Orthopedic Rehabilitation. He has a B.S in Health Sciences with an Emphasis in Athletic Training from Grand Valley State University in 1999 and a M.S in Physical Therapy from GVSU in 2001. In 2009, Dan earned a Doctor of Physical Therapy from the University of St. Augustine. From 2004-2005, Dan completed the Duke University Sports Physical Therapy Fellowship. Following the stint at Duke, he was an assistant athletic trainer and physical therapist for the Kansas City Chiefs from 2005-2007. Currently, he is the Chair of the Sports Performance Enhancement Special Interest Group (SIG) for the AASPT. Dan has presented numerous times at national and state conferences on sports medicine, focusing on performance enhancement in the terminal phases of rehabilitation. Recently, he was awarded the Sports Medicine/Rehabilitation Professional of the Year by the National Strength and Conditioning Association.

Scot Morrison, PT, DPT, OCS, CSCS
Scot Morrison is a well respected physical therapist and strength coach who focuses on the intersection of sports medicine and training for high performance. He is the former director of medical services for the Professional Referee Organization and regularly consults at the collegiate and professional levels. His special interests include: the management of tendinopathies and other athletic overuse injuries, data-driven return-to-play processes, and the integration of sound exercise prescription into rehabilitation and return to performance. Scot has published in a number of peer-reviewed journals, and he regularly conducts private educational seminars for sports medicine professionals. He is currently located in Portland, OR.

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AGENDA

7:30 am - 8:00 am
Registration/Check in

8:00 am - 9:20 am
Session I: NIFS Auditorium
Principles of Strength and Conditioning

9:20 am - 10:10 am
Begin at the Beginning: Screening and Testing

10:10-10:30 Break

10:30 am - Noon
Practical Programming for Strength and Power

12-12:45 pm Lunch (provided)

12:45 pm - 1:30 pm
Session II: NIFS Fitness Center
UE Exercise Prescription

1:30 pm - 2:15 pm LE Exercise Prescription

2:15 pm - 2:30 pm Break

2:30 pm - 3:00 pm Dynamic Flexibility/Warm Up

3:00 pm - 3:30 pm Practical LE/UE Plyometric Progressions

3:30 pm - 4:00 pm Connecting the Extremities “Core” Training

4:00 pm - 4:30 pm Progressions/Regressions & Making it All Work

4:30 pm - 5:00 pm Q and A, Wrap Up

Recommended Hotels
Courtyard by Marriott (317) 822-9029
JW Marriott (317) 860-5800
Fairfield Inn and Suites (317) 636-7678
Downtown Marriott (317) 822-3500

Parking
Parking is available at Lot 89 across from NIFS

NIFS map available at [https://www.nifs.org](https://www.nifs.org) for information.