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ABSTRACT

Background: Trigger points, which have been defined as highly localized, hyperirritable locations in a palpable taut band of skeletal muscle fibers, have been identified with a variety of musculoskeletal conditions. The incidence of trigger point pain is high, with studies showing them as the primary source of pain in 30-85% of patients presenting in a primary care setting or pain clinic. Dry needling has emerged as a possible intervention for trigger points, but its effectiveness has not yet fully been determined.

Purpose: To assess and provide a summary on the current literature for the use of dry needling as an intervention for lower quarter trigger points in patients with various orthopedic conditions.

Study Design: Systematic review

Methods: CINAHL, NCBI-PubMed, PEDro, SPORTDiscus, Cochrane Library, and APTA’s PTNow were searched to identify relevant randomized controlled trials. Six studies meeting the inclusion criteria were analyzed using the PEDro scale.

Results: Four of the studies assessed by the PEDro scale were deemed ‘high’ quality and two were ‘fair’ quality. Each of the six included studies reported statistically significant improvements with dry needling for the reduction of pain intensity in the short-term. Only one study reported a statistically significant improvement in short-term functional outcomes; however, there was no maintenance of improved function at long-term follow-up. Furthermore, none of the studies reported statistically significant changes regarding the effect of dry needling on quality of life, depression, range of motion, or strength.

Conclusion: A review of current literature suggests that dry needling is effective in reducing pain associated with lower quarter trigger points in the short-term. However, the findings suggest that dry needling does not have a positive effect on function, quality of life, depression, range of motion, or strength. Further high quality research with long-term follow-up investigating the effect of dry needling in comparison to and in conjunction with other interventions is needed to determine the optimal use of dry needling in treating patients with lower quarter trigger points.

Keywords: Dry needling, lower quarter, systematic review

Levels of Evidence: 1

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INTRODUCTION

Trigger points (TrPs) have been associated with nearly every musculoskeletal pain condition, including but not limited to radiculopathies, joint dysfunctions, disc pathologies, tendinitis, craniomandibular dysfunction, spinal dysfunction, pelvic pain, urologic disorders, post-herpetic neuralgia, and complex regional pain syndrome.\(^1,2\) Although universally accepted criteria defining TrPs have not been established,\(^3\) they are typically classified as either active or latent.\(^1\) An active TrP is described as a highly localized, hyperirritable location in a palpable, taut band of skeletal muscle fibers.\(^2\) It is spontaneously painful and its palpation reproduces pain in typical patterns for each TrP that may, but need not radiate to distal sites.\(^3\) A latent TrP has the same physical characteristics as an active TrP, but requires manual palpation to elicit pain.\(^4\) Latent TrPs may reside in a pain-free skeletal muscle and become activated and become an active TrP when a continuous stimuli is applied.\(^6\)

While literature regarding the prevalence of TrPs is sparse, epidemiologic studies from the United States have shown that TrPs were the primary source of pain in 30-85% of patients presenting in a primary care setting or pain clinic,\(^2\) whereas other studies have reported that TrPs are often undiagnosed by physicians and physical therapists.\(^2,7\) Undiagnosed TrPs may lead to chronic musculoskeletal conditions with progressive scar tissue formation.\(^3,10\)

There is general agreement that development of TrPs can be the result of direct trauma, muscle overuse resulting from sustained or repetitive muscle contractions, or habitual postures that place abnormal stresses on various muscle groups.\(^3,5\) Evidence suggests that the first phase of TrP formation consists of the development of contractured muscle fibers or a taut band, although the exact mechanisms of this phenomenon are not well defined.\(^5\) It is hypothesized that TrPs develop at motor end plates, which leads to excessive release of acetylcholine resulting in a sustained contraction of sarcomeres.\(^3\) Sustained sarcomere contractions leads to compression of blood vessels, which creates hypoxic conditions.\(^3\) Due to local hypoxia, a sustained contraction cannot be achieved due to energy insufficiencies.\(^11\)

Researchers also hypothesize that muscle pain causes spasms to develop, thus increasing pain intensity and the number of spasms in that muscle.\(^5\) Cagnie et al\(^12\) suggested that TrPs can provide nociceptive input that disturbs the balance in pain modulation due to impaired inhibition and/or enhanced pain facilitation, which may lead to central sensitization. While the proposed mechanisms of TrP formation remain debatable, evidence is consistent regarding the clinical manifestations. These include local and/or referred pain, disturbed motor function, muscle weakness, increased muscle tension preventing full lengthening of the muscle, restricted range of motion (ROM), and diminished joint function and stability.\(^1,5,13\)

Many techniques have been used to treat TrPs, such as stretching, massage, ischemic compression, laser therapy, thermotherapy, ultrasound, transcutaneous electrical nerve stimulation (TENS), and biofeedback, but no one particular intervention has been proven successful.\(^2,14\) Another method gaining increased attention for treatment of TrPs is dry needling (sometimes referred to as intramuscular stimulation, Westernized acupuncture, and medical acupuncture).\(^2\) Dry needling is defined as the penetration of a solid needle through the skin without introduction of any drug\(^10,17\) to stimulate TrPs and connective tissue for the management of neuromusculoskeletal pain.\(^10,17,18\)

It is cost-effective, low risk, minimally invasive, and is easy to learn through appropriate training and certification.\(^2\) Dry needling has been shown to be an effective method of treatment in alleviating symptoms caused by TrPs; however, the exact mechanism of action has yet to be determined.\(^1,2,12\) Proposed mechanisms include mechanical disruption of the integrity of dysfunctional endplates,\(^19,20\) alterations in the length and tension of muscle fibers and stimulation of mechanoreceptors,\(^21\) increased muscle blood flow and oxygenation,\(^22\) and endogenous opioid release affecting peripheral and central sensitization,\(^29\) among others.\(^12\) Strong pressure stimulation from a monofilamenent needle sends strong neural impulses to the dorsal horn, which breaks the TrP pain-spasm-pain cycle through the gate control theory.\(^30\)

In a study by Kubo et al,\(^22\) researchers found that dry needling increased blood flow to the needle insertion site for up to 30 minutes after the needle was removed. An additional proposed mechanism of increased blood flow is due to an axonal reflex.\(^30\) Clinical studies have shown that insertion of a needle into the point of
maximum pain and eliciting a local twitch response results in the largest therapeutic effects,\(^3\),\(^2\),\(^3\) such as restoration of ROM, less use of pain medication, improved quality of life (QoL), and pain relief.\(^3\)

Kietrys et al\(^3\) conducted a systematic review and meta-analysis examining the effectiveness of dry needling for upper quarter myofascial pain. Three of the four studies\(^3\) in the meta-analysis favored the use of dry needling and found a large therapeutic effect of dry needling compared to sham or control.\(^3\) To the best of the authors’ knowledge, there are currently no systematic reviews investigating the effectiveness of dry needling as an intervention for alleviating TrPs in the lower quarter, which includes the joints, musculature and connective tissue of the lumbar spine and lower extremity. The authors of this review hypothesize that a review of the literature will reveal similar outcomes in the therapeutic effect of dry needling in lower quarter TrPs as those shown in the systematic review and meta-analysis conducted by Kietrys et al\(^3\) for the upper quarter. In this review, lower quarter is considered to be all joints and musculature inferior to the thoracolumbar junction. The purpose of this systematic review is to assess and provide a summary of the current literature for the use of dry needling as an intervention for lower quarter TrPs in patients with various orthopedic conditions.

**METHODS**

**Information Sources**

A review of six databases was performed by four authors from November 2014 to February 2015. The databases included: Cumulative Index to Nursing and Allied Health Literature (CINAHL), United States National Library of Medicine (NLM) at the National Institutes of Health (Pubmed), Physiotherapy Evidence Database (PEDro), SPORTDiscus, Cochrane Library, and the American Physical Therapy Association’s (APTA) PTNow.

**Search and Eligibility Criteria**

The search terms used in all databases included: ‘(dry needling OR acupuncture OR intramuscular stimulation) AND (trigger point OR myofascial pain)’. Selection of search terms were based on a publication by Dunning et al,\(^1\) which states that the APTA, among other sources, has also used “intramuscular stimulation” and “acupuncture” to describe the intervention of dry needling. Furthermore, “acupuncture” and “dry needling” were also used interchangeably in a recent APTA sponsored publication.\(^2\) Inclusion of “acupuncture” in the search terms produced a greater number of results; however, studies utilizing only traditional acupuncture, which relies on principles and diagnoses from Traditional Chinese Medicine (TCM),\(^1\) as the method of needle insertion were excluded from consideration. Search results were limited to: (1) clinical trials or reviews, (2) text in the English language, (3) use of dry needling to the lower extremity and/or lumbar region for various conditions, (4) inclusion of individuals with muscular TrPs in the lower quarter, and (5) use of dry needling compared to another intervention such as sham dry needling or no intervention. Only randomized clinical trials (RCTs) were considered for inclusion; however, reference lists of systematic reviews and literature reviews were explored for relevant studies related to dry needling. To maximize the number of search results, no date range limitations were placed on the search. The initial search using the aforementioned inclusion criteria returned studies between the years of 1983 to 2014. To be as inclusive as possible, all studies within this date range were screened for eligibility.

**Study Selection**

Four authors independently searched databases using the search terms listed above. The authors compiled a list of studies to be screened for eligibility based on title and abstract. After reading the full text of eligible studies, the individuals documented reasons for exclusion. The authors excluded studies that (1) utilized traditional acupuncture as the method of needle application, (2) were written in a non-English language, (3) included injection treatments, such as platelet-rich plasma or OnabotulinumtoxinA, (4) treated the upper quarter only, and (5) were not RCTs. Studies not published in the English language were excluded due to the potential risk of translation error associated with translating the text to English. Discrepancies in the studies to be included and/or excluded were discussed amongst all four authors until a consensus decision was reached.
Risk of Bias
Each of the six studies were independently reviewed by the same four authors and scored with the Physiotherapy Evidence Database (PEDro) scale. Discrepancies in scoring were resolved by a group consensus. The PEDro scale is a methodological quality assessment tool that was designed to evaluate RCTs and contains a 10-point scale to measure internal validity. There are 11 total items appearing on the PEDro scale; however, criterion one is not included in the overall score, as it represents external validity. Table 1 contains a description of each of the ten criteria. The studies included in this review were assigned methodological quality ratings as recommended by Walser et al. A PEDro score of seven or greater was considered to be of ‘high’ quality. Additionally, a study that received a score of five to six was said to be ‘fair’ quality and a score of four or below was found to be ‘poor’ quality.

Data Collection Process and Synthesis of Results
One individual extracted data from each article and the remaining three authors verified the information regarding study methods and outcome measures. The information extracted regarding methods was as follows: (1) study design, (2) study participants, (3) description of dry needling technique and the duration and frequency of treatment for experimental group, (4) description of intervention for comparison group, and (5) outcome measures including, but not limited to, the Visual Analog Scale (VAS), Foot Health Status Questionnaire (FHSQ) pain subscale, Short Form McGill Pain Questionnaire (SFMPQ), Western Ontario McMaster Universities Osteoarthritis Index (WOMAC) and Pressure Pain Threshold (PPT). Two impairment measures, ROM and peak isometric strength, were also extracted from the included studies. When considering outcome measures, the fol-

Table 1. Pedro scoring of included studies

<table>
<thead>
<tr>
<th>Study</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 Score</th>
<th>Quality</th>
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<tr>
<td>Cotchett et al&lt;sup&gt;47&lt;/sup&gt;</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
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<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>9/10</td>
<td>High</td>
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<tr>
<td>Edwards et al&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>7/10</td>
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<tr>
<td>Huguenin et al&lt;sup&gt;14&lt;/sup&gt;</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
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<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>7/10</td>
<td>High</td>
<td></td>
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<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>8/10</td>
<td>High</td>
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</tr>
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<td>Itoh et al&lt;sup&gt;38&lt;/sup&gt;</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>6/10</td>
<td>Fair</td>
<td></td>
</tr>
<tr>
<td>Macdonald et al&lt;sup&gt;50&lt;/sup&gt;</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>5/10</td>
<td>Fair</td>
<td></td>
</tr>
<tr>
<td>% of yes per criterion</td>
<td>100%</td>
<td>50%</td>
<td>100%</td>
<td>66%</td>
<td>0%</td>
<td>100%</td>
<td>83%</td>
<td>16%</td>
<td>100%</td>
<td>83%</td>
<td>Score Avg: 7/10</td>
<td></td>
</tr>
</tbody>
</table>

Y = Criterion satisfied; N = Criterion not satisfied
2. Random allocation to groups
3. Allocation was concealed
4. Similar groups at baseline regarding prognostic factors
5. Blinding of all subjects
6. Blinding of therapists who administered the therapy
7. Blinding of all assessors who measured at least one key outcome
8. Measure of at least one outcome for more than 85% of subjects
9. All subjects received the intervention or “intention to treat” was stated
10. Between-group statistical comparisons for at least one key outcome
11. Point measures and measures of variability for at least one key outcome
lowing information was extracted: (1) group means at the baseline and each follow-up period and (2) statistical analysis of group differences. Results from various reported outcome measures were analyzed to determine if the experimental group was considered superior, equal, or inferior to the comparison group. Although pain was assessed by an outcome measure in all included studies, a meta-analysis was not performed because the studies were not found to be clinically homogenous with regard to patient demographics, treatment duration or follow-up time frames.

While there was considerable variability in tests and measures, each of the six studies included in the review utilized the VAS to assess response to treatment. The VAS was found to have high test-retest reliability ($r = 0.94, p < 0.001$) before and after attending an outpatient clinic with literate patients. The intraclass correlation coefficient (ICC) was 0.97 with a confidence interval of 0.96 to 0.98. The SFMPQ was found to have high interrater reliability (ICC = 0.96) for total pain in a patient population with OA. Based upon construct validity, the SFMPQ moderately correlated to the WOMAC ($r = 0.36$) in patients with hip and knee OA. The WOMAC also has been found to have high test-retest reliability (ICC = 0.77) for patients with hip and knee OA. The WOMAC has been proven to have high test-retest reliability, not only when measured immediately, but when reassessed at six months (ICC = 0.91) and 12-months (ICC = 0.86) after initial injury. The Foot Health Status Questionnaire (FHSQ) pain subscale was found to have a Cronbach's alpha of 0.88 and an ICC of 0.86 for test-retest reliability.

RESULTS

Study Selection and Characteristics

A total of 20 studies were considered for inclusion based on title and abstract. After a full-text review of each study was performed, six studies met the inclusion criteria (Figure 1). Reasons for exclusion included use of traditional acupuncture methods only and presence of upper quarter TrPs only with the intervention group. Each of the six studies selected for inclusion were RCTs. Outcome measures used to assess pain intensity included VAS, FHSQ pain subscale, SFMPQ, WOMAC, and PPT. Outcome measures used to assess function and disability included the FHSQ foot function subscale, Roland Morris Questionnaire (RMQ), and WOMAC physical function subscale. Impairment measures extracted from the studies included ROM and peak isometric strength. ROM measurements of the hip are commonly used to assess pain the lumbar region and posterior thigh. Measurements of hip ROM are used to monitor treatment response to gluteal trigger points. ROM of knee flexion and extension along with peak isometric strength of knee flexors and extensors at a single point were analyzed in post operative total knee arthroplasty (TKA) subjects. A detailed list of selected studies can be found in Table 2.

The average age of participants in the Cotchett et al study was 56 years. Participants in the Itoh et al and Mayoral et al studies had an average age of 72 years. Huguenin et al and MacDonald et al did not report age characteristics. Application of dry needling included either the “multiple insertion” or superficial technique, while comparison interventions included sham or placebo dry needling, placebo TENS, stretching or no treatment. Placebo dry needling involves insertion of the needle followed by withdrawing it partially and then advancing the needle into the skin repeatedly. Placebo dry needling is applying the tip of a blunted needle on the surface of the skin. Duration and frequency of treatment ranged from a single session to one or more sessions per week for up to 10 weeks.

Methodological Quality Assessment

Each of the six studies was independently reviewed by the same four authors who performed the database searches and assessed for methodological quality using the PEDro scale. Four of the studies were deemed to be high quality (PEDro score > 7), while two studies were determined to be fair quality (PEDro scores of 5 and 6). Four of the PEDro criteria were seen in all six studies: random allocation to groups, similar groups at baseline regarding prognostic factors, blinding of all assessors who measured at least one key outcome and between-group statistical comparisons for at least one key outcome. None of the studies included blinding of the therapists who administered the treatment, which was expected due to the use of dry needling as the inter-
Table 1 contains the PEDro scores for each individual study.

**Bias Within and Across Studies**

Three of the studies demonstrated gender differences between groups that can be seen in Table 2. In the Mayoral et al. study, VAS scores greater than 40-mm represented significant pain, which is present in almost half of the patients that undergo a TKA. As a result, Mayoral et al. used a change in VAS of greater than 40-mm to demonstrate a significant decrease in VAS scores with dry needling instead of comparing all VAS scores. The use of VAS in this manner could introduce bias because Mayoral et al. chose their own significant decrease in VAS scores instead of implementing a valid measure. Lastly, in the study by Huguenin et al., one author, McCrory, was affiliated with the study and the journal that it was pub-

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**Figure 1. Study Selection**

2,206 studies identified through database searching (CINAHL, PubMed, PEDRO, SportsDiscus, PTNow) → 26 studies identified through reference list of systematic reviews and studies found → 51 studies screened for eligibility showed face validity with the inclusion criteria based on title/abstract → 2,181 records excluded based on title/abstract due to lack of face validity → 14 full-text studies excluded due to non-RCT, use of traditional acupuncture methods only with intervention group, upper quarter involvement only → 20 full-text studies assessed for eligibility → 6 studies included in systematic review

*Results were limited to English language peer-reviewed research articles performed on human subjects.*
Table 2. Summary of included studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Purpose of Study</th>
<th>Participants</th>
<th>Intervention</th>
<th>Time Frame of Study</th>
<th>Outcome Measures and Tests</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cottrell et al.</td>
<td>To evaluate how effective trigger point dry needling is as a treatment for plantar heel pain.</td>
<td>The study included 84 patients, &gt;18 y.o. with plantar heel pain with symptom duration of at least one month.</td>
<td>Patients received either sham or real dry needling for 1 treatment per week, 30 minutes duration, for 6 weeks to the gastro-soleus complex, quadratus plantae, flexor digitorum brevis, and abductor hallucis. Each needle was inserted for 5 minutes.</td>
<td>The subjects participated for 6 weeks and were followed for 12 weeks. Outcomes were measured at 2, 4, 6, and 12 weeks.</td>
<td>1. Visual Analog Scale (VAS) 2. Foot Health Questionnaire (FHSQ) 3. Short-Form (SF-36) for QoL 4. Depression Anxiety and Stress Scales (DASS-21) 5. Foot Posture Index 6. Credibility Expectancy Questionnaire (CEQ) 7. Physical Activity Recall (PAR)</td>
<td>Both groups had decreased pain after 12 weeks, evident by the statistically significant differences in VAS (p=0.007) and FHSQ (p=0.026) scores. Overall, real dry needling was favored over sham dry needling.</td>
</tr>
<tr>
<td>Edwards et al.</td>
<td>To evaluate the effectiveness of combining superficial dry needling with active stretching for deactivating TrPs.</td>
<td>The study included 40 subjects, mostly female, with an active TrP. The TrP was most commonly reported in the upper body.</td>
<td>The subjects were divided into three groups: needling and stretching (13), stretching only (13), and control (13). The average number of dry needling sessions was 3.7. The needles were kept subcutaneously for an average of 3.4 minutes.</td>
<td>The groups received treatment for 3 weeks and had no treatment for the subsequent 3 weeks.</td>
<td>1. Short Form McGill Pain Questionnaire (SFMPQ), including a VAS component 2. Pressure Pain Threshold (PPT)</td>
<td>The dry needling and stretching group required fewer follow-up visits after the study compared to the other groups. The mean number of treatment sessions was lower for the stretching only group (2.9) compared to needling and stretching group (4.6). SFMPQ decreased (p=0.009) and PPT increased (p=0.10) in the needling-stretching group.</td>
</tr>
<tr>
<td>Fluguerin et al.</td>
<td>To evaluate placebo and therapeutic dry needling on SLR♂, pain, tightness, and hip IR in male athletes with posterior thigh pain due to TrPs.</td>
<td>The study included 85 male runners (59 completed measures before and after intervention, 58 completed the measures at 24 hours, and 52 completed the measures at 72 hours) with posterior thigh pain.</td>
<td>The subjects received either therapeutic or placebo dry needling to gluteal TrPs on one occasion.</td>
<td>Outcome measures were collected before treatment, immediately after, 24 hours post, and 72 hours post treatment for a total of 3 days for the study.</td>
<td>1. VAS for pain 2. ROM of hamstring muscle with passive straight leg raise and hip IR $</td>
<td>No significant change in VAS scores for gluteal pain after running, but both groups improved in hamstring tightness (p=0.001) and hamstring pain (p=0.001). There was no significant change in ROM. Patient report was a good indicator of dry needling success.</td>
</tr>
<tr>
<td>Itoh et al.</td>
<td>To determine whether acupuncture at TrPs is more effective than standard acupuncture for treating chronic low back pain in the geriatric population.</td>
<td>The study included 35 subjects (25 women, 10 men) age 65-81 with chronic low back pain.</td>
<td>Subjects were divided evenly into three groups: standard acupuncture, superficial acupuncture, and deep acupuncture. They received treatment to posterior thigh, gluteal, and lumbar musculature. There were a total of 6 30-minute treatment sessions, once per week.</td>
<td>The study was conducted over 12 weeks with 2 phases of treatment, each lasting 3 weeks.</td>
<td>1. VAS for pain 2. Roland Morris Questionnaire (RMQ)</td>
<td>The group that received dry needling to deep TrPs reported less pain intensity (p=0.5) and improved QoL (p=0.01), compared to the other groups.</td>
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<td>MacDonald et al.</td>
<td>To examine the effectiveness of superficial acupuncture compared to placebo in the treatment of chronic low back pain.</td>
<td>The study included 17 subjects (12 female, 5 male) with chronic low back pain.</td>
<td>Eight subjects received acupuncture and 9 received placebo dry needling. Needles were inserted 4mm into the skin over TrPs for 5 minutes in the acupuncture group. The placebo group received electrical transcutaneous stimulation to the lumbar region.</td>
<td>Treatments were performed once per week for a maximum of 10 weeks. The number of treatments was reduced if further improvement failed to occur or if symptoms worsened in response to treatment.</td>
<td>No specific outcome measures were used, however, pain was assessed numerically (1-minimal, 2-moderate, 3-severe), area of pain was mapped on a dermatome body chart, and mood was measured from 1 (normal) to 5 (abnormal state).</td>
<td>The acupuncture group had pain relief (p=0.01), reduction in pain activity score NS$, decreased physical signs (p=0.01), and decreased pain severity (p=0.01) compared to the placebo group. The measurements were statistically significant with p&lt;0.05.</td>
</tr>
<tr>
<td>Mayoral et al.</td>
<td>To examine the effectiveness of dry needling to placebo in the prevention of pain after a total knee arthroplasty.</td>
<td>The study included 40 subjects (28 female, 11 male) with a scheduled total knee replacement surgery and presence of TrPs.</td>
<td>The subjects were assigned to 1 of 3 dry needling groups or a sham dry needling group. They were assessed prior to surgery and at months 1, 3, and 6 after surgery. Dry needling was applied under anesthesia.</td>
<td>Subjects were examined prior to surgery and at 1, 3, and 6 months post-surgery.</td>
<td>1. VAS for pain 2. Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) 3. ROM 4. Peak isometric strength of knee extensors and flexors</td>
<td>Subjects who received true dry needling had less pain at 1 month with statistical significant differences in the VAS (p=0.294). There was no statistical significance between groups for the WOMAC (p=0.837 pain, p=0.802 stiffness, p=0.149 function) or ROM (p=0.539) at baseline.</td>
</tr>
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</table>

QoL = Quality of Life; TrP = Trigger Point; TrPs = Trigger Points; ROM = Range of Motion; IR = Internal Rotation; SLR = Straight Leg Raise; NS = Not Significant
lished in. According to Thaler et al,52 publication bias exists when the publication of research depends on the nature and origin of the research and the direction of the results. Thus, the selective publication or non-publication of scientific literature has the potential to negatively influence the ability to draw objective conclusions regarding patient care and resource allocation.52 Being that the author was affiliated with the journal, the potential existed for publication bias.

Effect of Dry Needling on Pain Intensity
Cotchett et al47 (n=84) investigated the effects of trigger point dry needling compared to sham dry needling in the management and treatment of plantar heel pain. Primary outcome measures were first-step pain (pain when getting out of bed in the morning) over the previous week, as measured with a 100-mm VAS (minimal important difference (MID) of 19 mm)53 and foot pain, which was measured using the pain subscale of the FHSQ, where 0 represents “worst foot health” and 100 represents “best foot health” (MCID = 13 points).47,53 At the primary end point (6 weeks), statistically significant differences existed between groups for first-step pain (p=0.002) and FHSQ (p=0.029), both favoring the treatment group.47 At 12 weeks, statistically significant differences in first-step pain (p=0.007) and FHSQ (p=0.026) favoring the treatment group persisted; however, the MCID for both outcome measures was not met at either measurement period.47

Edwards et al3 (n=40) compared the effects of superficial dry needling and stretching (G1) to stretching alone (G2) and to no intervention (G3) in subjects with pain due to TrPs. Outcome measures used to assess pain were the SFMPQ and PPT of the primary TrP. Measurements were taken prior to intervention and at three and six week follow-ups. Fifty percent of the subjects in G1 presented with TrPs not in the upper quarter, while 16% and 47% of the subjects in G2 and G3, respectively, had TrPs outside of the upper quarter. At six weeks, statistically significant differences in favor of G1 existed in SFMPQ scores (p=0.043) compared to G3 and in PPT scores (p=0.011) compared to G2.3 No other statistically significant differences existed between groups at either follow-up point.

Huguenin et al14 (n=59) evaluated the effect of therapeutic and placebo dry needling in subjects with posterior thigh pain. Pain in the gluteals and hamstrings was measured on separate VAS scales at rest and during activity. Measurements were performed at baseline, immediately after treatment, 24 hours after treatment, and 72 hours after treatment. There was no significant change in gluteal pain at rest or during activity at any measurement time frame following treatment.14 Both the treatment and placebo groups reported significant improvements in hamstring pain (p<0.001) immediately after interventions, but there was no significant change in subsequent measurements and no significant difference in the magnitude of the change related to group allocation (p>0.013).14

Itoh et al48 (n=35) conducted a study to determine whether acupuncture for TrPs is an effective treatment for LBP in the elderly when compared to standard acupuncture at traditional points. Subjects were divided into three groups: (1) superficial TrP (S-TrP), (2) deep TrP (D-TrP), and (3) standard acupuncture (SA). The S-TrP and D-TrP groups received treatment at TrPs, while the SA group received treatment at traditional points for LBP.48 Pain intensity was measured with the VAS, administered immediately before the first treatment and at one, two, three, six, seven, eight, nine, and 12 weeks after the first treatment.48 In the D-TrP group, statistically significant improvements were seen in VAS scores (p<0.01) at four weeks compared to the initial pretreatment measurement; however, this improvement was reversed by the end of the study.48 There were no significant differences between pretreatment scores and follow-up scores for the SA or S-TrP groups.48

MacDonald et al50 (n=17) investigated whether superficial acupuncture applied to TrPs was more effective than placebo TENS in treating chronic LBP. Subjective pain assessments included patient reported VAS scores at rest and during activity and patient perceived pain relief, also measured by VAS. Clinical observers noted the presence or absence of the following physical signs at the beginning and end of each course of treatment: gait impairment, spinal mobility impairment, loss of lordosis, scoliosis, impaired straight leg raising, pain on hip movements, crossed leg pain, femoral nerve stretch test, pelvic tilt, sensory deficits, motor deficits, and reflex changes.50 Only complete resolution of positive pre-treatment physical signs were taken into consideration when determining the effect of treatment...
on physical signs pain reduction.\textsuperscript{50} Observers also scored the severity of pain numerically and mapped the area of pain on a dermatome body chart.\textsuperscript{50} At the end of a course of treatment, the percent change in the severity of pain and the area it occupied on the dermatome chart were noted. Statistically significant differences were observed in the following outcomes: pain relief after each treatment ($p<0.01$), activity pain score reduction ($p<0.05$), physical signs reduction ($p<0.01$), and severity and pain area reduction ($p<0.01$).\textsuperscript{50}

Mayoral et al\textsuperscript{49} ($n=40$) examined whether dry needling of TrPs was superior to placebo in the treatment of pain following TKA. The outcome measures used to assess pain were the VAS and WOMAC. The WOMAC index is the most widely used instrument to evaluate symptomatology and function in patients with OA of the knee.\textsuperscript{49} It contains 24 questions: five about pain, two about stiffness, and 17 about difficulty with physical functions.\textsuperscript{49} Only the pain subscale scores are reported in this results section for the purposes of the systematic review. Measurements were taken at baseline and at one, three, and six months following surgery. The WOMAC pain scores were worse at baseline and at all follow-up examinations in the treatment group; however, the between group differences were not statistically significant.\textsuperscript{49} Because the baseline values of the VAS were higher in the treatment group, the authors analyzed the variation rate at one month postsurgery and percentage of subjects that had a VAS score $>40$-mm or were pain free ($\text{VAS}=0$). Variation rate was calculated according to the following formula: $[(\text{value at one month} - \text{baseline value})/\text{baseline value}] \times 100$ for VAS scores.\textsuperscript{49} According to Brander et al,\textsuperscript{44} VAS scores $>40$-mm are considered to represent a significant level of pain. Statistically significant differences in favor of the treatment group were found for variation rates for VAS score ($p=0.048$), percentage of subjects with VAS scores $>40$ ($p=0.003$), and percentage of subjects that were pain free ($p=0.042$).\textsuperscript{49} The difference in VAS variation rate across groups suggests that subjects in the treatment group experienced a greater reduction in significant pain ($\text{VAS}>40$) compared to the sham group. The subjects in the treatment group reached the same pain levels (as measured by percentage of subjects with VAS $>40$) in one month as subjects in the sham group reached in six months.\textsuperscript{49} No values were reported for subsequent follow-up measurements.

**Effect of Dry Needling on Function and Disability**

Cotchett et al\textsuperscript{47} reported FHSQ foot function subscale scores at baseline and at six and 12 week follow-ups. No significant differences in FHSQ foot function subscale scores existed between the real and sham dry needling groups at either six week ($p=0.875$) or 12 week ($p=0.889$) measurements.\textsuperscript{47} Itoh et al\textsuperscript{46} measured functional impairment with the RMQ. In the D-TrP group, a statistically significant difference was observed between pretreatment and four week RMQ scores ($p<0.01$), while no significant reductions in the scores for this period occurred in the SA or S-TrP groups.\textsuperscript{46} No significant differences existed between groups by the end of the study.\textsuperscript{46} Mayoral et al\textsuperscript{49} observed lower quarter functional impairment as measured by the WOMAC physical function scale in the treatment group compared to the sham dry needling group. However, the differences between groups were statistically insignificant at all measurement points.\textsuperscript{49} The remaining studies\textsuperscript{3,14,50} did not publish any data pertaining to function.

Peak isometric strength and ROM functional measurements were analyzed by Huguenin et al\textsuperscript{14} and Mayoral et al.\textsuperscript{49} Huguenin et al\textsuperscript{14} stated that there was no significant difference in hip internal rotation ROM and straight leg raise when comparing the treatment and control groups. Mayoral et al\textsuperscript{49} found no differences between groups regarding ROM and peak isometric strength at all follow-up visits. ROM results were explained by joint limitations due to the arthroplasty limitations and scar tissue formation in the knee joint capsule.\textsuperscript{49} Isometric strength was measured using a single contraction versus isotonic and endurance measures.

**Discussion**

The purpose of this systematic review was to determine whether there is sufficient evidence to support the use of dry needling as an effective intervention for the treatment of lower quarter TrPs in patients with orthopedic conditions.

**Summary of Evidence**

The literature review revealed six RCT studies\textsuperscript{3,14,47,50} that analyzed the effectiveness of dry needling for
the reduction of symptoms associated with muscular TrPs. While considerable variations in dry needling methods exist, the studies included in this review employed either the superficial dry needling or “multiple insertion” technique. The superficial dry needling technique involved inserting the needle to a depth of 3 to 4-mm in the area immediately overlying the TrP. In the “multiple insertion” technique, needles were repeatedly inserted and withdrawn into multiple loci of TrP regions to a depth necessary to penetrate the TrP with the goal of eliciting a “local twitch response”, which correlates to increased effectiveness of dry needling, according to Hong. Three of the studies included in the review utilized the “multiple insertion” technique, two applied the superficial dry needling technique, and one analyzed both. Only one study compared standard acupuncture (SA) to superficial (S-TrP) and deep dry needling (D-TrP). In both SA and D-TrP groups, needles were inserted to a depth of 20-mm, while the subjects in the S-TrP group received treatment consistent with the superficial technique described above. The VAS was used to measure pain intensity in all six selected studies. MacDonald et al enlisted unbiased clinical observers to assess physical signs and symptoms of pain using non-standardized numeric scales. In addition, Edwards et al measured pain pressure threshold to assess pain response to dry needling. Overall, the results of the studies demonstrated statistically significant positive outcomes with the use of dry needling for reducing pain associated with lower quarter TrPs in the short-term. Only one study administered outcome measures beyond three months of treatment; however, a statistically significant difference in pain intensity between dry needling and sham groups was not observed at the six-month follow-up. The combination of dry needling and stretching used by Edwards et al showed greater improvement in symptoms compared to stretching alone. A notable finding by Itoh et al was the superior analgesic effect with increased depth of dry needling, as evidenced by greater reduction in pain intensity experienced by the D-TrP group compared to the S-TrP group. This is consistent with the findings of Ceccherelli et al and was also confirmed in a separate study conducted by Itoh et al. From the results of Itoh et al, researchers can speculate that dry needling combined with other interventions may enhance the positive effects on TrPs; however, there is not enough research at this time to confirm this hypothesis.

In addition to pain intensity, three of the six studies examined the effect of dry needling on function and disability. The researchers implemented different outcome measures to quantify these effects. Cotchett et al and Mayoral et al found no statistically significant functional improvement as measured by the FHSQ function subscale and WOMAC physical function scale, respectively. Itoh et al was the only one of the three studies to demonstrate that dry needling had a positive effect on function. Of the three groups in the study, only the D-TrP group showed a statistically significant improvement in RMQ scores, providing further evidence of improved outcomes with deep dry needling compared to superficial dry needling techniques. Other outcome measures used to analyze the effects of dry needling included the Depression Anxiety Stress Scales (DASS-21), SF-36 for QoL, WOMAC stiffness subscale, FHSQ general foot health subscale, VAS for tightness, ROM, and peak isometric strength. Five out of the six studies found a statistically significant improvement in outcomes resulting from dry needling intervention.

According to the PEDro scale (Table 1), four of the six studies are high quality, indicating greater internal validity, while the remaining two studies received fair scores. The main threats to internal validity were non-concealed allocation to groups (50% of studies included), non-blinding of subjects and therapists (0% of studies included), paucity of attrition information (only 16% of studies included), and lack of intention-to-treat analysis (83% of studies included). All of the studies included are RCTs, which is considered level 1b quality of evidence. Considering the strength of the PEDro scores and level of evidence, the results of dry needling as an intervention are relevant to all healthcare providers assessing patients with pain and functional limitations associated with TrPs in the lower quarter.

Limitations
The primary limitation of this systematic review is the paucity of literature available based on the chosen inclusion criteria. The search of the previously
stated databases returned a paltry amount of evidence investigating the effects of dry needling for lower quarter TrPs. As evidenced by Figure 1, of the 2,232 potential studies screened for eligibility, only six were identified for inclusion.

A second limitation of this review is the chosen search criteria placed on the studies. The Centre for Evidence-Based Medicine (CEBMa) ranks Systematic Reviews and Meta-analyses as level Ia and RCTs as Ib. Therefore, only RCTs were included in the search criteria in order to present findings based on the highest quality of evidence, as defined by the CEBMa. While the PEDro scale is specifically designed to assess the quality of RCTs, it was the sole method of investigating internal validity across all studies in the review. Clinically relevant findings from lower levels of evidence may have been excluded from consideration. The authors also did not include any unpublished studies or studies not written in the English language.

Another limitation was subject sample size and population. For example, five out of six studies included a relatively small sample of subjects, which ranged from 17 to 84 subjects (Table 2). In the study by Edwards et al, G2 included 13 subjects of which 84% had TrPs of the upper body, but the other groups were similar in composition. Three studies consisted of subject populations that were significantly different in regards to gender. Huguenin et al included 59 males recruited from Australian rules football teams.

Five of the six studies did not report any MCIDs in their publications. Cotchett et al was the only study to report MCIDs; however, the MCIDs were calculated by the authors, rather than adhering to published values. The majority of results were based upon statistical significance, and clinically significant findings were not reported. Since clinical significance was not reported, no inferences can be made on the practicality of dry needling in a clinical setting.

An important limitation is the lack of subject and author blinding. Two studies did not implement blinding of subjects. The lack of blinding can misconstrue the intervention outcomes because patients can perceive that the treatment is beneficial or not, given their symptoms. Furthermore, in all studies the treating therapists were not blinded due to the nature of the interventions. The authors of the studies were not blinded to subject groups or interventions provided to the subjects.

All studies included in the systematic review consisted of varying follow-up periods ranging from 24 hours to six months (Table 2). No single study investigated the long-term effects of dry needling past six months. Furthermore, only one of the six studies included in this review investigated the short-term effect of dry needling combined with stretching. None of the studies examined the short- or long-term effects of dry needling in comparison to or conjunction with other physical therapy interventions. Therefore, recommendations can only be made on the short-term effects of dry needling as a sole method of treatment for the purposes of this review.

An additional limitation of this review is the potential of publication bias. In the study by Huguenin et al, one author was affiliated with the publisher at the time of publication. Publication bias may reduce the report of negative results or access of information not beneficial to the study outcomes and has the potential to negatively influence the ability to draw objective conclusions regarding patient care and resource allocation.

In the studies by Mayoral et al and MacDonald et al there were non-standardized outcome measures that threatened external validity. The studies utilized clinical observers instead of validated outcome measures, which may have decreased interrater reliability. Clinical observers do not have the same reliability and reproducibility that a verified outcome measure contains, as subjective assessments may be prone to error. Additionally, due to the limited number of studies included in the systematic review, the authors did not have the ability to define inclusion criteria regarding specific outcome measures. While all six of the studies utilized a VAS to measure pain intensity, there was a general lack of consistency regarding other outcome measures. Although the reported outcome measures are subjective in nature, they have been proven to be valid and reliable (refer to Data Collection Process and Synthesis of Results section for provided values).
CONCLUSION

The purpose of this systematic review was to assess and provide a summary of the current literature for the use of dry needling for TrPs in the lower quarter. Muscular TrPs of active or latent origin are commonly associated with many musculoskeletal conditions of the lower quarter, as evidenced by this systematic review. The results of the studies included in this review suggest that dry needling is an effective intervention for reducing pain associated with lower quarter TrPs in the short-term. The findings suggest that dry needling does not have positive short or long-term effects on function, QoL, depression, ROM, or strength. There may be additional benefit in utilizing dry needling in combination with other therapeutic interventions (i.e., stretching and exercise) for the treatment of TrPs; however, further research is required to validate this assertion.

Future Research

This systematic review provides the potential foundation for future research and clinical application of dry needling due to the results of the studies. Further studies investigating the effect of dry needling in comparison to and in conjunction with other interventions would be beneficial to optimize outcomes in clinical settings. Standardized, valid outcome measures should be implemented and analyzed for both statistical and clinical significance in future studies in order to reveal the effectiveness of dry needling with respect to various orthopedic conditions. Furthermore, long-term follow-up measurements should be obtained in order to determine whether dry needling is able to produce lasting, positive effects on pain and disability associated with lower quarter TrPs.

REFERENCES


45. Riskowski JL, Hagedorn TJ, Hannan MT. Measures of foot function, foot health, and foot pain: American
Academy of Orthopedic Surgeons Lower Limb Outcomes Assessment: Foot and Ankle Module (AAOS-FAM), Bristol Foot Score (BFS), Revised Foot Function Index (FFI-R), Foot Health Status Questionnaire (FHSQ), Manchester Foot Pain and Disability Index (MFPSI), Podiatric Health Questionnaire (PHQ), and Rowan Foot Pain Assessment (ROFPAQ). *Arthrit Care Res (Hoboken)*. 2011;63 Suppl 11:S229-39.


ABSTRACT

Background: Emerging evidence suggests poor core stability is a risk factor for low back and lower extremity injuries in athletes. Recently, the trunk stability test (TST) and unilateral hip bridge endurance test (UHBE) were developed to clinically assess core stability. Although these and other clinical tests of core stability exist, how well they assess core stability when compared to biomechanical measures of isolated core stability has not been thoroughly evaluated.

Purpose/Hypothesis: The purposes of this study were to 1) determine concurrent validity of two novel clinical core stability assessments (TST and UHBE), and 2) assess relationships between these assessments and the trunk endurance and Y-Balance tests. The authors’ hypothesized that the TST and UHBE would be highly correlated to the lab-based biomechanical measure of isolated core stability. Also, the TST and UHBE would be moderately correlated with each other, but not with the trunk extensor endurance and Y-Balance.

Study Design: Cross-Sectional design

Methods: Twenty healthy active individuals completed the TST (recorded number of errors), UHBE (s), trunk extensor endurance (s), Y-Balance (% leg length) test (YBT), and biomechanical test of core stability.

Results: Correlational analyses revealed a small, non-significant association between TST and biomechanical measures ($r_s = 0.2 - 0.22$), while a moderate, significant relationship existed between UHBE and biomechanical measures ($r_s = -0.49$ to $-0.56$, $p<0.05$). There was little to no relationship between TST and UHBE ($r = -0.07$ to $-0.21$), or TST and extensor endurance ($r = -0.18$ to $-0.24$). A moderate, significant association existed between TST and two reach directions of the YBT ($r = -0.41$ to $-0.43$, $p<0.05$).

Conclusions: Study data support the utility of UHBE as a clinical measure of core stability. The poor relationship between the TST and biomechanical measures, combined with observation of most control faults occurring in the lower extremity (LE) suggest the TST may not be an appropriate clinical test of core stability.

Levels of Evidence: Level 3

Keywords: athletic injuries, neuromuscular control, core stability

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INTRODUCTION
Many sporting activities require complex coordination between the upper and lower extremities. The core (trunk, pelvis, and hip) functions as the central link between the upper and lower extremities, and stability of this region is proposed to be a requisite for optimal athletic performance and injury prevention. The kinetic chain theory describes core stability as the ability to control the position and motion of the trunk and pelvis relative to the extremities in order to allow for optimal force production, dissipation, and transfer to the extremities during movement.

Optimal core stability is dependent upon both muscle capacity (strength and endurance) and neuromuscular control. Neuromuscular control is defined as the ability to accurately orchestrate a synchronized muscular response to internal and external perturbations based on sensory information in order to control the position or movement of the body. While the anatomical definition of the core is not universally agreed upon, most definitions include musculature associated with the trunk, pelvis and hips. These muscles are activated prior to extremity movement, which indicates that the core provides proximal stability upon which movement of the extremities occurs. Additionally, optimal core stability is important for performance of athletic tasks that result in perturbations of the athlete’s body outside of their base of support.

Poor core stability has been identified as a risk factor for low back and extremity injuries in athletes. In light of this information, core stability training has gained popularity in clinical settings for prevention and rehabilitation of upper and lower extremity injuries in athletes. Therefore, there is a need for valid assessments of core stability that can readily be applied in a clinical setting.

Clinical assessments of muscle endurance are commonly used to evaluate core stability. Numerous tests of core muscle endurance (prone plank, side plank, abdominal curl, trunk extension) have been described for assessing core stability in healthy adults and athletic populations. Decreased trunk/pelvis/hip extensor muscle endurance has been shown to be predictive of future low back pain (odds ratio: 3.4, 95% CI, 1.2-10) in a non-athletic population. Noehren et al recently described a new clinical test of core stability; the trunk stability test (TST), which they suggest tests core neuromuscular control. The trunk stability test was designed as a clinical version of a valid and reliable lab-based test of core neuromuscular control. Findings from their study revealed poorer TST performance in a group of subjects undergoing ACL rehabilitation. The authors suggest that this finding indicated impairments of core neuromuscular control.

The Y-Balance Test (YBT) is another clinical test used to assess lower extremity and trunk neuromuscular control during a dynamic single-limb balancing task. Recent studies have demonstrated usefulness of the YBT for predicting lower and upper extremity injuries in high school and collegiate athletes.

Poor core stability is recognized as a risk factor for musculoskeletal injury; however, most clinical measures of core stability have not been validated against lab-based biomechanical measures of core stability. This has resulted in knowledge gaps that hinder a clinician’s ability to accurately assess core stability. The purposes of this study were to 1) determine the concurrent validity of two novel clinical assessments of core stability (TST and UHBE test), and 2) assess the relationships between these novel assessments and currently used clinical core stability measures of trunk endurance test and YBT. The authors hypothesized that the TST and UHBE test would demonstrate a moderate to strong correlation with lab-based biomechanical measures of isolated core neuromuscular control. The authors further
hypothesized that TST and UHBE test would be moderately correlated with each other, but not with the trunk extensor endurance test and YBT.

METHODS

Study Design
A cross-sectional design was used to assess the relationship between two novel clinical measures of core stability (UHBE test and TST) and a lab-based biomechanical test of isolated core stability, as well as the relationship between two novel clinical measures and two commonly used clinical measures of core stability. The TST was chosen as it was modeled after the lab-based biomechanical test used in the current study and has not been validated against this measure. Commonly used clinical measures of core stability were chosen based on current evidence and published procedures were used. Standardized procedures were developed for the novel clinical assessments.

Subjects
Twenty healthy active subjects were recruited to participate in the study (11 males; age 23.5 +/- 1.7 years; height 173.0 +/- 8.3 cm; weight 71.9 +/- 15.5 kg). All subjects participated in physical activities 4-6 days per week. These activities included strength training, cardiovascular exercise, and club sports. Prior to the start of any testing procedures, all participants signed informed consent documents approved by the Institutional Review Board. Inclusion criteria were anyone between the ages of 18-40 and considered to be regularly active. Subjects were excluded if they presented with any of the following: concussion (current or within the previous six months), current leg, trunk or neck injury, a diagnosed balance disorder, and/or a current head cold, sinus infection, or inner ear infection.

Procedures
Following completion of the intake forms, subjects performed a series of clinical and lab-based measures with standardized rest periods between tests (5 minutes) and trials (1 minute). The trunk extensor endurance test (Figure 3) was performed first as two trials of this test were conducted and it was necessary to separate them within the protocol. The second trial was completed at the end of the testing session. To perform the trunk extensor endurance test, subjects were positioned prone on a treatment table with the iliac crests at the edge of the table and their upper trunk hanging down from the edge of the table. Mobilization belts were used to secure the subject to the table at the buttocks, thigh, and lower leg. Subjects were instructed to place their arms across their chest and raise their torso until it was parallel to the floor. An examiner then placed a digital inclinometer on the subjects back between their shoulder blades, the subject was told to hold this position for as long as possible, and the amount of time the position could be maintained was recorded via a stopwatch. The test was terminated when the trunk angle changed 10° from the start position or the subject stopped on their own volition. Two trials were performed and the average was used in subsequent analyses.

Figure 1. Unilateral Hip Bridge Endurance Test. Test requires an individual to maintain a neutral pelvis in both the transverse and sagittal planes for as long as possible with one leg planted and one leg extended.

Subjects then performed the TST and lab-based measures of core neuromuscular control. The order of testing for these two assessments was randomly determined. The trunk stability test required subjects to sit on either a 65cm or 75cm Swiss ball with both feet on the ground. Ball size was, in part, determined by the height of the subject. For all subjects it was essential that the size of the ball allowed both ankles to be in a neutral position (0° dorsiflexion) with the knees and hips in 90 +/- 10 degrees of flexion. Subjects were
asked to sit up tall with their arms across their chest and extend one knee so that the heel of the lifted leg was at the height of the stationary ankle. Subjects performed one 30s practice trial on each leg with their eyes open while attempting to maintain the position of the raised foot for the duration of the trial. Following the practice trial, three trials per leg were collected where the individual repeated the same testing procedures except with their eyes closed. If they moved out of the test position, they were instructed to return to the test position as quickly as possible. Throughout the 30-second trial an examiner visually assessed and recorded deviations from the test position (errors). Errors included: plant foot moving, uncrossing the arms, raised foot touches ground, eyes open, and reaching for the table. Additionally the amount of time that an individual error existed was recorded. Subjects were allowed to open their eyes; however, this would be recorded as an error. The time from when they opened their eyes until they returned to the test position was counted and each second from the initial error to the return to position was recorded as an error. For example, if the subject placed the foot on the ground and opened their eyes, two errors were recorded. The number of seconds from the last error (i.e. eyes open) to the return to the testing position was counted (i.e. 3 seconds) and that 3-second period was counted as three errors. The total errors for each trial were recorded and the average of the three trials was used for analysis. The TST has a reported measurement error of 0.25 errors and within-session reliability [ICC (3,k)] of 0.93. Lab-based biomechanical measures of isolated core neuromuscular control were obtained from an unstable sitting test (Figure 2b). This apparatus and test isolates neuromuscular control to the core by minimizing involvement of the lower extremities through use of straps and a footplate that is attached directly to the chair. The seat is attached to a solid hemisphere (44 cm diameter), which sits atop a force plate. Padded safety railings surrounded the subject in the event that they lost their balance. Details of the apparatus design and protocol have been previously reported. Center of pressure (CoP) measures derived from the force plate data collected during the unstable sitting test were used to quantify core neuromuscular control by use of a 95% confidence ellipse (CEA) that represents 95% of the area that CoP traveled during the test, and mean velocity (MVEL) which represents the mean displacement of the CoP per second. Subjects performed three-60s trials in which they were instructed to close their eyes, sit up tall with their arms across their chest, and move as little as possible during the trial. The average of three trials was used for analysis. A larger CEA and higher MVEL are representative of poor control of the body’s center of mass, or poor core stability. These variables have been previously validated and used to identify poor core neuromuscular control in patients with low back pain. The UHBE test was performed with the subject lying supine with their arms across their chest, knees in flexion, and feet flat on the table. The subject performed a double-leg hip bridge, and once a neutral spine and pelvis position were achieved the subject was instructed to extend one knee (randomly determined) so their leg was straight and their thighs were parallel to one another. Subjects were instructed to hold this position as long as possible. The test was terminated when they were no longer able to maintain a neutral pelvic position as noted by 10-degree change in transverse or sagittal plane alignment. Pelvic positioning in the transverse plane was monitored by a digital inclinometer attached to a mobilization belt that was tightly secured to the individual’s pelvis. A second rater visually assessed
sagittal plane alignment. Two trials were performed on each side and the average of each side was used for subsequent analyses.

The YBT (Figure 4) was performed as described by Pilsky et al, 2009. Subjects were given six practice trials on each leg in each direction prior to performing three recorded trials. Hands had to remain on hips and foot in full contact with the support surface to be considered a good trial. Trials were averaged for each direction, normalized to the subject's leg length, and expressed as a percentage of leg length.

**Statistical Analysis**

All data were tested for normal distribution via the Shapiro-Wilk test. Paired t-Tests were used to assess for side differences with the UHBE, TST, and YBT. One-tailed Pearson's and Spearman's rho correlations were used to examine relationships between the trunk stability and UHBE tests and lab-based biomechanical measures, and the TST, UBHE, YBT and trunk extensor endurance test clinical measures. Significance was set at p ≤ 0.05. All data analyses were conducted using Statistical Package for the Social Sciences (SPSS v22, Chicago, IL). Correlations were interpreted according to Cohen [0.1 = weak; 0.3 = moderate; 0.5 = strong].

**RESULTS**

Descriptive statistics for clinical and lab-based biomechanical measures are reported in Table 1. All data, except mean CoP velocity and 95% confidence ellipse area, were normally distributed. There were no significant differences in side-to-side performance of the UHBE test or any YBT direction, thus the values were averaged to produce one score for the UHBE test and one score for each direction of the YBT. There was a significant difference in performance between sides of the TST; therefore sides were analyzed separately. The UHBE test demonstrated a significant, moderate to strong negative correlation with lab-based biomechanical measures of isolated core stability (Table 2). There was little to no correlation between TST and lab-based biomechanical measures of core stability (Table 2). The TST was significantly and moderately correlated to the YBT, but not UHBE and trunk extensor endurance test (Table 3). There was a small and non-significant correlation between UHBE and trunk extensor endurance test and YBT (Table 3). A breakdown of the location of errors by body region for the TST is located in Table 4.

**Figure 3.** Trunk Extensor Endurance Test. The trunk extensor endurance test requires an individual to maintain neutral trunk and pelvic alignment in the sagittal plane for as long as possible.

**Figure 4.** Y-Balance Test (YBT). A) Anterior Reach (YBT ANT); B) Posteromedial Reach (YBT PM); C) Posterolateral Reach (YBT PL). YBT tests require balance and control in dynamic single-limb stance while reaching as far as possible in three directions.
DISCUSSION

The primary purpose of this study was to determine the concurrent validity of two novel clinical assessments (TST and UHBE test) of core stability. The UHBE test was significantly correlated with lab-based biomechanical measures of core stability, thereby partially supporting our hypothesis. Data revealed that the UHBE test explains 24-31% of the variance in the lab-based biomechanical measures of isolated core stability. Since the lab-based biomechanical measures of core stability and UHBE test require control of the lumbopelvic region to maintain stability in the testing position, the moderate relationship between these tests support the use of the UHBE test as a clinical measure of core stability. There was no significant association between the TST and the lab-based biomechanical measures. This finding is contrary to our hypothesis and suggests that the TST does not primarily measure isolated core stability, despite the fact that it was modeled as a clinical version of a lab-based seated core stability test.17,19

The TST demonstrated a significant relationship with the YBT and explained up to 19% of the YBT variance. In addition, 85% of the errors recorded during the TST were related to lower extremity deviations while 11% were related to the trunk or upper extremity deviations (Table 4). Previous work has demonstrated that performance on the YBT appears to be primarily driven by lower extremity control.22 The lack of a relationship between the TST and isolated core stability lab-based tests, combined with the predominance of lower extremity errors on the trunk stability test suggests that the TST may not be a good assessment of core stability performance.

Interestingly, the TST was significantly correlated to posteromedial and posterolateral directions of the
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The YBT but not the anterior direction. The significant and moderate relationship between the posteromedial and posterolateral directions of the YBT and the TST may be due to the increased demand for ankle stability and control during tasks that incorporate trunk and hip motion (such as the trunk counterbalancing in the YBT or sitting on a Swiss ball). It is also plausible that optimal lower extremity neuromuscular control strategies are essential for correct performance of the TST, and only when this fails does compensation need to occur further up the kinetic chain at the pelvis/trunk. Further research is needed to evaluate the mechanics of how the test is performed, such as muscle activation and timing patterns and/or kinematics.

Relationships between the TST, UHBE, trunk extensor endurance and YBT provide further insight into these clinical assessments of core stability and dynamic single-limb balance. The TST and UHBE tests were not significantly related to each other, suggesting that they assess different regions of the kinetic chain. The TST may assess lower extremity control while the UHBE test primarily assesses lumbopelvic control. The small, non-significant relationships between the UHBE and trunk extensor endurance tests suggest these tests are measuring different aspects of core stability (neuromuscular control vs. muscle capacity). The lack of a relationship between the trunk extensor endurance and UHBE tests might be explained if it is considered that the UHBE test may primarily address multi-planar lumbopelvic neuromuscular control and localized muscle capacity, while the trunk extensor endurance test primarily assesses global extensor muscle endurance. A follow-up analysis of the relationship between the trunk extensor endurance test and lab-based tests found a moderate and significant correlation (EC_CEA = -.45, p < .05; EC_MVEL = .47, p < .05). Interestingly, the trunk extensor endurance test, accounts for 20-22% of the variance in the lab-based measure of core stability. This relationship suggests that the lab-based biomechanical test requires both multi-planar neuromuscular control for stability and extensor muscular endurance. The extensor muscle endurance aspect of the test could be based on the position required (upright sitting) and repeated 60s trials; however, this finding requires further investigation. Together, these findings provide preliminary support for the use of the UHBE and trunk extensor endurance tests as complimentary clinical measures, potentially capturing both neuromuscular control and muscle capacity aspects of core stability. However, further work is needed to support this idea as well as to determine if additional tests can further compliment the assessment of core stability. In addition, more research is necessary on the UHBE to determine normative values and minimal detectable change scores, which will make the test clinically useful.

Acknowledged limitations in this study may restrict the generalizability of the findings. This study utilized a small sample, which may have been underpowered to find a moderate correlation. No previous injury history information was available on this cohort of young healthy individuals. While injury history is a reported risk factor for future injuries, the influence of prior injury (particularly in the lower extremity) on task performance is not available in this study. Therefore it cannot be said with full confidence that these relationships do not shift in light of injury history or that this test is predictive of injury. This subject group, while recreationally active, does not represent a sample of competitive athletes, and therefore the performance of these tests in competitive athletes should be assessed. In addition, it should be noted that the lab-based biomechanical test emphasizes isolated trunk/pelvic control with emphasis on neuromuscular control of an upright-seated posture and thus the current findings do not represent all aspects of core stability. Future work seeking to assess validity of clinical tests of core stability should consider these limitations.

CONCLUSIONS

These findings preliminarily support use of the UHBE test as clinical measure of core stability. Future work is needed to determine both the psychometric properties and clinical utility of the UHBE test to identify poor core stability and predict injury. While the trunk stability test was not correlated with the lab-based measures of core stability it demonstrated a significant association with the Y-Balance test. Though future work is needed to fully understand this relationship, these data do not support use of the TST as a clinical tool to assess core neuromuscular control. Identification of other clinical assess-
ments of core stability that are helpful in clinical decision-making remains a research priority.

REFERENCES


ABSTRACT

Background: Substantial deficits in performance of hip abductor in patients with common lower extremity injuries are reported in literature. Therefore, assessing hip abductor endurance might be of major importance for clinicians and researchers.

Purposes: The purpose of this study was to examine the test-retest reliability of two hip abductor endurance tests in healthy females. Learning effect, systematic difference in the rate of perceived exertion and relationship between endurance performance and some clinical characteristics of participants were also investigated.

Design: Observational study, with a test-retest design.

Methods: Thirty-six healthy females, aged 18-30 years, were recruited. In two identical assessment sessions, the participants performed an isometric hip abductor strength test and two different hip abductor endurance tests.

Results: Isometric and dynamic endurance tests demonstrated good test-retest reliability (intraclass correlation coefficients (ICC) = 0.73 and 0.78, respectively). The standard errors of measurement (SEM) and the minimal detectable changes (MDC) were, respectively, 19.8 and 54.9 seconds for isometric endurance test and 21.2 and 58.7 repetitions for dynamic endurance test. Moderate correlation between both endurance tests ($r = 0.60$, $p = 0.0001$) and weak correlation between dynamic endurance test and strength ($r = 0.44$, $p = 0.008$) were found.

Conclusions: The results of the present study demonstrate good test-retest reliability of two non-instrumented clinical tests of hip abductor endurance in healthy females.

Level of evidence: 2b

Key Words: Hip muscular endurance, reliability
INTRODUCTION
During the last decade, many researchers have reported an influence of hip muscles on common lower extremity conditions, such as patellofemoral pain (PFP), iliotibial band syndrome, anterior cruciate ligament injuries, and hip osteoarthritis.\(^1\)\(^,\)\(^2\)\(^,\)\(^3\)\(^,\)\(^4\) Several authors have evaluated hip muscle function in participants with PFP and reported strength deficit of hip muscles compared with healthy controls.\(^5\)\(^,\)\(^6\)\(^,\)\(^7\)\(^,\)\(^8\)\(^,\)\(^9\)\(^,\)\(^10\) Dierks et al\(^4\) reported that variations in hip kinematics were more pronounced at the end of a prolonged run in runners with PFP and Prins et al\(^11\) suggested that patients with PFP have greater deficit in muscular endurance than in muscular strength. This implies that hip muscle endurance should be evaluated as well as hip muscle strength. Prins et al\(^11\) and Van Cant et al\(^10\) have conducted systematic reviews and reported that substantial deficits exist in the performance of hip abductors in patients with PFP compared with healthy controls. Although the cause of PFP is multifactorial, impaired muscular control of hip abductors can affect lower extremity movements in the frontal plane and can increase patellofemoral contact pressures during activities such as walking, ascending and descending stairs.\(^2\)\(^,\)\(^5\)\(^,\)\(^6\) Several non-instrumented clinical tests for the assessment of trunk extensors,\(^12\)\(^,\)\(^13\) neck flexors\(^14\) or ankle plantar flexors endurance\(^15\) in healthy and unhealthy subjects are reported in the literature. However, to the best knowledge of the authors, no test has been developed to assess the endurance of the hip abductors. In this study, two clinical tests for the assessment of hip abductors endurance in healthy females are described.

The purpose of this study was to examine the test-retest reliability of two hip abductor endurance tests in healthy females. Learning effect, systematic difference in the rate of perceived exertion and relationship between endurance performance and some clinical characteristics of participants were also investigated. Because the literature suggests that hip neuromuscular deficits are more prevalent in females than in males,\(^16\)\(^,\)\(^17\) only females were recruited to participate in this study.

METHODS

Subjects
Thirty-six healthy females, aged 18-30 years and reporting routine participation in recreational sports, were recruited among students of the Institut Par- nasse-ISEI, Brussels, Belgium. Participants with a history of orthopedic injury or surgery of the lower limb within the previous 12 months, cardiovascular, pulmonary, neurological, or systemic conditions were excluded from the study. Additionally, subjects with a history a low back or lower limb pain or who had been diagnosed with a previous ligament injury of the knee, ankle or hip were also excluded from this study. Participant demographics and characteristics, such as age, weight, body mass, lower limb length and physical activity levels were collected and are presented in Table 1. Lower limb length was measured as the distance between the anterior superior iliac spine and the medial malleolus with subject in supine position.\(^18\) The Baecke Activity Questionnaire (BAQ) was also completed by participants in order to assess their physical activity levels (daily participation in sports and leisure activity).\(^19\) It is made-up 22 closed questions and indexes are calculated on a scale from 1 (low level of physical activity) to 5 (high level of physical activity).\(^19\) All subjects gave written consent for participation in the study, which was approved by the Erasme Hospital Ethics Committee.

Table 1. Demographic and clinical characteristics of the study sample (n = 36)

<table>
<thead>
<tr>
<th></th>
<th>Means</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>21.8</td>
<td>1.49</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>166.3</td>
<td>5.79</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>58.6</td>
<td>5.84</td>
</tr>
<tr>
<td>Lower limb length (cm)</td>
<td>83.9</td>
<td>3.96</td>
</tr>
<tr>
<td>Sport activity indices in BAQ</td>
<td>5</td>
<td>1.5</td>
</tr>
<tr>
<td>Free-time activity indices in BAQ</td>
<td>3</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Abbreviations: SD, standard deviation; BAQ, Baecke Activity Questionnaire
therapist with over 10 years of clinical experience). Following a five-minute sub-maximal warm-up on a stationary cycle, each subject performed an isometric hip abductor strength test and two different hip abductor endurance tests (a static test and a dynamic test), with fifteen minutes of seated rest between the two endurance tests.

For each subject, the order of the endurance tests was determined randomly by throwing a dice and maintained identical for both sessions. The dominant limb was used for all tests and was defined as the limb used for kicking a soccer ball. Similar instructions and verbal encouragement were provided to all participants.

Isometric strength test
The maximal isometric strength of hip abductors was measured with a hand-held dynamometer (HDD) (Chatillon Model CSD 500, Chatillon & Sons, Greensboro, NC). Measurements with such dynamometer have been reported to be reliable (intra-class correlation coefficient (ICC3,1) values ranging from 0.86 to 0.94).

Testing was performed supine with the pelvis and opposite femur secured with stabilization straps to minimize compensation (Figure 1). Participants provided additional stabilization of the trunk by grasping the side edges of the examination table. The dynamometer was positioned 1 cm superior to the lateral femoral condyle of the tested limb and secured by a belt to wall bars (Figure 2). After two sub-maximal contractions for familiarization, each subject performed three 5-second maximal-effort contractions with intervals of 15 seconds between trials. The highest value was recorded and expressed as a percentage of body mass using the following equation:

\[
\text{([Force (kg)/body mass (kg)] x 100)}
\]

Isometric endurance test
To evaluate the isometric endurance of hip abductors, the subject was in a side lying position on the examination table with the evaluated hip placed superiorly in neutral alignment and with the trunk resting against a wall. The opposite limb was flexed at the hip and knee. The hand of the upper arm was placed on the pelvis (Figure 3). Considering that authors of previous studies reported that the muscle contractions elicited by tests evalu-
At the end of the test, the subject was asked to give an overall perception about how hard the exercise felt according to the Borg Rating of Perceived Exertion Scale (Borg RPE). The Borg RPE is a 15-point single-item scale ranging from 6 to 20, with anchors ranging from 6 “No exertion” to 20 “Maximum exertion”.24

**Dynamic endurance test**

To evaluate the dynamic endurance of hip abductors, the subject was placed in the same position as described for the isometric endurance test. The subject was instructed to perform repeated active abduction of the hip from -10° to 30°, while keeping the knee extended, the hip in neutral rotation and aligned with the trunk and maintaining the frontal plane alignment of the pelvis. No external weight was used. Range of motion was determined using an inclinometer strapped 10 cm superior to the lateral femoral condyle and markers were placed on the wall to give tactile feedback of the range of motion to the participant during the test (Figure 4). The subject was invited to perform the maximum number of hip abduction movements at a rate of one abduction every two seconds, as given by a metronome.

The test was terminated if, even after investigator warnings, movements were not performed in the complete range of motion or at the indicated pace, the moving limb flexed or rotated, if the subject could no longer maintain the trunk position (loss of contact with the wall) or until she reached limit of fatigue. After the test, the number of repetitions was recorded and the rate of perceived exertion was determined with the Borg RPE.

**Statistical analysis**

First, descriptive statistics were calculated. The test-retest reliability of endurance tests was calculated with a two-way random model intraclass correlation coefficient (ICC$_{2,1}$). Reliability coefficients was considered to be poor for an ICC less than 0.51, moderate between 0.51 and 0.70, good between 0.70 and 0.90 and very good for an ICC greater than 0.90.25 To determine consistency of measurements, the standard error of measurement (SEM) was calculated as SD×√1-ICC, where SD is the standard deviation of all scores from the participants.26 The minimal detectable change (MDC) was calculated as SEM×1.96×√2 to construct a 95% CI.26

The Wilcoxon test was used to assess learning effect for the endurance tests and whether there was a systematic difference in the rate of perceived exertion.
between test and retest and between isometric and dynamic endurance test.

The associations between endurance tests and strength, height, body mass, lower limb length, sport activity indices in BAQ, free-time activity indices in BAQ and Borg RPE were examined using Pearson's correlations. Correlation was defined as weak (<0.3), moderate (0.3-0.5) and strong (>0.7).\(^6\) Because learning effect that may have occurred during the research for the endurance tests was not known, only data from second day was used to calculate correlations. The statistical analyses were performed using SPSS statistical software (SPSS Inc, Chicago Illinois) with a significance level of \(p < 0.05\).

**RESULTS**

**Descriptive statistics**

Thirty-six healthy females, with a mean age of 21.8 ± 1.5 years, a mean body mass of 58.6 ± 5.9 kg and a mean height of 166.3 ± 5.8 cm, volunteered for this study (Table 1). The mean endurance time was 87.3 ± 38.7 s in the first session and 88.4 ± 38.24 s in the second session. The mean number of repetitions was 83.8 ± 42.42 in the first session and 92.9 ± 49.06 in the second session. The mean of maximal isometric strength, expressed as a percentage of body mass, was 35.6 ± 9.7. Descriptive statistics by test session are reported in Table 2.

**Test-retest reliability**

The data for the test-retest reliability (ICC, SEM and MDC) are presented in Table 3. Isometric and dynamic endurance tests demonstrated good test-retest reliability (ICC = 0.73 and 0.78, respectively).

The SEM was 19.8 seconds for isometric endurance test and 21.2 repetitions for dynamic endurance test, and the MDC was 54.9 seconds and 58.7 repetitions, respectively.

**Correlation analysis**

Pearson's correlation coefficients between endurance tests and strength, height, body mass, lower

---

**Table 2. Descriptive statistics on the tests for both sessions.**

<table>
<thead>
<tr>
<th>Test session</th>
<th>Isometric endurance test (s)</th>
<th>Dynamic endurance test (n)</th>
<th>Isometric endurance test (s)</th>
<th>Dynamic endurance test (n)</th>
<th>Isometric strength test (% BW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Session 1</td>
<td>87.7</td>
<td>83.8</td>
<td>88.4</td>
<td>92.9</td>
<td>35.6</td>
</tr>
<tr>
<td>Session 2</td>
<td>88.4</td>
<td>92.9</td>
<td>88.4</td>
<td>92.9</td>
<td>35.6</td>
</tr>
</tbody>
</table>

| Abbreviations: SD, standard deviation; BW, body weight; Min, minimum; Max, maximum |

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**Table 3. Test-retest reliability of the isometric and dynamic endurance tests.**

<table>
<thead>
<tr>
<th></th>
<th>Isometric endurance test</th>
<th>Dynamic endurance test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson (r)</td>
<td>1</td>
<td>0.600*</td>
</tr>
<tr>
<td>Dynamic endurance</td>
<td>0.600*</td>
<td>1</td>
</tr>
<tr>
<td>Strength</td>
<td>0.297</td>
<td>0.436*</td>
</tr>
<tr>
<td>Height</td>
<td>0.066</td>
<td>-0.077</td>
</tr>
<tr>
<td>Body mass</td>
<td>0.058</td>
<td>-0.109</td>
</tr>
<tr>
<td>Lower limb length</td>
<td>-0.198</td>
<td>-0.223</td>
</tr>
<tr>
<td>Sport activity indices in BAQ</td>
<td>0.151</td>
<td>0.065</td>
</tr>
<tr>
<td>Free-time activity indices in BAQ</td>
<td>0.242</td>
<td>0.266</td>
</tr>
<tr>
<td>Borg RPE</td>
<td>-0.017</td>
<td>-0.285</td>
</tr>
</tbody>
</table>

*Significantly different (\(p < 0.05\))
limb length, sport activity indices in BAQ, free-time activity indices in BAQ and Borg RPE are summarized in Table 4. Moderate correlation between both endurance tests ($r = 0.60, p = 0.0001$) and weak correlation between dynamic endurance test and strength of hip abductors ($r = 0.44, p = 0.008$) were found.

**Learning effect**
The results of the first session for both endurance tests were compared with the results of the second session. No statistically significant differences were found between performances of the isometric endurance test ($p = 0.60$), or the dynamic endurance test ($p = 0.09$), meaning there was no learning effect for the tests.

**Rate of perceived exertion**
The rate of perceived exertion for both tests are described in Table 5. When comparing both sessions, participant reported Borg RPE was significantly higher at the second session for the isometric endurance test ($p = 0.003$) but there were no significant differences for the dynamic endurance test ($p = 0.09$). There were no significant differences in Borg RPE between isometric and dynamic endurance tests during the first ($p = 0.80$) or during the second sessions ($p = 0.49$).

**DISCUSSION**
The first purpose of this study was to assess the test-retest reliability of two clinical tests of hip abductor endurance in healthy females. The results showed good test-retest reliability of both clinical tests. Indeed, the ICC-values were 0.73 (SEM = 19.8 s) for the isometric endurance test and 0.78 (SEM = 21.2 repetitions) for the dynamic endurance test.
To the best of the authors’ knowledge, no other studies have assessed reliability of non-instrumented tests of hip abductor endurance. Therefore, direct comparisons with related reports in the literature are difficult. In contrast, reliability of several clinical endurance tests of other muscle groups, including healthy subjects, has been reported by researchers. Demoulin et al. have carried out a critical appraisal of the literature about the Sorensen test (an isometric endurance test of the trunk extensor muscles) and reported ICC-values ranging from 0.73 to 0.99 in healthy individuals. Latimer et al. reported reliability indices of the Sorensen test in asymptomatic subjects (ICC, 0.83; SEM, 17.4 seconds) and average performance of the test was 132.6 seconds. In a study by Harris et al., the reliability of a neck flexor isometric endurance test was also tested; the authors found that ICC-values ranged from 0.67 to 0.91 and the SEM from 8.0 seconds to 15.3 seconds in healthy subjects (average performance of 38.9 +/- 26.4 seconds). Considering that the SEM can also be presented as a SEM % by dividing the SEM by the average values of the test and retest and by multiplying the result by one hundred, an indirect comparison with the other tests described in the literature is possible: the SEM% amounted to 22.5% for the hip abductors isometric endurance test versus, 21-39% for the neck flexor isometric endurance test and 13% for the Sorensen test. In summary, test-retest reliability of the isometric endurance test of hip abductor is similar to the reliability of the Sorensen test and the neck flexor endurance isometric endurance test, which are recommended for the examination of patients with low back pain and neck pain, respectively.

Studies assessing the reliability of dynamic endurance tests have also been reported in the literature. Sman et al. found excellent reliability of the heel rise test, a dynamic test used to assess calf muscle endurance (ICC, 0.97; SEM 2.4 repetitions; SEM%, 10.4%). In comparison, ICC, SEM and SEM% were 0.78, 21.2 repetitions and 24%, respectively, for the hip abductors dynamic endurance test. The ICC provides information about relative reliability, which refers to the ability of a measure to distinguish between people, but only limited information about measurement error. Chinn recommends that a measurement should have an intra-class correlation coefficient of at least 0.6 to be useful. The absolute reliability was then assessed by calculating the SEM and MDC, which provide the extent of measurement error. The SEM indicates the limit for the smallest change that explains a real modification or change in groups of subjects, while the MDC should be used for single subject. The MDC for the isometric endurance test and the dynamic endurance test were 54.9 seconds and 58.7 repetitions, respectively. The question of the acceptable level of reliability using the SEM is unanswered. It is difficult to know the clinical utility of the tests for therapists who want to evaluate endurance of hip abductor, taking into account the MDC, because few studies have compared endurance deficit between healthy and unhealthy subjects. Souza and Powers evaluated endurance of hip abductor, using isokinetic dynamometer, and observed that females with PFP performed 49% for less hip extensor endurance when compared with healthy controls. If the size of deficits is comparable for hip abductor, the tests proposed in the present study could be useful.

The secondary purpose of this study was to assess the relationship between performance on endurance tests and clinical characteristics of participants. Moderate correlation between both endurance tests and weak correlation between dynamic endurance test and strength was found. Strength and isometric endurance were not correlated. The weakness or the absence of correlation between strength and endurance suggest that both measures should not be used interchangeably and should be evaluated separately. The current findings were consistent with the results of previous studies, which showed weak or non-significant relationship between isometric strength and endurance tests. A possible explanation may be that muscle contractions elicited by endurance tests are equal to 40–52% of the maximal voluntary contractile force and induce specific muscle activation strategies. Finally it is interesting to note that no correlations were found between the physical activity levels of participants, height, body mass, lower limb length and results in both endurance tests, indicating that both clinical tests measure endurance regardless of participant characteristics.

Demoulin et al. assessed the reproducibility and the suitability of clinical assessments of trunk flexor and
extensor muscles. The authors aimed to determine, among other things, the most tolerable and reproducible extensor endurance tests for assessing patients with chronic low back pain. The Sorensen test was compared with the repetitive arch-up test, a dynamic endurance test of trunk extensor muscles. A significant correlation was found between performances of both tests but reproducibility of the dynamic test was lower than for the Sorensen test. The authors suggested that including only the Sorensen test in a test battery was enough for patients with low back pain. The design of the present study do not allow to determine if one of the two tests is more appropriate that the other. Reliability, ratings of perceived exertion and variability were comparable between both tests and moderate correlation between both endurance tests was found. More studies are needed to determine the most appropriate test in patients with lower extremity injuries and to compare the performance of those with injuries to those of healthy groups.

Researchers have suggested that ratings of perceived exertion can provide information regarding the intensity of resistance exercise and about the degree of muscular activation.38,39 Dedering et al40 evaluated the correlation between objective measurements of spinal muscle fatigue, measured with surface electromyography (EMG) and endurance time, and the subject's own assessment of fatigue rated on a Borg CR-10 scale. Authors reported significant correlation between the Borg scale, EMG and endurance time suggesting a close relationship between subjective and objective assessment of muscle fatigue. This relationship should encourage clinicians and researchers to assess ratings of perceived exertion during endurance testing. Demoulin et al13 add that the use of the Borg RPE during endurance testing might be a way to reflect muscle fatigability while limiting the role for individual factors such as motivation. In this study, the minimum and maximum rates of perceived exertion ranged from 13 to 19 (from somewhat hard to very hard) to the Borg RPE, suggesting that the muscular performances may have been underestimated in some results in both sessions. There were no significant differences in Borg RPE between isometric and dynamic endurance tests during the first and the second session. The rates of perceived exertion were significantly higher at the second session for the isometric endurance only but the mean difference was too small to be clinically relevant. Further research using surface electromyography is needed to evaluate the activity and the contribution of hip abductors during both tests and to assess the correlation with ratings of perceived exertion.

No learning effect was found in this study. This can probably be explained by the fact that the data collection sessions were separated by seven days.

Several limitations of this study should be considered. First, the subjects tested in the present study are healthy females, aged 18-30 years. Although good test-retest reliability was found, the results should therefore not be generalized to males, unhealthy females or females from other age group. Second, because the aim of the study was to develop simple non-instrumented clinical tests that could easily be used in the clinic, we did not use standardized equipment for the endurance tests, such as handheld dynamometers, which could significantly improve reliability. Third, although correlations between both endurance tests and strength and Borg RPE were calculated, future studies are needed to evaluate the validity of the tests, using surface electromyography. Finally, further research should determine the clinical importance of the tests, both in healthy and unhealthy people and determine if one of the two tests is more effective that the other.

**CONCLUSION**

The results of the present study indicate that good test-retest reliability exists for two non-instrumented clinical tests of hip abductor endurance in healthy females. Future studies are needed to assess validity and clinical importance of both tests.

**REFERENCES**

3. Cowan SM, Crossley KM, Bennell KL. Altered hip and trunk muscle function in individuals with


29. Delitto A, George SZ, Van Dillen LR, et al. Orthopaedic Section of the American Physical


ABSTRACT

Background: Different limb training demands and limb preference may determine anthropometric and muscle force inter-limb asymmetries in Rhythmic Gymnastics (RG) athletes.

Purpose: The purpose of this study was to evaluate the influence of lateral preference of the lower extremity on anthropometric, range of motion, and isokinetic torque measurements of RG athletes.

Study Design: Cross sectional study

Methods: Lower limb anthropometric measurements (girth, estimated anatomical cross-sectional area), hip, knee and ankle range of motion, flexor and extensor isokinetic torques (angular velocities = 60, 180, e 240°·s⁻¹) and bilateral asymmetry index were evaluated in 11 international level Rhythmic Gymnastics athletes (17.9 ± 4.0 years of age; 9.1 ± 5.1 years of experience; 26.8 ± 6.0 weekly training hours).

Results: The preferred limb showed larger thigh girth and anatomical cross-sectional area, higher ankle dorsiflexor range of motion, higher hip flexor torque at 60°·s⁻¹ and higher plantarflexor torque at 180°·s⁻¹ compared to the non-preferred limb.

Conclusions: The observed differences seem to be strictly related to lateral preference and rhythmic gymnastics training.

Levels of Evidence: 3

Keywords: Ankle joint; hip joint; isokinetic dynamometer; knee joint; muscle strength.
INTRODUCTION
Aesthetic movements and flexibility are distinct characteristics of Rhythmic Gymnastics (RG). This unique sport encompasses both artistic and competitive characteristics. At the artistic level, talent and creativity are evident through both motor control and movement harmony. With regard to the competitive aspect, this female sport requires a high degree of physical, technical and psychological skills aimed at obtaining a perfect execution of the corporal movements with the different types of equipment (ball, ribbon, hoop, clubs, rope).1

In order to achieve the necessary preparation for a good performance, high-performance gymnasts train on average 25-30 weekly hours and, in some cases, 40 weekly hours due to the high technical demands of this sport modality.2,3 These high technical demands, in turn, increase the athletes' physical demands. According to Douda et al,4 the prolonged training time required of these athletes might induce structural changes in the gymnasts' motion system. These authors demonstrated that juvenile and adult RG athletes with the highest training time presented with asymmetries of lower limb girth due to the prevalence of exercises performed on the preferred side. This preference for one side might cause bilateral differences in torque output, similar to those that have been shown in athletes of other sports such as soccer, where although the non-preferred side also participates in the sports activities the use of the preferred side is prioritized. The use of preferred side is not exclusive in the execution of the majority of the technical gestures5,6 and bilateral torque asymmetry is accepted as being normal up to a 10% level.6

Based on the training volume, the presence of lateral preference and its influence on the structural and functional adaptation of RG athletes, it was hypothesized that bilateral differences would exist in the anthropometric, range of motion, and torque measurements, favoring the preferred side over the non-preferred side. Very few studies have examined this issue and there is a lack of studies examining sports performance in RG. Most studies have examined sexual maturation, eating disorders and corporal image distortion.7,8 Therefore, the purpose of this study was to evaluate the influence of lateral preference of the lower limb on anthropometric, range of motion, and isokinetic torque measurements of RG athletes.

METHODS
This study was approved by the Federal University of Santa Catarina Human Ethics in Research Committee (370.108). Eleven RG international level athletes from a Brazilian Sports Club signed an informed consent form agreeing to participate in the study. Informed consent of athletes under the age of 18 years old was given by their parents. Athletes were 17.9 (± 4.0) years old, and were 1.63 (± 0.07) meters tall, had body mass of 51.2 (± 7.2) kg, a body mass index of 19.3 (± 1.8) kg/m² and had been practicing RG for 9.1 (± 5.1) years. Athletes practiced for an average of 26.8 (± 6.0) weekly training hours, and the athletes included South American gold medalists, Pan-American gold medalists, and one Olympic finalist.

Lateral preference was determined by the Waterloo - WFQ-R questionnaire.9 Five other questions used by Goulart,10 related to specific RG activities, were incorporated in the evaluation. Before the beginning of any physical effort, mid-thigh girth, leg girth (calf maximum girth), skinfold (front thigh and medial calf skinfold site), femur biepicondyle diameter and passive range of motion for hip flexion, hip extension, knee flexion, knee extension, ankle plantar flexion and ankle dorsiflexion were determined bilaterally.

The thigh anthropometric measurements were used to estimate the thigh anatomical cross-sectional area (ACSA) using equation 1.11

\[
\text{ACSA} = 0.649 \times (\text{TC}/\pi - \text{TSF})^2 - (0.3 \times \text{FBD})^2
\]

where ACSA represents the thigh cross-sectional area, TC the thigh circumference, TSF the thigh skinfold and FBD the femoral biepicondyle diameter.

Joint range of motion was determined according to the movement patterns described on the Flexitest (Dr. Claudio Gil Soares de Araujo, São Paulo, Brazil). The Flexitest is a method for measurement and evaluation of the passive mobility of 20 joint movements in which each movement is quantified in an ordinal scale from 0 to 4. The method allows the examiner to obtain a global flexibility index and to perform
specific and isolated analysis of different movements and joints. In the present study, the Flexitest isolated analysis was used by passively moving the hip and knee into flexion and extension and the ankle into plantar flexion and dorsiflexion. These movement patterns were recorded with a digital camera, and the joint angles were obtained from the video analysis of these movements. Anatomical markers (12 mm of diameter), a 12.1 megapixel digital camera (Sony Cyber-shot DSC - W310, Tokyo, Japan) and a leveled tripod (Vivitar – VPT 1200, Sakar International, Inc., New Jersey, USA) were used to determine angular measurements by photogrammetry method.

For the range of motion measurements, the anatomical position was considered as zero degrees for all joints. The anatomical markers were placed at the bony protuberances of each joint and were replaced whenever necessary at each of the positions to minimize the changes caused by skin movement. For hip flexion and extension the femur greater trochanter was regarded as the central joint axis of motion. Angles were obtained from straight lines formed between (1) the vertex and the femoral condyle of the tested leg, which was conducted to carry out the movement, and (2) to the ankle medial malleolus of the opposite leg, which remained in contact with the ground. For knee flexion and extension the knee femoral condyle was regarded as the center of motion, and the angles were obtained between the lines (1) from the lateral malleolus to the femoral condyle and (2) the femur greater trochanter to the femoral condyle of the tested lower limb. For ankle dorsi and plantar flexion, the lateral malleolus was considered the center of motion and the angles were obtained between the lines (1) from the fifth toe (tip) to the lateral malleolus and from (2) the lateral tibial condyle of the tested lower limb. Kinovea 0.8.15 (Joan Charmant & Contrib. Bordeaux, France) software was used to determine angular joint measurements.

Peak torque values were obtained for the hip (flexion-extension), knee (flexion-extension) and ankle (plantar-dorsiflexion) joints using an isokinetic dynamometer (Biodex System 4 Pro, Biodex Medical Systems, New York, USA). A five-minute warmup was executed on a cycle-ergometer (Ergocycle 167 Cardio, Ergo-fit GmbH & Co. KG, Pirmasens, Germany), with 25 W of load before the tests. After the warmup period, the athletes executed a familiarization session with the dynamometer, consisting of five submaximal voluntary concentric contractions at the angular velocities of 60°·s⁻¹ and 240°·s⁻¹.

The torque testing protocol consisted of five maximal voluntary concentric contractions at the angular velocities of 60°·s⁻¹, 180°·s⁻¹ and 240°·s⁻¹ with a random order between velocities and between joints. A 90 second rest interval was observed between angular velocities to avoid possible fatigue effects. For all joints, at the end of the test, the first angular velocity performed was repeated in order to assess for fatigue. Paired t-tests were used to evaluate differences between the first maximal voluntary contraction and its repetition and no differences were found. All subjects received verbal encouragement in order to obtain their maximal performance on each test.

The angular velocities of 60°·s⁻¹, 180°·s⁻¹ and 240°·s⁻¹ were chosen for being a slow, an intermediate, and a fast angular velocity, respectively. The 60°·s⁻¹ angular velocity has been widely used in different studies to determine maximal peak torque and work, whereas angular velocities of 180°·s⁻¹ and higher have been used to determine muscle power, with 180°·s⁻¹ being the angular velocity where peak power was observed in women, during knee extension.

Absolute torque values were determined by normalizing to the body mass for each athlete in order to minimize possible anthropometric effects on maximal torque production. A 10% bilateral difference was established as the maximum value for a normal difference (i.e. no asymmetry) between the preferred and non-preferred sides. The asymmetry index (AI) was calculated using equation 2:

$$AI\% = \left( \frac{P - NP}{P} \right) \times 100$$  

where AI represents the asymmetry index, P is the preferred side and NP the non-preferred side.

**Statistical Methods**

Statistical analysis was performed using SPSS 15.0 for Windows Software. Paired t-tests were used to evaluate between preferred and non-preferred differences in anthropometric and torque values. The
Pearson correlation test was used to evaluate the relation between torque and the characterization variables (age, height, weight, years of training, hours of training per week, pubertal status) and between torque and the anthropometric variables (girth values, cross-sectional area and range of motion). For variables that showed high correlation values (above 0.7) a simple linear regression was used to evaluate the functional relation of variables on torque. A level of significance of p < 0.05 was adopted for all tests.

RESULTS
The Waterloo Questionnaire revealed the right lower limb as the preferred limb for all athletes. While the right limb was used for manipulation tasks, the left (non-preferred) side was used by the majority for weight bearing and balance.

The anthropometric evaluation revealed higher thigh cross-sectional area and girth for the preferred limb compared to the non-preferred limb (Table 1).

There were no differences between limbs for joint range of motion at the hip, knee and ankle, except for dorsiflexion that was higher at the preferred side compared to the non-preferred side.

There was no difference for the normalized torque between the preferred and the non-preferred limbs, except for the hip flexion at 60°·s⁻¹ and for the plantarflexion at 180°·s⁻¹ that were higher in the preferred compared to the non-preferred limb (Table 2).

No fatigue was observed during the protocol, as no difference was observed between the first and the last repetitions at the same angular velocity (results not shown).

The asymmetry index also revealed no difference between the preferred and non-preferred limbs for the different angular velocities and joint motions. Asymmetries were observed only for ankle plantarflexion at 180°·s⁻¹ and for ankle dorsiflexion at 240°·s⁻¹ in favor of the preferred limb (Table 3).

| TABLE 1. Anthropometric measurements and joint range of motion for the preferred (PREF) and non-preferred (NPREF) sides of the Rhythmic Gymnastics athletes. Values are expressed as mean and SD. |
|---------------------------------------------|----------------|----------------|
| PARAMETERS                          | SEGMENT      | PREF          | NPREF         |
| Girth (cm)                           | Thigh        | 45.2 ± 3.0*   | 44.5 ± 2.9    |
|                                    | Leg          | 33.2 ± 2.3    | 33.4 ± 2.1    |
| Skin fold (cm)                      | Thigh        | 1.41 ± 0.5    | 1.40 ± 0.6    |
|                                    | Leg          | 1.0 ± 0.5     | 1.0 ± 0.4     |
| Bone Diameter (cm)                  | Biepicondilar femur | 7.1 ± 0.4    | 7.1 ± 0.4     |
| Cross-sectional Area (cm²)          | Thigh        | 106.8 ± 12.4* | 102.7 ± 11.8  |
| Flexion (degrees)                   | Hip          | 141.8 ± 9.5   | 138.3 ± 5.4   |
| Extension (degrees)                 |              | 44.0 ± 17.2   | 44.8 ± 19.0   |
| Plantarflexion (degrees)            | Knee         | 151.8 ± 7.0   | 151.3 ± 7.4   |
| Dorsiflexion (degrees)              | Ankle        | -8.1 ± 5.2    | -8.4 ± 5.1    |
| PLANTI                               |              | 86.9 ± 7.1    | 88.4 ± 7.9    |
| DORSI                               |              | 25.9 ± 7.4*   | 21.7 ± 8.8    |

CSA = Cross-Sectional Area; ROM = Range of Motion; FLX = Flexion; EXT = Extension; PLANTI = Plantarflexion; DORSI = Dorsiflexion.
* indicates (p<0.05) with the preferred > non-preferred side.
No strong correlations were observed between torque and the characterization variables (age, height, weight, years of training, hours of training per week and pubertal status). Similarly, no strong correlations were observed between hip torque values and range of motion, cross-sectional area and other anthropometric variables. Strong, statistically significant correlations were observed for knee joint range of motion during flexion and knee extensor torque at 60°·s⁻¹ for both limbs (preferred: p=0.011; r=0.728; non-preferred: p=0.014; r=0.711) and for knee extensor torque at 240°·s⁻¹ in the preferred limb (p=0.007; r=0.759).

The linear regression test showed a determination coefficient (R²) of 0.53 between knee extensor torque at 60°·s⁻¹ of the preferred limb and of 0.51 for the non-preferred limb, which suggests that, on both sides, more than 50% of the torque values were influenced by knee flexion range of motion (preferred=53%; non preferred=51%). For knee extensor torque at 240°·s⁻¹ on the preferred side the determination coefficient was 0.58, with 58% of knee extensor torque related to the joint flexion range of motion.

At the ankle joint, correlation was observed only in the non-preferred limb between dorsiflexor torque

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### Table 2. Peak torque normalized to body mass (mean ± SD) at the different angular velocities for the different joints of the preferred and non-preferred limb.

<table>
<thead>
<tr>
<th>ANG VEL</th>
<th>Movement</th>
<th>HIP</th>
<th>KNEE</th>
<th>ANKLE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PREF</td>
<td>NPREF</td>
<td>PREF</td>
<td>NPREF</td>
</tr>
<tr>
<td>60°·s⁻¹</td>
<td>FLX/PLANTI</td>
<td>1.3 ± 0.3*</td>
<td>1.2 ± 0.4</td>
<td>1.4 ± 0.3</td>
</tr>
<tr>
<td></td>
<td>EXT/DORSI</td>
<td>3.3 ± 0.5</td>
<td>3.0 ± 0.4</td>
<td>2.0 ± 0.4</td>
</tr>
<tr>
<td>180°·s⁻¹</td>
<td>FLX/PLANTI</td>
<td>0.9 ± 0.4</td>
<td>0.9 ± 0.4</td>
<td>1.2 ± 0.3</td>
</tr>
<tr>
<td></td>
<td>EXT/DORSI</td>
<td>2.6 ± 0.4</td>
<td>2.5 ± 0.3</td>
<td>1.4 ± 0.2</td>
</tr>
<tr>
<td>240°·s⁻¹</td>
<td>FLX/PLANTI</td>
<td>0.8 ± 0.4</td>
<td>0.8 ± 0.4</td>
<td>1.2 ± 0.2</td>
</tr>
<tr>
<td></td>
<td>EXT/DORSI</td>
<td>2.6 ± 0.5</td>
<td>2.4 ± 0.5</td>
<td>1.3 ± 0.2</td>
</tr>
</tbody>
</table>

* = p<0.05; ANG VEL = Angular Velocity; PREF = Preferred limb; NPREF = Non-Preferred limb; FLX = Flexion; EXT = Extension; PLANTI = Plantarflexion; DORSI = Dorsiflexion.

### Table 3. Asymmetry index (mean ± SD) for the hip, knee and ankle joints at the different angular velocities and joint motions.

<table>
<thead>
<tr>
<th>HIP</th>
<th>KNEE</th>
<th>ANKLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLX</td>
<td>EXT</td>
<td>FLX</td>
</tr>
<tr>
<td>(%)</td>
<td>(%)</td>
<td>(%)</td>
</tr>
<tr>
<td>60°·s⁻¹</td>
<td>9.8 ± 12.0</td>
<td>8.5 ± 15.4</td>
</tr>
<tr>
<td>180°·s⁻¹</td>
<td>3.8 ± 24.4</td>
<td>3.1 ± 12.7</td>
</tr>
<tr>
<td>240°·s⁻¹</td>
<td>-1.8 ± 36.3</td>
<td>6.3 ± 16.3</td>
</tr>
</tbody>
</table>

* indicates p<0.05. Positive values represent asymmetries in favor of the preferred limb, whereas negative values for the non-preferred limb. FLX = Flexion; EXT = Extension; PLANTI = Plantarflexion; DORSI = Dorsiflexion.
values at 240°·s⁻¹ and the girth values (p = 0.002; r = 0.831). The linear regression test revealed a dete-
mination coefficient of 0.69, indicating that 69% of the torque values were influenced by the leg girth. For all correlation and regression cases the signifi-
cance level was less than p = 0.05.

**DISCUSSION**

Douda, Laparidis and Tokmakidis⁵ have shown that bilateral asymmetry was present for lower limb girth in both the juvenile and adult gymnastics categories, and attributed this asymmetry to the prevalence of exercises performed using the preferred side during training. Based on this idea, the first hypothesis was that the higher use of the preferred limb compared to the non-preferred limb during RG training would determine an increase in bilateral asymmetry both for the anthropometric parameters and for the func-
tional parameters (i.e. joint range of motion, torque). The higher thigh girth and cross-sectional area of the preferred side compared to the non-preferred side partially supported this hypothesis. However, these two higher anatomical measurements of the preferred limb were not accompanied by a higher capacity to generate torque at the hip, knee and ankle joints, where only a few asymmetries were observed. Characterization variables (age, height, weight, years of training, hours of training per week and pubertal status) also showed little evidence of correlation between these variables and functional parameters (joint range of motion and torque). The absence of a relationship between these variables suggests that they do not directly contribute to the observed differences.

One of the characteristics of RG is that athletes need to perform aesthetic movements at high angular velocities. In order to accomplish this, athletes try to maintain a slim body shape, and increase joint angular velocities by increasing muscle contraction velocity. Muscle contraction velocity can be increased by increasing the percentage of fast-twitch fibers and/or by increasing the fascicle length. The authors believe that these athletes increase contraction velocity through the latter, as most of the RG routines involve a large aerobic component and muscles apparently do not show a large increase in cross-sectional area, which is a characteristic of athletes involved in power-based sports. Indeed, RG estimated thigh cross-sectional area and segment girth presented very low values compared to athletes from other sports and to non-athletes.¹⁷ Gómez-Campos et al¹⁸ suggest that RG athletes show reduced muscle areas due to their very intense training regimen. Goulart¹² found an increase in fascicle length of RG athletes compared to non-athletes with similar anthropometric characteristics (height and weight). This supports the idea that RG athletes have long muscles, which helps to increase angular velocity at the joints due to the larger muscle excursion.

The low values observed for thigh girth (preferred: 45.2 cm; non-preferred: 44.5 cm) and thigh CSA (preferred: 106.8 cm²; non-preferred: 102.7 cm²) are likely related to the intense training routines and to the athletes’ preferred physical presentation in aesthetic sports such as RG, where a slim body favorably displays the specific technical movements.¹⁷,¹⁸ These small dimensions in a slim body are apparently accompanied by an increase in muscle fascicle length, but not in muscle cross-sectional area.¹⁰ In a study of athletes involved in classical Ballet, which is highly related to the movements and performance of RG, Golomer et al¹⁹ found no differences in muscle mass and maximal jump height between the preferred and non preferred limbs in professional ballet dancers (mean age = 17.5). The authors suggested that athletes with less developed muscula-
ture improved their performances by increasing the duration of the push-off force rather than the magni-
tude of the peak force.

The estimated cross-sectional area in the athletes in the current study was higher in the preferred com-
pared to the non-preferred limb. The mean cross-
sectional difference between limbs (4.08 cm²) was not related to any increase in strength, as there were no bilateral differences in knee flexor and/or exten-
sor torques. The results of the correlation analysis did not show results indicating the condition of higher torque values to be related to higher muscular areas. Jones et al²⁰ suggested that differences in force could not be caused solely by increases in muscle cross-sectional area. Another neuromuscular characteristic, such as electrical activation, not evaluated in the present study, may have influenced the present results.
Similar disagreement was observed between the lower leg girth and ankle plantarflexor torque, as no bilateral differences were observed between the preferred and non-preferred limbs girth and the plantarflexor torque was higher on the preferred limb. However, there was a correlation between the non-preferred limb girth and the dorsiflexor torque values at $240^\circ \cdot \text{s}^{-1}$, with the linear regression model showing an $R^2$ of 0.69, which suggests that 69% of the dorsiflexor torque at $240^\circ \cdot \text{s}^{-1}$ was influenced by the variation in leg girth. It is speculated that this relation between the leg girth and dorsiflexors torque values at $240^\circ \cdot \text{s}^{-1}$ of the non-preferred limb results from the systematic cocontraction of this musculature in order to increase ankle and foot stability during powerful movements.\textsuperscript{21,22} The tibialis anterior muscle has the important role of stabilizing foot inversion-eversion during jumps and during the point and demi point (half-kiptoe/forefoot) movements.

Another factor that might be related to the present findings is the fact that in the majority of the jumps in RG, such as the split leap, the non-preferred leg acts as the propulsion leg. One of the strategies that benefits performance of these jumps is the countermovement produced by the ankle dorsiflexion and consequent solicitation of the dorsiflexor muscles.\textsuperscript{23} The gymnast will leap with her right leg forward (PREF) and use her left leg (NPREF) as the propulsion leg. This propulsion requires significant, rapid, kinetic force generation from the left leg (NPREF) to propel the gymnast's body upwards and forwards.

Although muscle length was not tested, greater range of motion may be associated with greater muscle length. Muscles with longer fascicles affect force production due to the larger number of serial sarcomeres and larger muscle excursion.\textsuperscript{24,25} The larger dorsiflexor range of motion on the preferred limb, that may associated with larger sarcomere numbers, could lead to a greater shortening velocity\textsuperscript{10,26,27} that might explain the differences found during the isokinetic tests at the angular velocity of $180^\circ \cdot \text{s}^{-1}$, where the preferred limb produced higher torque values compared to the non-preferred side during plantarflexion.

Although the similarity in the asymmetry index (9.8%) for hip flexion is close to 10% and suggests that there is no asymmetry between limbs, the normalized hip flexor peak torque values were higher in the preferred compared to the non-preferred limb at $60^\circ \cdot \text{s}^{-1}$, which suggests that the 10% limit for the asymmetry index is not necessarily a fixed value, and even lower than 10% values may be related to some kind of asymmetry. This apparent torque asymmetry seems to be related to the need for the non-preferred limb to act as the support limb and stabilize hip motion, being less exposed to stimuli variations during dynamic contractions.

Results found for the lateral preference test and those in the literature suggest that preference is intimately related to task performance.\textsuperscript{28,29} During many sports practices the non-preferred limb, with respect to the hip-trunk muscle contractions, works naturally in postural stabilization, whereas the preferred limb acts more in the development of forces for the dynamic act of technical gestures, thereby diminishing its role in balance control.\textsuperscript{30}

The working versus supporting leg is dependent on the movement being executed and also driven by split preference and rotational preference, which are correlated to, but not identical to footedness. The gymnast will use her left leg (NPREF) for support when the right leg (PREF) needs to be to the side or forwards to perform an element that requires it. But she will use her right leg (NPREF) for support when the left leg (NPREF) needs to be behind her. The demands on the supporting leg, whether preferred or non-preferred, are light co-contraction of hip, knee, and ankle musculature to maintain position. But even in situations in which the non-preferred leg is the supporting leg, the muscular demands on the leg are quite different than when the preferred leg acts as the supporting leg. Agreeing with this supposition, Golomer et al\textsuperscript{31} found no difference in lateral preference and the choice of the supporting foot in untrained girls (mean age = 9.5 years) and professional dance students (mean age = 11.9). No relationship between foot most often used as support for turns and balance and preferred foot was found in either group. Golomer et al\textsuperscript{31} showed that the choice of a supporting leg for turning might exploit some biomechanical properties that facilitate the movement, so the choice is not linked to laterality but to the movement type.
Despite the fact that Waterloo Questionnaire revealed the right lower limb as the preferred limb, the authors believe that, for RG, the lateral preference designation is probably not appropriate, since this changes depends on the task performed, especially in three situations: leaps, balances, and turns. This characteristic makes identifying leg or side preference somewhat difficult.32

Another factor that should be considered is task difficulty and time spent on training the tasks. As turns and leaps are technically more difficult to perform, these skills will be practiced more than balance-related tasks during training sessions. Turning in single-leg stance requires a great amount of muscle co-contraction at the hip, knee, and ankle in order to maintain body position and is considerably more difficult than balancing statically. Time spent on the supporting leg is considerably greater during turns than during leaps or balance tasks. During a given choreographed routine the gymnast will also execute more turns and leaps than balance-related tasks.

It is important to remember that RG is strongly based on classical ballet technique, and many ballet dancers claim to be able to sense differences between their legs in terms of strength, flexibility, and functionality. However, Mertz and Docherty33 showed that dancers’ opinions of their leg characteristics did not correlate with their actual ability. RG athletes that have a right lower limb preference also use the left lower limb for support, which plays an important role in several elements of RG. Therefore, RG athletes may not necessarily display higher force, flexibility or other qualities in one limb due to these different roles during sports practice.

Wu et al.34 examined high performance RG athletes (mean age = 18 years) and found that the knee flexors and extensors of the left (non-preferred) limb were stronger than those of the right (preferred) limb at low and medium angular velocities. Different results were found by Lanshammar and Ribom,35 who suggested that, in any sports practice, a considerable asymmetry exists for the force relation between hamstrings and quadriceps in young adult females, with the hamstrings being weaker on the preferred limb and the quadriceps weaker on the non-preferred limb. The authors took into account the sports practice and not the specific physical training of the activity. Therefore, it appears that RG training may have promoted strength equilibrium between the preferred and non-preferred limbs of the studied athletes in the current research.

According to results of the regression test, increased knee flexor range of motion positively influenced the torque results. These findings suggest that longer muscles are related to the torque produced at higher angular velocities, as apparently more that 50% of the knee extensor torque at 240°·s⁻¹ was influenced by the total joint range of motion.

Although a large part of the observed asymmetries are related to sports practice, the specific exercises and gestures that are performed during RG in a combination of compensatory movements were minimized by the way the athlete was fixed to the isokinetic dynamometer. It is possible that these athletes depend on a series of multi-joint compensations for the execution of specific movements, and single joint torque measurements do not accurately represent their sport specific strength. These compensations might affect the neuromuscular efficiency throughout the whole kinetic chain and could be caused by muscle imbalances.36

The limited sample size resulted in large variance in the data and a consequent reduction in statistical power. Although RG training has common elements among the different teams, some characteristics seem difficult to compare due to the specificity of training routines. This makes comparisons between teams and individuals difficult and does not allow for extrapolation of the observed results. Another fact that should be considered in future studies is the inclusion of athletes with left lower limb preference in order to determine whether inter-limb differences are indeed the result of preference, but, of note, the authors were unable to find a left lower limb preference RG athlete available to participate in the study. Nevertheless, the results of the present study show evidence of few lower limb asymmetries in high performance RG athletes of a Brazilian team, and might serve as a reference point for future comparisons with other high performance teams.
CONCLUSIONS
The results of the current study indicate that lateral preference and RG training had an effect on the thigh girth and torque production in some muscles, while having no effect on the lower leg girth. The preferred limb showed larger thigh girth and anatomical cross-sectional area, higher ankle dorsiflexor range of motion, higher hip flexor torque at 60°·s⁻¹ and higher plantarflexor torque at 180°·s⁻¹ compared to the non-preferred limb. Further research that controls for other neuromuscular and structural variables will allow for better understanding of the reasons for the differences found in this research.

REFERENCES


ABSTRACT

Background: Successful rowing participation requires leg power, back strength, cardiovascular endurance, and balance. SportsMetrics™ training improves lower limb alignment, hamstring peak torque, and vertical jump height; however, this training has not been used in athletes who row and may have different outcomes based on experience level.

Purpose/Hypotheses: The purpose of this study was to compare the effects of a six-week SportsMetrics™ training program on vertical jump height (VJH), Y Balance Test (YBT), and Drop Jump Screening Test (DJST) between novice and varsity high school rowers. The authors hypothesized that following Sportsmetrics™ training; novice rowers would not be different from varsity rowers in VJH and YBT. All rowers will have improved normalized knee joint separation distance in DJST following training.

Study Design: Cross sectional.

Methods: 52 (31 varsity: 16.4±0.8 years, 62.0±9.0 kg, 1.7±0.1m [mean ± SD], 21 novice: 14.5±0.7 years, 58.6±5.4 kg, 1.7±0.1m [mean ± SD]) high school rowers completed the Sportsmetrics™ training and participated in the study. Varsity rowers were defined as a returner; any new rower was considered novice. Differences in age, weight, and height were examined using independent t-tests. Repeated measures ANOVA assessed pre- to post-training differences between groups in VJH, YBT composite score (CS) and reach asymmetry (ASY), and normalized knee joint separation distance (DJST).

Results: VJH significantly improved for all athletes from pre- to post-training (mean ± SD: 29.0±7.0 vs. 31.9±5.1cm; p=0.001) and normalized knee separation distance significantly increased for all athletes pre to post training at the pre-landing (mean ± SD: 58.2±12.5 vs. 68.7±7.4%; p<0.001), landing (mean ± SD: 49.4±18.2 vs. 66.3±14.2%; p<0.001), and take off (mean ± SD: 47.8±18.4 vs. 64.8±13.8%; p<0.001) phases of the jump; there was no effect for group. There was no difference in varsity and novice pre to post training in YBT CS (99.3±7.5 vs. 99.7±7.1%; p=0.53) or ANT ASY (mean ± SD: 3.4±4.6 vs. 2.7±2.3; p=0.36).

Conclusions: SportsMetrics™ training improved VJH regardless of experience level; which suggests that rowers may have more leg power following training. Normalized knee joint separation distance increased to greater than 60% of hip joint separation distance following training, indicating that training reduced serious knee injury risk.

Level of Evidence: Level 3

Keywords: Drop Jump Screening Test, Rowing, Sportsmetrics™, Vertical Jump Height, Y-Balance Test

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INTRODUCTION
In order to be successful in the sport of rowing it is vital that athletes have substantial leg power,1 back strength,2 cardiovascular endurance,3 and balance.4 Not only do these characteristics dictate the success of the rower, but they often differ based on level of rowing participation, (varsity or novice) and years of sport experience. Varsity rowers have greater vertical jump heights compared to rowers with zero years of rowing experience; additionally, varsity rowers and rowers with three years of rowing experience have faster two kilometer row times on a rowing ergometer compared to rowers with zero years of rowing experience.5 Also, non-elite rowers with greater leg strength generated greater leg extension power compared to non-elite rowers with lower strength.6 The demonstrated differences between rowers of different levels of experience, as well as compared to control participants, suggests that training experience impacts leg power and rowing performance. The authors of a recent review suggest that explosive power exercises may be beneficial during the competitive phase of training for rowing athletes to achieve peak sport performance.7 One way to address explosive power is through plyometric training, which includes exercises of varying intensities that focus on eccentric contractions immediately followed by explosive concentric contractions. Plyometric training utilizes the stretch shortening principle, with a short amortization phase, to gain explosive power.8 There are a variety of plyometric exercises that target both upper and lower extremity power, one such pre-packaged plyometric exercise regimen is the Sportsmetrics™ training program.

Sportsmetrics™ is a proprietary training program consisting of progressive plyometric exercise that has been documented to improve vertical jump height,9 agility and dynamic balance,10 and landing kinematics.11 Vertical jump height9 and single leg triple crossover hop,10 both measures of leg power, have been documented to increase by at least 1cm and 36cm, respectively, after six weeks of plyometric training in athletes in a variety of sports. Knee joint separation distance, which has been suggested to represent dynamic knee valgus, is measured using the Drop Jump Screening Test.11 Knee joint separation distance also improves following Sportsmetrics™ training with research suggesting that athletes with normalized knee joint separation distance of greater than 60% of hip joint separation distance are at a decreased risk for ACL injury.11 This may suggest that theoretically, following Sportsmetrics™ training, core stability may be improved as core muscle weakness and decreased endurance may contribute to dynamic knee valgus during repetitive jumping.12

Dynamic balance has been suggested as a measure of core function13 and core stability, which is important for injury prevention.14 The Y-Balance Test (YBT) is one way to measure dynamic balance. The YBT has two outcomes commonly reported after its administration. One is a composite score that is created by summing the maximum reach distances and normalizing to the individuals' leg length. The second is a measure of reach asymmetry, which is the absolute difference in the maximum right to left reach distance for each of the three reach directions, anterior, posteromedial, and posterolateral. In one study, YBT anterior reach asymmetry was associated with an increased noncontact and overuse injury risk across a diverse Division I sample of collegiate athletes15 and reduced composite score has been associated with noncontact injuries in collegiate football.16 In female high school17 athletes both increased anterior reach asymmetry and reduced composite score were associated with noncontact injury. However, the composite score associated with an increased risk of injury was different between these two participant samples. Further, research suggests that exercises that enhance core function improve dynamic balance performance;13 however, the effect that Sportsmetrics™ training may have on dynamic balance has yet to be established.

Therefore, the purpose of this study was to compare the effects of a six-week SportsMetrics™ training program on vertical jump height (VJH), Y Balance Test (YBT), and Drop Jump Screening Test (DJST) between novice and varsity high school rowers. The first hypothesis was that following Sportsmetrics™ training, novice rowers would not be different from varsity rowers in VJH and YBT (composite score and anterior reach asymmetry). The second hypothesis was that all rowers would have improved normalized knee joint separation distance in DJST following training.

METHODS
Study Design
This study was a cross sectional study with the independent variable being level of high school rowing
(varsity – returning rower; novice – new rower) and the dependent variables of vertical jump height (VJH), Y Balance Test Composite Score (YBT CS), Y Balance Test Anterior Reach Asymmetry (YBT ANT ASY), and normalized knee joint separation distance during the pre-landing, landing, and take off phase of the Drop Jump Screening Test (DJST).

Participants
All participants were female varsity (n = 31) or novice (n = 21) rowers from a single high school rowing team who completed a Sportsmetrics™ training program under the direction of a physical therapist certified in Sportsmetrics™ as part of their normal training program during the pre-season. As a result this research was classified as Exempt Research by the institutional review boards at both Daemen College and Catholic Health System. Any rower who was not in attendance for more than two training sessions was removed from the analysis of the data. Fifty-eight rowers started the Sportmetrics™ training program; however, seven were not included in data analysis due to not completing the training program or quitting the team.

Sportsmetrics™ Training Program
A general Sportsmetrics™ training program (Table 1) was performed two times per week for six weeks. Prior to each training session participants performed the suggested dynamic warm consisting of the following exercises: heel/toe walk, straight leg walk, hand walk (walking out on hands while keeping feet planted on ground), forward lunge, backward lunge, leg cradle walk (walking while alternating picking up one leg with hip flexion and external rotation), dog and bush walk (walking while alternating legs in hip flexion, then internal rotation, and hip extension). All training sessions took place on a basketball court.

Vertical Jump Height
Vertical Jump Height (VJH) was performed using a countermovement jump. A tape measure was fixed to the wall. Prior to performance of VJH the participant stood against the wall and extended their arm up as far as possible above their head. This was used as the standing height. Participants were given a small piece of tape to place on the wall as close to the measurement tape as possible during the VJH performance to mark the maximum height at which they jumped. VJH was then determined by taking the difference between the maximum height at which they jumped and the standing height. All participants completed three VJHs and the maximum of the three was used for comparison.

Y Balance Test
The Y Balance Test (YBT) was administered by an individual certified in YBT administration. Prior to performing the YBT all participants watched a video as this has been suggested to be helpful with the learning curve associated with test performance. All participants were given four to six practice trials in each anterior (ANT), posteromedial (PM), and posterolateral (PL) reach directions as this has also been demonstrated to allow for learning to plateau. After the practice trials leg length was measured from the ASIS to the distal tip of the medial malleolus on the right limb. Participants then maintained single leg balance on the right and left lower extremity while the contralateral limb reached in the ANT, PM, and PL directions (Figure 1). Three successful reaches were performed for each reach direction; the maximum reach distance in each direction was used for data analysis. Anterior Reach Asymmetry (ANT ASY) was calculated by the absolute difference between right and left extremities reach distance in ANT direction and expressed in centimeters. YBT CS was determined by summing the average of the maximum right and left reach distances in each direction, dividing by three times leg length, and multiplying by 100 to obtain a percentage.

\[
\text{ANT ASY} = \left| \text{MAX RANT} - \text{MAX LANT} \right|
\]

\[
\text{CS} = \left\{ \left( \text{RANT} + \text{LANT}/2 \right) + \left( \text{RPM} + \text{LPM}/2 \right) + \left( \text{RPL} + \text{LPL}/2 \right) / 3 \times \text{LL} \right\} \times 100
\]

Drop Jump Screening Test
The Drop Jump Screening Test (DJST) was performed as originally described by Noyes et al such that participants performed a drop jump from a 30cm height box and immediately upon landing participants were instructed to perform a maximal vertical jump (Figure 2). Participants were outfitted with reflective markers placed on right and left greater trochanter, right and left lateral malleolus, and the center of the right and left patella. The DJST
was demonstrated for all participants prior to com-
pleting three successful jumps.

A SONY HDR-CX190 video camera was placed
directly in front of the box at a distance of 366cm
(12 feet) from the front of the box and the Sports-
metrics™ Calibrating Placard was placed next to the
front edge of the box. The video camera recorded
the DJST for offline digitizing and analysis using the
Valgus Digitizer Software (Sportsmetrics™ Software
for Analysis of Jumping Mechanics, Cincinnati, OH)
to assess normalized knee joint separation distance
(%) at three digitized points: pre-landing (point at
which toes initially make contact with ground), land-
ing (deepest point in the landing on the ground),
and take off (point at which there is initial forward
and upward movement of arms and body) of the
video that demonstrated the participants best jump-
ing ability. The retroreflective markers on the right
and left greater trochanters and left and right patel-
las were used to determine hip joint separation and
knee joint separation, respectively, in centimeters
(cm), at each of the digitized landing points. Normal-
ized knee joint separation distance was calculated as
the percentage of the knee joint distance measure-
ment (in cm) to the hip joint distance measurement
(in cm). The hip joint separation distance measure-
ment was used to normalize the knee joint separa-
tion distance measurement because the distance
between the hip markers remains unchanged during
each phase of the DJST. Normalized knee joint separa-
tion distance percentages below 60% of hip joint
separation distance indicates that an athlete may be
at higher risk for a serious knee injury.

Procedures
All high school female rowers took part in a six-week
Sportsmetrics™ training program (Table 1) during
pre-season of the 2014 spring rowing season. Prior

Figure 1. The Y-Balance Test. a. Posteromedial Reach b. Anterior Reach

Figure 2. Images of the Drop Jump Screening Test. Participants drop off of the box and upon landing on the ground they are asked to immediately explode up in to a vertical jump. Image is at max height of vertical jump.
to participation in the training program an initial assessment of VJH, YBT, and DJST was performed using the protocols previously described. All six weeks of training were overseen by a licensed physical therapist and/or a certified athletic trainer to ensure accuracy of exercises and to provide corrective feedback when necessary. Within one week of the conclusion of the training program all rowers had a post training assessment of VJH, YBT, and DJST using the same methods as the initial assessment.

Statistical Analysis
Data were assessed for skewness and kurtosis via histograms. Levene’s Test was used to assess error variances. Independent t-tests were used to determine differences in age, weight, and height between varsity and novice rowers. For normally distributed data with equal error variances, repeated measures ANOVAs were used to assess differences pre- to post-training and between groups in VJH, YBT CS, YBT ANT reach asymmetry, and normalized knee joint separation distance (DJST) at pre-landing, landing, and take off. In the case of non-normally distributed data or lack of equal error variances, non-parametric analyses consisted of Mann Whitney U to assess differences between groups during both pre- and post-training, while a Wilcoxon Sign Rank test was used to assess differences from pre to post training. Intraclass Correlation Coefficients were calculated to assess the Standard Error of the Measurement (SEM) \[SEM = SD\sqrt{1-SEM}\] for VJH; SEM was calculated using the average SD from the pre and post-training VJH. An alpha level of < 0.05 was used to indicate statistical significance. All statistical analysis was performed using IBM SPSS version 23 (IBM, Armonk, NY).

RESULTS
Analysis of histograms for pre and post VJH, knee joint separation distance, YBT CS, and ANT AYS demonstrated normal distribution across both groups. Further, Levene’s Test for equality of error variances was not significant for VJH (pre-training: p = 0.05; post-training: p = 0.60), knee joint separation distance during pre-landing (pre-training: p = 0.12; post-training = 0.90) and take off (pre-training: p = 0.07; post-training: p = 0.08), YBT CS (pre-training: p = 0.35; post-training: p = 0.75), and ANT ASY (pre-training: p = 0.21; post-training: p = 0.48). However, there were unequal

<table>
<thead>
<tr>
<th>Table 1. Sportsmetrics™ Training Program</th>
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<tbody>
<tr>
<td><strong>Jumps</strong></td>
</tr>
<tr>
<td>Week 1</td>
</tr>
<tr>
<td>Wall Jumps</td>
</tr>
<tr>
<td>Tuck Jumps</td>
</tr>
<tr>
<td>Squat Jumps</td>
</tr>
<tr>
<td>Barrier Jumps (S/S)</td>
</tr>
<tr>
<td>Barrier Jumps (F/B)</td>
</tr>
<tr>
<td>180° Jumps</td>
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<tr>
<td>Broad Jumps</td>
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<tr>
<td>Bounding in Place</td>
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<tr>
<td>Week 3</td>
</tr>
<tr>
<td>Wall Jumps</td>
</tr>
<tr>
<td>Tuck Jumps</td>
</tr>
<tr>
<td>Jump, Jump, Jump Vertical</td>
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<tr>
<td>Squat Jumps</td>
</tr>
<tr>
<td>Barrier Jumps (S/S)</td>
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<tr>
<td>Barrier Jumps (F/B)</td>
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<tr>
<td>Scissor Jumps</td>
</tr>
<tr>
<td>Single Leg Hops (stick)</td>
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<tr>
<td>Bounding for Distance</td>
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<tr>
<td>Week 5</td>
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<tr>
<td>Wall Jumps</td>
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<tr>
<td>Up Down 180 Vertical</td>
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<tr>
<td>Squat Jumps</td>
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<tr>
<td>Mattress Jumps (S/S)</td>
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<tr>
<td>Mattress Jumps (F/B)</td>
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<tr>
<td>Hop, Hop, Hop Stick</td>
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<tr>
<td>Jump into Bounding</td>
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</tbody>
</table>

Sec= number of seconds for one set; Rep= number of repetitions for one set; run= the length of the basketball court; S/S= represents side to side; F/B= front to back
error variances in normalized knee joint separation
distance during landing (pre-training: p = 0.03; post-
training: p = 0.04). Varsity rowers were significantly
older than novice rowers; however, weight and height
were the same between groups (Table 2). There was a
main effect for VJH such that it significantly improved
in both groups pre to post training (SEM 3.55cm);
there was no effect for group (Table 3). There was also
a main effect for knee joint separation distance such
that it significantly increased in both groups pre to post
training at the pre-landing and take-off phases of the
jump; however, there was no effect for group (Figure
3). There was no difference between pre- to post-train-
ing YBT CS or ANT ASY in either varsity or novice row-
ers (Table 3). Although 52 of 58 rowers completed the
six-week Sportsmetrics™ training, some rowers were
not available for the post testing sessions; therefore,
the vertical jump height comparison represents data
from 49 participants (31 varsity and 18 novice), the
YBT comparisons represents data from 44 participants
(23 varsity and 21 novice), and the knee joint separa-
tion distance comparisons represents data from 51 par-
ticipants (31 varsity and 20 novice).

DISCUSSION
The purpose of this study was to compare the effects
of a six-week SportsMetrics™ training program on
vertical jump height (VJH), Y Balance Test (YBT),
and Drop Jump Screening Test (DJST) between nov-
ice and varsity high school rowers. All participants
improved vertical jump height and landing position
following six weeks of Sportsmetrics™ training.

### Table 2. Demographic and anthropometric means ± standard deviations for varsity and novice high school rowers

<table>
<thead>
<tr>
<th></th>
<th>Age (years ± SD)</th>
<th>Weight (kg ± SD)</th>
<th>Height (m ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Varsity Rowers</td>
<td>16.4 ± 0.8</td>
<td>62.0 ± 9.0</td>
<td>1.7 ± 0.1</td>
</tr>
<tr>
<td>Novice Rowers</td>
<td>14.5 ± 0.7</td>
<td>58.6 ± 5.4</td>
<td>1.7 ± 0.1</td>
</tr>
<tr>
<td>All Rowers</td>
<td>15.6 ± 1.2</td>
<td>60.7 ± 7.9</td>
<td>1.7 ± 0.1</td>
</tr>
</tbody>
</table>

| p-value          | <0.0001*         | 0.14             | 0.37            |

* denotes statistically significant difference between varsity and novice rowers

### Table 3. Pre- and post-training means ± standard deviations for varsity and novice high school rowers in vertical jump (VJH), Y Balance Test Composite Score (YBT CS) and Y Balance Test anterior reach asymmetry (ANT ASY)

<table>
<thead>
<tr>
<th></th>
<th>VJH Pre (cm)</th>
<th>VJH Post (cm)</th>
<th>YBT CS Pre (%LL)</th>
<th>YBT CS Post (%LL)</th>
<th>ANT ASY Pre (cm)</th>
<th>ANT ASY Post (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Varsity Rowers</td>
<td>29.9±7.8</td>
<td>32.1±4.9</td>
<td>99.4±6.8</td>
<td>99.3±7.0</td>
<td>2.6±1.8</td>
<td>2.6±2.5</td>
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<tr>
<td>Mean±SD</td>
<td></td>
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<tr>
<td>Novice Rowers</td>
<td>27.3±5.2</td>
<td>31.5±5.6</td>
<td>99.2±8.3</td>
<td>100.0±7.3</td>
<td>4.3±6.3</td>
<td>2.8±2.3</td>
</tr>
<tr>
<td>Mean±SD</td>
<td></td>
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<tr>
<td>All Rowers</td>
<td>29.0±7.0</td>
<td>31.9±5.1</td>
<td>99.3±7.5</td>
<td>99.7±7.1</td>
<td>3.4±4.6</td>
<td>2.7±2.3</td>
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<tr>
<td>Mean±SD</td>
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<tr>
<td>p-value</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(group x time)</td>
<td>0.29</td>
<td></td>
<td>0.43</td>
<td>0.38</td>
<td></td>
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</tr>
<tr>
<td>p-value</td>
<td>0.001*</td>
<td></td>
<td>0.53</td>
<td>0.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(main effect)</td>
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</table>

* denotes statistically significant main effect for time (significant change from pre to post training regardless of level of rower)
The first hypothesis was that following Sportsmetrics™ training, novice rowers would not be different from varsity rowers in VJH and YBT; however, all rowers had significant improvements in vertical jump height with varsity rowers improving by approximately 2cm and novice increasing by approximately 4cm. Although not statistically significant, novice rowers, clinically speaking, had an increase equal to double that of the varsity rowers. A lack of statistically significant differences between groups may have resulted from a Type II statistical error ($\beta = 0.82$), which could have been due to a small sample size. These changes in vertical jump height across both groups could be considered clinically relevant as others have reported significant improvements in vertical jump height of only a 1cm after Sportsmetrics™ training; however, one should use caution with the interpretation of the current data as the SEM was 3.55cm. The large increase in the novice rowers in this study may have been due to neural changes as jump training was likely a novel task for this type and level of athlete; it is possible that participants improved their ability to perform the task via a feed forward motor control strategy. Perhaps Sportsmetrics™ training induces changes to the feed forward motor control strategies utilized during landing preparation, which has been demonstrated following plyometric training in other research, as a means for knee ligament injury prevention reported in the literature.

To date the literature has not directly evaluated the effects of the Sportsmetrics™ program on dynamic balance, but research suggests that neuromuscular training, similar to that utilized in Sportsmetrics™, improves postural and dynamic stability. The use of hold positions during deceleration movements, similar to those used in the Sportsmetrics™ training, has been considered to be a functional balance or single-leg core stability training strategy. Core strength has been suggested to be integral to balance and physioball training focused on back and abdominal exercises (i.e. curl up and back extension) improved abdominal and erector spinae muscle activity and static balance times. Therefore, if there are changes in core stability following jump training it is possible that this could enhance dynamic balance. These findings did not support the hypothesis because YBT performance did not induce statistically significant changes in composite score or anterior reach asymmetry in novice rowers, and novice rowers were not different from varsity rowers. However, it is important to note that the novice rowers had an average anterior reach asymmetry of 4.3cm pre training and this was reduced to 2.8cm post training. Other studies suggest that reach distance difference greater than 4cm indicates asymmetry.

![Figure 3. Pre- and post-training means ± standard deviations for varsity (V), novice (N), and both groups (B) in normalized knee separation distance (%) during pre-landing (PL), landing (LAND), and take off (TO) phases of the Drop Jump Screening Test. Normalized knee joint separation distance represents the percentage of the knee separation measurements (cm) relative to the hip separation measurement (cm). * = p < 0.001](image-url)
between right and left limbs. Clinically speaking, the anterior reach asymmetry demonstrated by novice rowers post training was similar to varsity rowers who demonstrated a mean of 2.6cm anterior reach asymmetry. More importantly, following Sportsmetrics™ training novice rowers reduced their anterior reach asymmetry to be below the threshold (4cm) known to be associated with an increased risk of noncontact and overuse lower extremity injury.15,17

Authors of a recent review of rowing injuries29 and a prospective cohort study of rowing injuries30 suggests that knee injuries are predominant along with low back injury. These injuries reported by Hosea and Hanafin29 and Wilson et al30 are primarily overuse in nature. Smith el al15 showed a significant association with increased YBT anterior reach asymmetry and lower extremity noncontact and overuse injuries in collegiate athletes. Further, individuals with patellofemoral pain syndrome perform worse on the Star Excursion Balance Test (SEBT).31 Additionally, a reduction in asymmetry in novice rowers may improve rowing performance as asymmetry of the lower extremities during the task of rowing causes wiggle in the boat, which will slow forward progress.32 The current findings, as well previous literature, suggest that improvement in lower extremity asymmetry in novice rowers may be of particular importance as it may reduce the risk of overuse injuries as well as improve rowing performance while in the boat.

The second hypothesis was supported in that all rowers increased normalized knee joint separation distance in DJST following training in all three phases of landing: pre landing, landing, and take off. The findings of this current study are also supported in the literature across various populations engaged in Sportsmetrics™;9,33 however, this is the first study to document improved lower limb alignment at landing in rowers. Improved lower limb alignment at landing may reduce the risk for patellofemoral pain syndrome (PFPS) in rowers as increased knee abduction angle is one of several strong predictors of PFPS.34 Additionally, it has been suggested that improvement of frontal plane knee mechanics should be incorporated into PFPS injury prevention programs;35 thus Sportsmetrics™ could be incorporated into training programs for rowers to attempt to decrease the incidence of PFPS.

The average normalized knee joint separation distance improved to be greater than 60% of the hip separation distance in all three phases of landing for both novice and varsity rowers following training. This is important as less than 60% of normalized knee joint separation distance relative to hip joint separation represents dynamic knee valgus, which has been suggested to put athletes at risk for non-contact knee injury.11 Additionally, given the nature of the sport of rowing there is tremendous load to the patellofemoral joint, which can result a variety of overusing injuries including in PFP29 and patellar tendonitis.30 Therefore, improving dynamic knee alignment may reduce the incidence34 of lower extremity overuse injuries like PFP in rowers.

While this is the first study to assess the effects of Sportsmetrics™ training in rowing athletes, there are some limitations. First, the participants only took part in the training sessions two times per week rather than the suggested three times per week. This was based on training availability of the team; however, more substantial findings may have been present, particularly in the measurement of dynamic balance, had the training taken the recommended three times weekly. Additionally, the design of this study was pre-test post-test, but rather than a randomized control trial a cross sectional design was utilized to study a cohort of rowing athletes. This design limits the true cause and effect nature of the study as all participants completed their regularly scheduled training activities in addition to the Sportsmetrics™ training. However, it is important to note that there were improvements in all subjects in power and knee separation distance following the six weeks of training. It is likely, given the nature of normal training for the sport of rowing and past research using Sportsmetrics™, that normalized knee joint separation distance differences seen post training were directly attributable to Sportsmetrics™ and improvement in vertical jump was influenced by Sportsmetrics™.

CONCLUSION
SportsMetrics™ training improved vertical jump height regardless of experience level; suggesting rowers may have more leg power following training. YBT was not affected by training. Following training drop jump knee separation increased to greater than 60%; indicating training reduced serious knee injury
risk. Future researchers should consider evaluating the cause and effect nature of Sportsmetrics™ training on athletes who row through implementation of a randomized control trial.

REFERENCES


ABSTRACT

Purpose/Background: Running gait retraining to change foot strike pattern in runners from a heel strike pattern to a non-heel strike pattern has been shown to reduce impact forces and may help to reduce running related injuries. Step rate manipulation above preferred is known to help decrease step length, foot inclination angle, and vertical mass excursion, but has not yet been evaluated as a method to change foot strike pattern. The purpose of this study was to investigate the effect of step rate manipulation on foot strike pattern in shod recreational runners who run with a heel strike pattern. A secondary purpose was to describe the effect of step rate manipulation at specific percentages above preferred on foot inclination angle at initial contact.

Methods: Forty volunteer runners, who were self-reported heel strikers and had a weekly running mileage of at least 10 miles, were recruited. Runners were confirmed to be heel strikers during the warm up period on the treadmill. The subject's step rate was determined at their preferred running pace. A metronome was used to increase step rate above the preferred step rate by 5%, 10% and 15%. 2D video motion analysis was utilized to determine foot strike pattern and to measure foot inclination angle at initial contact for each step rate condition.

Results: There was a statistically significant change in foot strike pattern from a heel strike pattern to a mid-foot or forefoot strike pattern at both 10% and 15% step rates above preferred. Seven of the 40 subjects (17.5%) changed from a heel-strike pattern to a non-heel strike pattern at +10% and 12 of the 40 subjects (30%) changed to a non-heel strike pattern at +15%. Mean foot inclination angle at initial contact showed a statistically significant change (reduction) as step rate increased.

Conclusion: Step rate manipulation of 10% or greater may be enough to change foot strike pattern from a heel strike to a mid-foot or forefoot strike pattern in a small percentage of recreational runners who run in traditional running shoes. If changing the foot strike pattern is the main goal, other gait re-training methods may be needed to make a change from a heel strike to a non-heel strike pattern. Step rate manipulation shows a progressive reduction of foot inclination angle at 5%, 10%, and 15% above preferred step rate which reduces the severity of the heel strike at initial contact. Step rate manipulation of at least +10% above preferred may be an effective running gait retraining method for clinicians to decrease the severity of heel strike and possibly assist a runner to change to a non-heel strike pattern.

Key Words: Foot strike pattern, running gait retraining, step rate manipulation

Level of Evidence: 3
INTRODUCTION

The popularity of running in the United States is at an all-time high. The running population has grown over 70% in the last decade to nearly 42 million runners who run at least six days per year. In 2013 a record 19 million runners were road race finishers capping 10 consecutive years of record race finisher numbers. With the growing number of runners, especially those running greater mileage in preparation for half and full marathon distances, injuries related to running have also been on the rise. In a 2007 systematic review, Van Gent reported an incidence of running related injuries ranging from 19.4-79.3%. The time frame of studies examined by Van Gent included studies as short as 1 day and as long as 18 months.2 As more runners seek care for running related injuries, it becomes increasingly important that health care and rehabilitation professionals are equipped to provide care specific to running related injuries.

In recent years a number of researchers have examined the impact forces of running and have correlated or at least provided a theoretical basis for higher impact forces being a potential cause of various running related injuries.3,4,5 It has been well established that impact forces at the knees and hips are typically highest in runners with a heel strike pattern as compared to those with a mid-foot or forefoot strike pattern.6, 7, 8,9 Lieberman et al. was one of the first to examine the connection between foot strike pattern, impact forces, and the potential connection to injury.15 Their research showed that shod runners typically strike with the heel first and that barefoot runners tended to run with a non-heel strike pattern. Impact forces were shown to be much higher in the heel striking shod runners than the barefoot runners and it was suggested that this may have a connection to running related injuries. It has been suggested that if impact forces can be reduced, then distance runners may be able to reduce injuries or rehabilitate from injuries more effectively than if running form and resultant impact forces are not addressed. Changing foot strike pattern from a heel strike pattern to a mid-foot or forefoot strike pattern through running gait retraining may be one way to accomplish a reduction of impact forces and reduce running related injuries.10,11 Up to 96% of recreational runners who run in traditional running shoes have been reported to be heel-strikers making this a very relevant issue for rehabilitation professionals who take care of this population.12,13

Several methods of running gait re-training to modify foot strike pattern have been examined in the literature.14 Barefoot running has been one of the most prominent methods to accomplish a change in foot strike pattern from a heel strike pattern to a forefoot strike pattern. It has been well documented that barefoot running tends to support a more forefoot biased foot strike pattern, decreased contact time, and a quicker step rate as compared to shod running which tends to support a heel strike pattern.15,16,17 McCarthy described a 12 week transition program from shod to simulated barefoot running that resulted in runners changing from a heel strike pattern to a forefoot pattern.17 Hatala et al., however, found that not all habitually barefoot people prefer running with a forefoot strike pattern and that other factors may dictate foot strike pattern.18 Barefoot running also may not be for everyone. The feel and comfort of barefoot running is very different than running in shoes and may be difficult for many runners to get used to.

Minimalist shoes have become very popular in recent years marketed to provide similar benefits to runners as barefoot running. This may not be the case, however, as Willy et al. found that runners who switched to minimalist shoes did not change their foot strike pattern from a heel strike pattern to a non-heel strike pattern and actually experienced increased loading forces as compared to running in their traditional running shoes.19 Bergstraal et al. reported increased plantar pressures in women who run in minimalist shoes and no difference in landing patterns between running in minimalist versus traditional shoes. This raised concern for the potential of metatarsal stress fractures.20 Goss et al. also reported that 50% of runners recently introduced to minimalist footwear still ran with a heel strike pattern after a two week accommodation period.21 Those runners who wish to continue to run in traditional running shoes may need to look toward other methods to change their foot strike pattern to reduce impact forces.

Step-rate manipulation was described by Heiderscheidt et al. in 2011 to significantly reduce impact forces.
forces in distance runners with as little as a 5% increase in step rate. Their research showed that by increasing step rate kinematic variables such as step length, center of mass vertical excursion, and foot inclination angle were reduced in shod runners. Reduction of these variables was associated with decreased impact forces and could theoretically reduce injury risk for distance runners. Multiple other authors have supported the reduction of impact forces through increased cadence or step-rate. Increasing step rate has also been described to play a role in increasing leg stiffness and enhancing the leg-spring behavior which may be protective against injury. Step rate manipulation has also been presented as an easy and practical method of running gait re-training in the clinical environment utilizing metronome cues and faded feedback methodology. While past research has documented many positive changes in running kinematics related to step rate manipulation, step rate manipulation has not been examined as a method to change foot strike pattern nor has the percentage of step rate increase needed to make this change been established.

The purpose of this study was to investigate the effect of step rate manipulation on foot strike pattern in shod recreational runners who run with a heel strike pattern. A secondary purpose was to describe the effect of step rate manipulation at specific percentages above preferred on foot inclination angle at initial contact. This study seeks to provide more specific information to rehabilitation professionals regarding how step rate manipulation above preferred affects foot strike pattern and the position of the foot at initial contact as well as what percentage of step rate increase is needed for a significant change to occur. This information may serve as a useful guide for clinicians using step rate manipulation as a running gait retraining intervention method in the clinical setting.

METHODS

Subjects
A total of 40 healthy volunteers were recruited from local running clubs, running stores, advertisement via various media outlets, and by word of mouth. Participants were eligible for inclusion if they were heel-strikers at their preferred running pace and step rate, were currently running at least 10 miles per week, and had not had lower extremity pain, a history of ankle or foot surgery, a running injury within the previous three months, or cardiovascular/ neurological compromise. Included subjects were all healthy runners that were comfortable running on a treadmill. All runners had a weekly mileage of at least 10 miles. 43 total runners were recruited for the study. Three runners (2 male, 1 female) were excluded from the study because they were determined to be forefoot strikers at their preferred running pace and step rate during testing and verified upon video review. There were 23 female subjects and 17 male subjects included in the study with an average age of 36 (range 17-56 years old). Informed consent was obtained prior to testing. Prior approval was obtained to conduct this study through the Institutional Review Board of the Cleveland Clinic.

Procedure
All subjects were blinded as to what was being tested. Subjects ran in their standard running shoe. Three pieces of tape were applied to each shoe in the following areas: rearfoot (inferior to the apex of the fibular malleolus at the lateral calcaneus), mid-foot (base of the 5th metatarsal), and lateral forefoot (5th metatarsal head), to be used merely as a reference point to the runner’s anatomy when observing foot strike pattern. Prior to data collection, each subject performed a 5 minute warm up on the treadmill and gradually worked up to a comfortable running speed. Running speed was consistent with what the subject determined to be typical of a moderate intensity run. Running speed was recorded by the researchers and the subject then ran at this exact speed for all test conditions. The researchers then validated that each subject was a heel-striker. Foot strike patterns in this study were classified in three categories consistent with Lieberman et al., 2010: rearfoot, when the heel is the first region to contact the ground; mid-foot, when the heel and ball of the foot simultaneously contact the ground; and forefoot, when the ball of the foot contacts the ground before the heel. Any subject that was deemed to be a forefoot or mid-foot striker when running at their preferred step rate was eliminated from the study. For all confirmed heel-strikers, the preferred step rate was determined once the subject had been running for
at least one minute at their preferred pace. Step rate was determined over a 30 second period by counting the number of times the right foot hit the ground then multiplied by four. This was repeated by two researchers to ensure accuracy and the average was recorded. Data was then collected for four step rate conditions: preferred, +5%, +10%, and +15%. The various conditions were randomized for each subject by randomly drawing them out of a bag. The change in step rate was achieved through use of a metronome, which provided audible and visual cues to runners. Data collection, which consisted of video footage from the lateral view for 30 seconds, was obtained once the subject was able to maintain the appropriate step rate for at least one minute. The subject walked at a moderate pace for three minutes in between each step rate change in order to help fatigue. After all step rates were performed, the subject walked for a three minute cool down. All subjects were tested according to this protocol.

Data Collection and Analysis
Upon completion of testing, the video footage for each subject was reviewed to determine the subject's foot-strike pattern at each step-rate condition (Figures 1-4). The review was conducted by the testing researcher and then confirmed by the review of a second researcher (licensed physical therapists) independent of each other. In instances when there was disagreement a third researcher was used. Almeida et al. 201512 described inter-rater reliability of 96.7% using this method of review. Medical Motion video analysis software (Cardiff, CA) and the video camera (Canon DM-GL2, Japan) were utilized to review the video. The camera captured data at 60 frames per second. Foot-strike pattern and foot inclination angle at initial contact at each step-rate condition was recorded for each subject tested. One researcher performed all measurements of the foot inclination angles to ensure consistency. Foot inclination angle was measured using the Medical Motion video analysis software as the angle between the treadmill and the sole of the foot consistent with previous studies that have reported on this measure (Figure 5).6,29 The average foot inclination angle of three randomly selected foot strikes was reported to reduce potential variability.

Statistical Methods
Categorical variables were described using frequencies and percentages, while continuous variables were described using means, standard deviations,
medians, and ranges. Linear mixed effect models were used to evaluate changes in ankle inclination and step rate across study conditions. In the model, the correlation between results from the same runner was modeled using an autoregressive correlation. Trends in foot strike pattern overall and heel strike versus not were evaluated using Cochran-Mantel-Haenszel tests overall, followed by McNemar tests to compare agreement between conditions in a pairwise manner. SAS Software was used for data management and for generating data summaries (Version 9; Cary, NC). Pairwise comparisons between study conditions used a Bonferroni-corrected significance level of 0.0083 to limit the probability of a Type I error across the six comparisons to no more than 0.05. P-values below this level were considered statistically significant.

Results

Table 1 shows summary statistics for the cohort. Forty subjects were included in the data analysis with seventeen being male and twenty-three female. Average age was 36.0 (+/- 9.1) with age ranging from 17 to 56. Subjects reported that they ran an average of 24.9 miles per week (+/- 20.9) with the median running distance being 19 miles per week (range 10-120). Only eight of the forty subjects reported that they wore orthotics. Thirty-four (85%) subjects were self-reported heel strikers while six (15%) believed that they were mid-foot strikers.

Table 2 shows the comparison of the foot inclination angle. Mean foot inclination angles were: 13.6 degrees (preferred), 10.3 degrees (5%), 8.77 degrees (10%), and 6.04 degrees (15%). There was a significant difference across all groups, and a statistically significant reduction of the mean foot inclination angle.
angle as step rate increased (both p<0.001). The 5% condition had a 3.34 point smaller angle on average than the preferred step rate. The angle in the preferred rate was significantly greater than all other conditions (p<0.001), while the 15% condition had an angle that was significantly smaller than all other conditions (p<0.001). No significant difference between 5% and 10% was observed.

Table 3 shows a similar comparison of the recorded step rates. Mean step rates of the subjects were (reported as steps per minute): 165 (preferred), 173 (5%), 181 (10%), and 189 (15%). As expected, the step rates all were significantly different at each level and step rates showed a statistically significant increase as the step rate percentage increased.

Table 4 and Table 5 compare the foot strike pattern. Table 4 compares all three foot strike patterns at the different step rates, while Table 5 shows the heel strike versus not. Results of the two tables are similar. The percentage of non-heel strikers increases from 0% at the preferred rate to 10% at preferred rate + 5%, 17.5% at the preferred rate + 10%, and 30% at the preferred rate + 15%. There was an overall difference and a significant increasing number of non-heel strikers as the step rate increased. The preferred rate + 15% had significantly more non-heel strikers than the preferred rate and preferred rate + 5% conditions. When combining mid-foot and fore-foot strike versus heel strike (Table 5), the preferred rate + 10% condition had significantly more non-heel strikers than the preferred rate.

In summary, in both the foot inclination angle and foot strike pattern analysis, significant changes were observed with increases in step rate conditions. For
foot inclination angle, significant decreases in the angle were observed with even 5% increases in step rate, while for the foot strike pattern, increases of at least 10% in the step rate were needed to show a significant increase in the number of non-heel strikers.

Discussion
The intent of this study was to determine whether step rate manipulation alone was enough to change foot strike pattern in shod recreational distance runners. The results of this study show that there is a statistically significant change in foot strike pattern from a heel strike pattern to a mid-foot or forefoot strike pattern at both 10% and 15% step rates above preferred. Increasing step rate above preferred by 10% was successful in changing foot strike pattern from a heel strike pattern to a mid-foot or forefoot strike pattern in 17.5% of the runners while increasing step rate by 15% changed foot strike pattern in 30% of the runners in our study. These results suggest that step rate manipulation alone may be an effective way to change foot strike pattern in a small percentage of shod distance runners.

Step rate manipulation was chosen as a method to attempt to change foot strike pattern in distance runners wearing traditional running shoes. Step rate manipulation has been shown in the literature to be an effective means to reduce impact loading variables by changing sagittal plane variables such as stride length, center of mass vertical excursion, knee flexion angle at initial contact, and foot inclination angle. Hafer et al. found that runners were able to adopt a new running style at a step rate 10% above preferred after a six week cadence retraining program and showed carryover of decreased stride length, hip adduction angle and hip abductor moment. In addition to the beneficial effect of step rate manipulation on sagittal plane running biomechanics, it is also very easy to implement in the clinical rehabilitation setting. For rehabilitation professionals seeking to reduce impact forces and rehabilitate or prevent running related injuries, manipulating step rate can be done quickly with a simple metronome either on a treadmill or while running over ground.

Increasing subjects' step rate by 15% over their preferred step rate was effective at changing 30% of the subjects to a mid-foot or forefoot strike pattern. While this is a statistically significant change it does represent a relatively small percentage of the overall subject population. The majority of the runners in this study continued to run with a heel strike pattern at all step rate conditions. This would suggest that step rate manipulation alone may be an effective way to change foot strike pattern in a small percentage of shod recreational runners, but that if the intent is to change foot strike pattern that other methods may be more effective to accomplish this. One observation that was made by the researchers, although not statistically studied, was that many runners who changed foot strike pattern had a very small foot inclination angle at initial contact at their preferred step rate. This would appear to facilitate an easier transition to a mid-foot or forefoot strike pattern with an increased step rate.

What is probably the more significant finding of this study is that there was a strong trend toward a reduction in the foot inclination angle as step rates

Table 5. Comparisons of the heel strike are shown.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Heel (N=137)</th>
<th>Mid/Fore (N=23)</th>
<th>Overall</th>
<th>Trend vs. Preferred</th>
<th>vs. 5%</th>
<th>vs. 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preferred</td>
<td>40 (100.0)</td>
<td>0 (0.0)</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5%</td>
<td>36 (90.0)</td>
<td>4 (10.0)</td>
<td>0.046</td>
<td></td>
<td>0.083</td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>33 (82.5)</td>
<td>7 (17.5)</td>
<td>0.0082</td>
<td></td>
<td>0.005</td>
<td>0.025</td>
</tr>
<tr>
<td>15%</td>
<td>28 (70.0)</td>
<td>12 (30.0)</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
were increased. Heiderscheidt et al.\textsuperscript{6} documented in their research that foot inclination angles are reduced at higher step rates. The results of the current study support that change and found a significant reduction in the foot inclination angle even at a 5% increase above preferred. Wille et al.\textsuperscript{29} has previously shown that there is a correlation between a reduction in the foot inclination angle and reduced ground reaction forces and knee joint loads at initial contact. It may concluded that a reduction of foot inclination angle through increasing step rate above preferred by at least 5% may have beneficial effects on reducing impact forces and potentially reducing injury risk. The current study also showed that the foot inclination angle progressively decreased as step rate was increased at 5%, 10%, and 15% above preferred, therefore, it might be that increasing step rate by 10% or 15% may have a greater effect on the reduction of impact forces. Rehabilitation professionals can utilize step rate manipulation above preferred to potentially change foot strike pattern, but more likely to reduce the foot inclination angle or the severity of the heel strike in hopes of reducing impact forces and having a positive effect on injury rehabilitation or prevention.

This study did have some limitations. The current study utilized 2D video analysis and a camera filming at 60fps. This may have reduced the sensitivity of the measurements of foot inclination angle compared to what might be possible with a camera filming at greater than 100fps. It was the researcher's experience, however, that an individual video frame where that initial foot contact was taking place was able to be identified with good certainty to both determine the foot strike pattern as well as to measure foot inclination angle. Foot strike pattern was identified by one researcher and then verified by a second researcher for all conditions. The methodology also attempted to reduce the variability of observations by measuring foot inclination angle for each subject at three random foot strikes during the 30 second video footage and then taking the mean of the three angles to represent the subject's foot inclination angle at each condition. Damstead et al.\textsuperscript{31} determined that the reliability of determining foot strike pattern using 2D video analysis was acceptable in the clinical setting and showed very good intra-rater reliability for within day observations. Bertelsen et al.\textsuperscript{13} also reported that visual analysis of 2D video was a feasible and practical way of identifying foot strike pattern in novice runners and found good reliability of this method. The camera and video analysis software utilized in this study are very commonly used in many clinical settings. The results of this study show that clinicians with similar equipment can effectively film and analyze the foot strike pattern and foot inclination angle of runners and observe relevant and meaningful measures consistent with results found in laboratory studies such as Heiderscheidt et al.\textsuperscript{6}.

A second limitation to the current study was that subjects were filmed running on a treadmill rather than over ground. Observation of runners on the treadmill provides obvious convenience for conducting this type of research through the ability to observe a runner on a continuous basis over an extended period of time. It also allows for the standardization of camera and observation set-up which is important to the consistency and quality of observations. Riley et al.\textsuperscript{32} found that running mechanics of treadmill running can be generalized to over ground running as kinetics and kinematics of running on a treadmill are comparable, but not directly equivalent to running over ground. For the purpose of this study to merely identify foot strike pattern this similarity was determined to be sufficient.

A final limitation was that subjects were being observed running at each condition (step rates above preferred) while never having had the opportunity to practice running at these step rates prior to the study observation. It could be a valid discussion as to whether subjects were running naturally or just finding a movement strategy to effectively match their foot strikes to the metronome. The study methodology, however, was similar to several other step rate manipulation studies that have studied biomechanics of runners in a similar manner.\textsuperscript{27,6,7,22,24,33} Every effort was made to film the runner at each condition only after they had been able to successfully match the metronome beat and maintain that step rate while running for at least one minute. It was noted that the 5% and 10% above preferred conditions were typically very easy for the subjects to match and that only the 15% above preferred
condition was a challenge initially for some of the subjects. We agree with Heiderscheidt et al.⁶ that the perceived increase in effort of subjects, especially at the +15% condition, was more to do with attentional focus to achieve a novel task rather than a true increase in metabolic cost.⁴,⁵,⁶ This would suggest that while increasing step rate above one’s preferred, especially at rates as high as +15%, may seem challenging at first, that practice would reduce the attentional focus and perceived exertion. Allowing step rate increases to be phased in gradually in the clinical environment would potentially help to reduce this change in perceived exertion for the runner.

CONCLUSION
Step rate manipulation may be effective in changing the foot strike pattern of recreational runners wearing traditional running shoes from a heel-strike pattern to a mid-foot or forefoot strike pattern in 17.5% of runners at 10% above preferred and 30% of runners at 15% above their preferred step rate. If changing foot strike pattern is the primary goal other methods may be needed to make a change from a heel strike pattern to a non-heel strike pattern. Step rate manipulation above preferred does show a progressive reduction of the foot inclination angle at 5%, 10%, and 15% above preferred which represents a reduction in the severity of the heel strike angle at initial ground contact. Reduction of foot inclination angle may represent the primary benefit of step rate manipulation on foot position at initial contact rather than a change in the actual foot strike pattern. Step rate manipulation of at least +10% above preferred may be an effective running gait retraining method for clinicians to decrease the severity of heel strike and possibly assist a runner to change to a non-heel strike pattern. Further research is needed to investigate the effect of step rate manipulation on injury prevention in runners.

REFERENCES


ABSTRACT

**Background:** The posture of the foot has been implicated as a factor in the development of running-related injuries. A static measure of foot posture, such as the longitudinal arch angle (LAA), that can be easily performed and is predictive of the posture of the foot at mid-support while running could provide valuable information to enhance the clinician's overall evaluation of the runner.

**Purpose:** The purpose of this study was to determine if the LAA, assessed in relaxed standing, could predict the posture of the foot at mid-support while running on a treadmill.

**Study Design:** Cross-sectional Study

**Methods:** Forty experienced runners (mean age 26.6 years) voluntarily consented to participate. Inclusion criteria included running at least 18 miles per week, previous experience running on a treadmill, no history of lower extremity congenital or traumatic deformity, or acute injury three months prior to the start of the study. Each runner had markers placed on the medial malleolus, navicular tuberosity, and medial aspect 1st metatarsal head of both feet. A high speed camera (240 Hz) was used to film both feet of each runner in standing and while running on a treadmill at their preferred speed. The LAA in standing and at mid-support while running was determined by angle formed by two lines drawn between the three markers with the navicular tuberosity serving as the apex. The LAA in mid-support was determined using the mean of the middle five running trials.

**Results:** The levels of intra-rater and inter-rater reliability for the dynamic LAA were excellent. The results of the t-tests indicated that mean values between the left and right foot were not significantly different for the standing or running LAA. The results of the t-tests between male and female runners were also not significantly different for standing or running LAA. The Pearson correlation between standing and running LAA for all 80 feet was $r = 0.95$ ($r^2 = 0.90$).

**Conclusions:** The standing LAA was found to be highly predictive of the running LAA at mid-support while running. Approximately 90% of the variance associated with foot posture at mid-support in running could be explained by the standing LAA.

**Keywords:** Foot posture, longitudinal arch angle, running

**Level of Evidence:** 4, Controlled laboratory study
INTRODUCTION

The high incidence of lower extremity overuse or repetitive stress injuries has been well documented amongst both novice and experienced distance runners, with novice runners reporting more running-related injuries than experienced runners. While the etiology of running-related overuse or repetitive stress injuries is multi-factorial, both foot mobility, especially foot pronation, as well as the static posture of the foot have long been hypothesized as potential risk factors in the development of running-related injuries.

Recent research has called into question the significance of foot mobility as a risk factor in the development of running-related injuries. Dowling et al., conducted a systematic review and reported that very limited evidence exists to support the concept that dynamic foot mobility is a risk factor in the development of running-related overuse injuries. In one of the few prospective studies conducted to determine if increased foot mobility or pronation was a factor in the development of overuse injuries, Willems et al reported that 46 out of a group of 400 physical education students that were followed for one-year, developed exercise related lower leg pain and exhibited increased foot mobility or pronation. The difference in amount of rearfoot pronation, however, between the non-symptomatic group and the exercise related lower-leg pain group was only 1.7 degrees. In one of the few studies that has actually compared the amount of foot mobility using three-dimensional motion analysis between two groups of runners, one group classified as having a normal foot-type and the other group classified as having a pronated foot-type, McClay and Manal reported that the amount of foot mobility between the two groups was almost identical. The only difference between the two groups of runners was the position of the rearfoot at initial contact with the supporting surface. The pronated group made initial contact 8.5 degrees everted, while the normal group was 1.7 degrees inverted at initial contact. McClay and Manal concluded that the difference between these two groups of runners was not the actual amount of foot motion, but the position or posture of the foot at initial contact as well as at heel off with the pronated group in a pronated position throughout the stance phase of running. Thus based on best available evidence, the importance of foot mobility as a risk factor for the development of running-related overuse injuries is uncertain.

While the findings of the McClay and Manal study was one of the first to highlight the importance of considering foot posture in runners, a recent systematic review by Carvalho et al, has reported that both high-arch and low-arch foot postures are associated with running-related injuries. Although this systematic review did not include a meta-analysis and effect-size estimates, it substantiates the work of other researchers who have reported that a low-arch or pronated foot type is a risk factor for the development of various types of running-related injuries including medial tibial stress syndrome (MTSS) and plantar fasciitis. Yates & White conducted a prospective study to determine the incidence of MTSS in military recruits during basic training and used the Foot Posture Index (FPI) to classify foot posture. These authors reported that the recruits who developed MTSS had a more pronated foot posture and that identifying those individuals with a pronated foot type prior to the start of training might reduce the incidence of MTSS. Pohl et al compared 25 female runners with a history of plantar fasciitis in comparison to an age-matched control group and reported that the runners with a history of plantar fasciitis had a more low-arch or pronated foot posture. Williams et al assessed 20 high-arched and 20 low-arched runners to determine if difference existed in the injury patterns between the two groups of runners. They reported that the high-arched runners had a greater incidence of ankle and bony injuries while the low-arched runners demonstrated more knee and soft tissue injuries.

The posture of the foot is usually described as being a high (pes cavus) arch or a low (pes planus) arch or pronated foot posture and is typically assessed by measuring the medial longitudinal arch of the foot. One of the most common measures described in the literature to assess the medial longitudinal arch is the Longitudinal Arch Angle (LAA) which was first described by Dahle et al. Dahle et al used the LAA to visually and subjectively assess the medial longitudinal arch posture in 55 athletes. Although they did not attempt to objectively measure the LAA,
they did report a substantial degree of within-rater reliability using visual assessment of the LAA. Jonson and Gross objectively assessed the LAA in 63 healthy Navy recruits as part of a study that evaluated the within-rater and interrater reliability of lower-extremity and foot skeletal measurements. They reported that the mean LAA for this group of subjects was 141.6° and that the LAA had high levels of intra- and inter-rater reliability. McPoil and Cornwall were the first to determine if the LAA measured in relaxed standing position could predict the LAA at midsupport during running. They assessed 17 experienced runners who averaged running 32 miles per week and reported that the static LAA was highly predictive, explaining 84% of the posture of the foot at or near midsupport during running. While it could be argued that over-ground running is the preferred method for video recording, a treadmill is typically utilized in most clinical settings to perform a running gait analysis. Thus, the findings reported by McPoil and Cornwall may not be clinically applicable. In a more recent study, Langley et al replicated the study by McPoil and Cornwall to determine if the LAA measured in a relaxed standing position could predict the LAA at discrete points during running, including midsupport. In addition, they also attempted to determine if the static LAA could predict the motion of the medial longitudinal arch. Similar to the findings of McPoil and Cornwall, they reported that the static LAA could explain 86% of the posture of the foot at or near midsupport during running. These authors also reported that no significant relationship was found between the static LAA and motion of the medial longitudinal arch. However, in light of the limited evidence to support the importance of foot mobility as a risk factor for the development of running-related overuse injuries this finding would not diminish the importance of the LAA as a predictor of foot posture during running. While Langley et al did utilize a treadmill for data collection and indicated that the 15 physical active males in their study ran two to three times a week, they provided no information on the number of miles the subjects ran per week. In addition,

Based on current evidence, it would appear to be important for the clinician examining a runner with a repetitive-stress injury to be aware of the posture of the foot during the stance phase of running especially at the point where the foot is most pronated and the greatest amount of arch deformation would most likely occur. Several researchers have reported that the most pronated posture of the foot occurs at or near midsupport during running. As such, a static measure of foot posture that can be easily performed and is predictive of the posture of the foot at or near midsupport while running could provide valuable information to enhance the clinician's overall evaluation of the runner. McPoil and Hunt, in describing a tissue stress model as a basis for the management of foot and ankle problems, noted that an important role of foot orthoses is to control soft tissue stress. Static foot posture measurements that are predictive of foot posture during stance phase in running could also assist the clinician to determine if a foot orthosis prescribed for the runner has modified or changed the posture of the foot from relaxed standing position. Thus, the purpose of this study was to determine if the LAA, assessed in a relaxed standing position, could predict the posture of the foot at or near midsupport while running on a treadmill. To enhance the clinical applicability of the findings, a single low-cost high-speed camera to capture the running images as well as free-access video analysis software program was utilized. Based on previous research, it was hypothesized that LAA measured in a relaxed standing position would be highly predictive of foot posture at midsupport while running.

**METHODS**

**Participant Characteristics**

Forty experienced runners (16 men and 24 women) voluntarily consented to participate in this study. The mean age of the 40 runners was 26.6 years, with a range of 18 to 40 years. Participants were recruited from the Regis University population as well as the
greater Denver, Colorado, metropolitan area through community advertisements and public information sessions. All runners selected for the study met the following inclusion criteria: (1) between the ages of 18 to 40 years; (2) ran at least 18 miles per week for one-year prior to participation in the study; (3) had experience running on a treadmill; (4) no previous history of lower extremity congenital or traumatic deformity or previous surgery that resulted in altered bony alignment; and (5) no acute injury during the three months prior to the start of the study that led to inability to run at least three consecutive days during that time. The Institutional Review Board of Regis University approved the study protocol and all participants provided written informed consent prior to participation in the study.

**Procedures**

Upon arrival to the testing center, each participant's height, weight, and blood pressure were recorded. Next, each participant was asked to stand on an elevated platform, march in place for at least five seconds, and then stop in a comfortable relaxed standing position with their weight distributed equally on both feet. While the participant stood in this position with both arms at the side and looking straight ahead, the Foot Posture Index (FPI) was performed. The FPI is a measure of an individual’s resting standing foot posture, and it is composed of six items: talar head palpation, curves above and below the lateral malleoli, calcaneal angle, talonavicular bulge, medial longitudinal arch congruence, and forefoot abduction/adduction. Each item of the FPI is scored on a 5-point scale from –2 to +2, with a sum total of all items ranging from –12 to +12. Negative values represent a supinated posture, and positive values represent a pronated posture. The FPI was performed on all of the participants by the same investigator. Following completion of the FPI, each participant was asked to begin running without shoes on a treadmill for at least five minutes so that they could acclimate to the treadmill (Model Mercury S, Woodway USA Inc., Waukesha, WI 53186) as well as determine their preferred running speed for testing. Once the relaxed standing position (StandLAA) was recorded, the participant was then asked to start running on the treadmill at his or her pre-selected running speed. Once the relaxed standing position (StandLAA) was recorded, the participant was then asked to start running on the treadmill at his or her pre-selected running speed. Once the participant indicated they were in their typical running pattern, they continued to run at his or her preferred speed for five minutes while video data was recorded. Once the video recording was completed for the right foot, the same procedure was repeated lower extremities so that following bony landmarks were identified using palpation and marked using a water soluble ink pen on the left and right feet at the navicular tuberosity, the most prominent point of the medial malleolus, and the most prominent point of the medial aspect of the first metatarsal head. Black markers that were one centimeter in diameter were then attached to each ink mark using double-sided adhesive tape (Figure 1). Each participant was then asked to stand in the middle of the treadmill and place his or her feet six inches apart. To record data for the right foot, the participant was asked to first slide the left foot backward to just behind the right heel. The participant was then instructed to maintain the right leg perpendicular to the floor and place equal weight on both feet while video data was recorded for static standing. Once the relaxed standing position (StandLAA) was recorded, the participant was then asked to start running on the treadmill at his or her pre-selected running speed. Once the participant indicated they were in their typical running pattern, they continued to run at his or her preferred speed for five minutes while video data was recorded. Once the video recording was completed for the right foot, the same procedure was repeated...
to record both standing and running data for the left foot. Since each subject ran barefoot without shoes on the treadmill and in light of possible differences in the strike pattern when running with or without shoes, the strike pattern of each runner was recorded. For the 40 runners in this study, six (6) had a forefoot strike pattern, four (4) had a midfoot strike pattern, and 30 had a rearfoot strike pattern. The six runners with a forefoot strike pattern all lowered their heel so it was in complete contact with the surface of the treadmill prior to midsupport.

All standing and running images were recorded using a high speed camera (Model# EX FH25, Casio America Inc., Dover, NJ 07801) at a rate of 240 frames per second. To determine the reliability of different raters to consistently measure the LAA at midsupport while running, two different raters assessed the standing and running LAA images captured for the left and right feet of five randomly selected participants.

Data Analysis
The FPI foot type classifications for each participant were determined by converting raw scores using the criteria described by Redmond, with Highly Supinated = -5 to -12; Supinated = -4 to -1; Normal = 0 to +5; Pronated = +6 to +9; and Highly Pronated = +10 to +12. For each participant, one standing image and five running images for both the left and right foot were selected from the video recordings for analysis. The five running images for each foot were selected after three minutes from the start of the video data recording. The dynamic images used to calculate the LAA during running were captured at midsupport, which for this study was defined as the frame where the medial longitudinal arch (as indicated by the dorsum of the foot just above the marker on the navicular tuberosity) reached the most plantar position before the heel left the supporting surface. Midsupport was selected for capturing the five running images since previous studies assessing rearfoot and midfoot motion during running have reported that the maximum foot pronation occurs at or near midsupport during running. For the six images captured for each foot, a free-access video analysis software program (Kinovea, version 0.8.15, http://www.kinovea.org) was then used to determine the LAA by calculating the angle formed by drawing two lines between the three markers with the navicular tuberosity as the apex of the angle (Fig. 1). For further statistical analysis, the mean of the LAA for the five running trials were averaged (RunLAA).

Statistical Analysis
To assess the reliability of the five running LAA measures for each foot, intraclass correlation coefficients were calculated to determine the consistency of one rater assessing the same group of five runners (intra-rater; ICC 3,1) twice as well as two raters individually assessing the same group of five runners (inter-rater; ICC 2,1). The level of reliability for the ICC were classified based the characterizations reported by Landis and Koch. These characterizations were: slight, if the correlation ranged from 0.00 to 0.20; fair, if the correlation ranged from 0.21 to 0.40; moderate, if the correlation ranged from 0.41 to 0.60; substantial, if the correlation ranged from 0.61 to 0.80; and almost perfect, if the correlation ranged from 0.81 to 1.00.

In addition to descriptive statistics, t-tests were performed to determine if there were differences between extremities and gender for the StandLAA and RunLAA measures. Pearson product coefficients were used to determine the ability of the StandLAA to predict the mean RunLAA measured at midsupport in running. All statistical analyses were performed using JMP software, Version 8 (SAS Institute Inc., Cary NC 27513). An alpha level of .05 was established for all tests of significance.

RESULTS
Demographic data for all subjects are listed in Table 1. The intra-rater reliability for the single rater assessing the LAA for the left and right feet of five runners was 0.87. The inter-rater reliability for two

Table 1. Means (standard deviations) for participant demographics

<table>
<thead>
<tr>
<th></th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>BMI (kg/cm²)</th>
<th>Mileage per Week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females (n = 24)</td>
<td>25.2 (6.4)</td>
<td>164.4 (5.6)</td>
<td>58.6 (5.0)</td>
<td>21.7 (1.8)</td>
<td>34.8 (14.6)</td>
</tr>
<tr>
<td>Males (n = 16)</td>
<td>22.8 (4.4)</td>
<td>179.9 (4.4)</td>
<td>71.8 (8.1)</td>
<td>22.2 (2.4)</td>
<td>52.7 (17.4)</td>
</tr>
<tr>
<td>All runners (n = 40)</td>
<td>24.3 (5.7)</td>
<td>170.5 (9.3)</td>
<td>63.9 (9.1)</td>
<td>21.9 (2.0)</td>
<td>41.9 (17.9)</td>
</tr>
</tbody>
</table>
raters assessing the left and right feet of five runners was 0.96. The FPI classifications of the 80 feet of the 40 runners in this study were: highly supinated = 1; supinated = 13; normal = 41; pronated = 23, and highly pronated = 2.

Descriptive statistics for all measurements are listed in Table 2. The results of the t-tests indicated that mean values between the left and right foot were not significantly different for the StandLAA (p = 0.288; 95% CI: -1.0, 3.4) or RunLAA (p = 0.061; 95% CI: -0.1, 4.5). The results of the t-tests between male and female runners were not significantly different for StandLAA for the left (p = 0.432; 95% CI: -7.6, 3.3) or right foot (p = 0.248; 95% CI: -9.5, 2.6). The results of the t-tests between male and female runners were also not significantly different for the RunLAA for the left (p = 0.602; 95% CI: -9.5, 4.2) or right (p = 0.429; 95% CI: -7.9, 4.7) foot. Based on these findings, the StandLAA and RunLAA measures for the left and right feet were grouped together (n = 80 feet) for further statistical analysis. The correlation between StandLAA and RunLAA was r = 0.95 (r² = 0.90). The following regression equation was determined to allow the clinician to predict the RunLAA at midsupport during running using the StandLAA measured in relaxed standing:

\[ \text{RunLAA} = -20.755 + 1.069 \times \text{StandLAA} \]

To validate this regression equation, the predicted RunLAA value for each runner was calculated using the regression equation and compared to the actual RunLAA for each runner using a t-test. The mean value for the “predicted” RunLAA (132.71 degrees) was compared to the mean for the “actual” RunLAA (132.78 degrees) and these means were not significantly different (p = 0.962), which further validates the regression equation for the prediction of the RunLAA.

**DISCUSSION**

The intent of this study was to determine if the LAA, assessed in relaxed standing, could predict foot posture at midsupport while running on a treadmill. Based on previous research, it was hypothesized that the LAA would be highly predictive of foot posture at midsupport while running. Prior to interpreting the results of the current study, it was important to first establish that a single as well as multiple raters could consistently measure the LAA. The consistency of a single rater (ICC) assessing five running trails for the left and right feet of five randomly selected runners on two separate days was 0.87. The inter-rater reliability (ICC) for two raters assessing five running trails for the left and right feet of five randomly selected runners was 0.96. Based on the ICC classification system proposed by Landis and Koch, both the intra-rater reliability and inter-rater reliability for the LAA would be “almost perfect”. On the basis of these findings, further analysis of the results was performed.

Although recent research has reported that static foot posture assessed using the FPI may not be an accurate representation of dynamic rearfoot or midfoot mobility, it does provide important information
on the foot types of the runners who participated in the study. While the runners in this study were not selected based on foot type, based on the FPI classifications 51% had a normal foot type, 31% had a pronated or highly pronated foot type, and 18% had a supinated or highly supinated foot type. This varied distribution of foot types helps enhance the applicability of the findings of the current study.

The results of the Pearson correlation coefficients indicate that the StandLAA obtained in resting standing posture was highly predictive of the RunLAA measured at midsupport while running explaining approximately 90% of the variance. Based on this high degree of association, the regression equation described in the Results section can be used to predict the RunLAA at midsupport in running by inserting the StandLAA value measured in relaxed standing. As a result of this finding, the hypothesis that the StandLAA measured in relaxed standing would be highly predictive of RunLAA at midsupport while running was confirmed. It would also appear, based on these findings that the measurement of the StandLAA in resting standing would be a valuable addition to the physical examination of the individual with a running-related overuse injury. In addition, as previously noted the use of the StandLAA could also assist the clinician to determine if foot orthoses prescribed for the runner have modified or changed the position of the foot from relaxed standing posture. By measuring the change in the LAA with the runner standing on the orthosis, because of the close relationship (high degree of association) between the StandLAA and RunLAA demonstrated in this study, the clinician could assume that the posture of the foot at midsupport in running would also be changed thereby reducing the level of tissue stress. Of course, further research would be required to substantiate this hypothesis.

The findings of the current study are in close agreement with the previous research by McPoil and Cornwall who reported that the static LAA was highly predictive of the dynamic LAA in midsupport while running with a correlation of $r = 0.920$ ($r^2 = 0.846$). In the current study, the mean value for the StandLAA was 143.6 degrees. This is in close agreement to the mean values for the relaxed standing LAA reported by Jonson and Gross (141.6 degrees; $n = 63$) and McPoil and Cornwall (139.4 degrees; $n = 100$). In the current study, the magnitude of the change between the StandLAA and the RunLAA was 10.8 degrees. This measure of the deformation of the medial longitudinal arch between relaxed standing and midsupport of running is almost identical to the 9.7 degree change previously reported by McPoil and Cornwall.

As was noted in the introduction, to enhance the clinical applicability of the findings of the current study, a single low-cost high-speed camera to capture the running images while running on a treadmill was utilized. In addition, a free-access video analysis software program was used to analyze the standing and running images. Several researchers have reported on the validity of using a treadmill for running analysis with the major concern being the alteration of the runner’s pattern of lower extremity movement as well as ground reaction forces. In one of the only studies to compare overground versus treadmill running kinematics and kinetics using a force-transducer instrumented treadmill, Riley et al reported that a treadmill-based analysis of running mechanics can be generalized to overground running mechanics, provided the running speed on the treadmill is similar to individuals overground running speed.

Another limitation of the current study was the use of a single high-speed camera to capture sagittal plane (2-dimensional) movement of the medial aspect of the foot during running. While previous studies have discussed the issues associated with attempts to use two-dimensional motion analysis to assess rearfoot movement in running, Areblad et al reported that the use of two-dimensional techniques to assess angular values in the sagittal plane during running are similar to values obtained using three-dimensional motion analysis techniques. This is important since three-dimensional motion analysis that utilizes sophisticated equipment and software is not available in most clinical settings. Thus, the clinician can have confidence in using a single high-speed camera to record the LAA in the sagittal plane during running if they desire to assess the LAA using a treadmill.

**CONCLUSION**

While the etiology of running-related overuse injuries have been shown to be multifactorial, foot
posture has been implicated as a factor in several studies. Thus, it would appear to be important for the clinician examining a runner with a repetitive-stress injury to include an assessment of static foot posture. The use of a static measurement that can be reliably performed and accurately predict foot posture during running would be of value to the practitioner. The results of this study substantiate the use of the LAA, measured in relaxed standing, to predict the LAA at or near midsupport during running on a treadmill. The clinician can use the regression formula provided in this paper to understand how foot posture, when measured in relaxed standing, can change during running to enhance their physical examination findings.

REFERENCES


ABSTRACT

Background: There are conflicting results with respect to the validity and reliability of lower extremity strength measurements using a hand-held dynamometer (HHD) in the healthy population. Previous studies exploring foot inversion and eversion strength using a HHD were carried out with predominantly clinically affected participants in different positions. The question arises whether HHD measurements of isometric foot inversion and eversion strength performed with participants in different positions are valid, reliable and comparable and can be used alternatively.

Purpose: The aims of this study were to investigate: a) the intra- and inter-tester reliability of measurements of foot inversion and eversion strength in different participant positions using a belt-stabilized HHD; b) the comparability of results obtained in different positions; and c) the concurrent validity of the aforementioned measurements using an isokinetic dynamometer.

Methods: Thirty adults (12 females and 18 males; mean age 22.5 ± 3.9 years) volunteered to participate in this study. Maximal isometric foot inversion and eversion torques (Nm) were measured with participants lying supine, sitting with knees extended and lying on their side using a belt-stabilized HHD. Measurements were performed independently by two physiotherapists over two days and were repeated using an isokinetic dynamometer. Validity and intra- and inter-tester reliability were determined using the intra-class correlation coefficient (ICC). A two-way ANOVA (p<0.05) and post-hoc tests with Bonferroni correction were used to compare data from different positions. Bland-Altman plots were used to demonstrate the range of error and difference between HHD and isokinetic measurements.

Results: Intra-tester reliability for inversion and eversion torques was fair to excellent in all positions (ICC=0.598–0.828). Excellent inter-tester reliability was found for eversion torques in all positions (ICC=0.773–0.860). For inversion torques, inter-tester reliability was fair to excellent (ICC=0.519–0.879). ICC values of 0.205 to 0.562 indicated a low to fair concurrent validity. A significant difference was observed between the torques of the supine and side-lying positions as well as sitting and side-lying positions (p<0.05). Bland-Altman plots showed that the mean of the differences for inversion and eversion torques deviates considerably from zero, indicating that measurements with the HHD in the three positions produce lower values compared to using the isokinetic dynamometer.

Conclusions: Inversion and eversion strength measurements with subjects in different positions using HHD seem to be reliable, but consistently underestimated torque output when compared with measurements using isokinetic dynamometry. While the HHD outcomes measured in supine and sitting positions seem to be comparable, those measured in supine/sitting and side-lying positions differed.

Keywords: different test positions; dynamometry; eversion; inversion; reproducibility

Level of Evidence: Diagnostic study, Level 3
INTRODUCTION

Ankle inversion and eversion muscle strength may become impaired as a result of disorders or acute injuries. Physiotherapists need to use a practical method for identifying muscle strength deficits in the ankle and foot during examination. Strength measurements, usually expressed as force or torque, can be performed using commercially available isokinetic dynamometers, which are considered to be the gold-standard. However, these time-intensive measurements require large and expensive equipment. As an alternative, hand-held dynamometers (HHD) have been used for clinical muscle strength examinations and research with demonstrated reliability and validity.

There are conflicting results with respect to the reliability of lower extremity strength measurements using a HHD in the healthy population. A wide range of correlation coefficients was found for hip extension, hip abduction, knee flexion, and ankle dorsiflexion in a small sample of only four healthy subjects. On the contrary, high correlations (>0.80) for muscle strength measurements of ankle dorsiflexion and plantarflexion as well as knee and hip flexion and extension within and between raters were determined in 55 healthy students. For strength measurements of the ankle plantarflexors and dorsiflexors, ICC values of 0.31-0.79 were found between measurements using a HHD and a fixed KinCOM electromechanical dynamometer, demonstrating poor to good concurrent validity. These results were similar to those of Marmon et al who used a KinCOM dynamometer and a HHD. Insufficient data for isometric strength measurements of foot inversion and eversion using a HHD in the healthy population are available in the literature. To investigate the influence of ankle orthoses, Paris & Sullivan measured rearfoot inversion and eversion strength with the participants sitting at the edge of the bench or table with the knee flexed and the lower leg hanging down, fixed with a padded and adjustable device. Under these conditions, gravity may have had an important influence on force development.

However, high intra-tester reliability has been determined for isokinetic inversion (ICC = 0.92-0.96) and eversion (ICC = 0.87-0.94) torque measurements at 60 and 180 degrees/s angular velocities in healthy people. An ICC value of 0.95 demonstrated high inter-tester reliability in the same study. Test-retest reliability with ICC values between 0.87 and 0.96 have also been reported for isometric inversion and eversion strength measurements using an isokinetic dynamometer.

In the clinically affected population, strength measurements of foot inversion and eversion using a HHD were carried out with participants in different positions. Foot inversion and eversion muscle strength in subjects with Type I myotonic dystrophy and healthy controls was measured with the participants lying supine in order to reduce the influence of gravity. Docherty et al. tested the foot eversion strength, and Hall et al. measured eversion and inversion strength in patients with chronic instability of the ankle with the participants lying on their side. Carroll et al. assessed foot inversion and eversion strength in patients with rheumatoid arthritis and healthy controls, with the subjects sitting on the treatment bench with their knees extended. Thus, the question arises whether HHD measurements of foot inversion and eversion strength performed with participants in different positions are valid, reliable and comparable and can be used alternatively. Furthermore, different testing procedures using a HHD may influence internal validity. Results from previous studies indicate that the rater’s gender, body weight, grip strength and various strength levels of different testers can have an impact on reliability of testing with a HHD. The experience of the raters was considered to not affect reliability of strength measurements using a HHD. However, a decisive factor was the strength of the tester to withstand the force generated by the tested person. When forces above 120 Newton (N) are applied, the tester’s strength appears to determine the magnitude and reliability of the forces measured with the HHD. This may lead to an underestimation of the muscle strength. Therefore, a fixation of the HHD using a belt/strap or a steel frame during measurements has been recommended. To the authors knowledge to date, strength measurements of foot inversion and eversion have not been investigated using a belt-stabilized HHD. Finally, the angle of the talocrural joint during testing appears to affect muscle strength measurements. Foot inversion and
eversion torques were found to be greater at 10° of plantarflexion than those generated at neutral dorsiflexion and plantarflexion as well as 10°-dorsiflexed foot positions during isokinetic testing.28

Reliability and validity of foot inversion and eversion muscle strength measurements using a HHD in healthy participants and the comparability between measurements with participants in different positions have not been determined previously. Therefore, the aims of this study were to investigate: a) the intra- and inter-tester reliability of measurements of foot inversion and eversion strength in different participant positions using a belt-stabilized HHD; b) the comparability of results obtained in different positions; and c) the concurrent validity of the aforementioned measurements using an isokinetic dynamometer.

It was hypothesized that the measurements of foot inversion and eversion muscle strength in different participant positions would be reliable but not comparable when measured twice by the same tester and when measured by different testers. Furthermore, it was expected that the measurements using HHD would be valid compared to the isokinetic method considered to be the gold standard.

METHODS

Participants
Thirty healthy participants (12 females and 18 males) volunteered to participate in the study. Their mean age was 22.5 (± 3.9) years, their mean height was 176.0 (± 11.6) cm, their mean body mass was 71.7 (± 2.6) kg, and their mean body mass index was 23.1 (± 2.6) kg/m². The participants were recruited from a local school of physical therapy and occupational therapy education. A questionnaire was used to select participants for the study. Inclusion criterion was being between the ages of 18 and 35 years. The following exclusion criteria were utilized:

- A history of a traumatic injury of the lower extremity, the pelvis, and/or trunk within the previous 12 months
- A chronic disorder of the lower extremity, e.g., chronic instability of the ankle joint or Achilles or patellar tendinopathy
- Acute, sub-acute or chronic low back pain with and without radiating symptoms
- Acute pain and dysfunction of the lower extremity
- Neurological diseases or disorders

All of the participants gave written informed consent prior to participation and were able to withdraw from the study at any time without any consequences. The study was approved by the Ethik-Kommission der Deutschen Sporthochschule Köln.

Procedures
Maximal isometric foot inversion and eversion torques of one foot were measured by two experienced physiotherapists (one female and one male) independently over two days in three different subject test positions using a belt-stabilized hand-held dynamometer (Commander™ Muscle Tester, JTECH Medical, Salt Lake City, USA). This HHD consists of a transducer used to record peak force (in Newtons), which is connected to a console that collects, stores, and displays data from the transducer. The belt was used for stabilization because of the expectation that the forces generated by healthy subjects would exceed the withstanding force of the tester, which is necessary to perform “make” tests precisely.26 Furthermore, using a belt is convenient29 and reduces the influence of the testers’ different strength levels.27,30

Participants were first positioned supine on a treatment bench with the head and neck supported by a foam therapy half roll with the feet off the end of the treatment bench (Fig. 1). The tester stood beside the participant's tested foot. The HHD was stabilized using a non-elastic belt that was placed around the pelvis of the tester. The pelvis, thighs, and tibias of both legs of the subjects were secured with non-elastic belts.
between the first metatarsal head (dynamometer placement) and the superior part of the sustentaculum tali, and for eversion strength between the fifth metatarsal head (dynamometer placement) and the superior part of the cuboid.

Isometric “make” tests were performed. During the make test, the participant applies a maximal force against the HHD, that is stabilized by the examiner or a belt. In contrast, the break test is performed by the examiner pushing the HHD against the participant’s extremity until the participant’s maximal muscular exertion is exceeded and the joint gives way. Resistance was held for three seconds. After one trial of a submaximal contraction was used to familiarize the subject with the task, three consecutive maximal contractions were performed by the subject which were recorded by an independent assessor. The tester, the subject and the assessor were blinded to the results from the previous day and to the results of the other tester. The mean of the three trials was used for further analysis. Participants rested for approximately one minute when changing between the test positions and for approximately three minutes between groups of inversion and eversion measurements. All participants were finally, participants were positioned on their side, again with the measured foot off the end of the treatment bench and with the tibia and thigh of the tested leg fixed with non-elastic belts (Fig. 2). The knee was supported by a rolled towel. The HHD was stabilized using a non-elastic belt that was vertically applied around the forefoot of the subject and the foot of the tester standing on the ground.

In all test conditions, the foot was positioned at 10° of plantarflexion. For testing foot eversion strength, the transducer of the hand-held dynamometer was positioned at the lateral border of the forefoot directly below the fifth metatarsal head. For measuring foot inversion strength, the transducer of the hand-held dynamometer was placed at the medial border of the forefoot directly below the first metatarsal head. These points were marked with a waterproof pen for the retest. The recorded force in Newton (N) was converted to torque and expressed as Newton-meters (Nm) by multiplying it by the corresponding lever arm (in meters). The functional axis of rotation for eversion and inversion enters the front superior part of the talus on the medial side and crosses downwards to the lateral rearfoot. For testing inversion strength, the lever arm was defined as the distance between the first metatarsal head (dynamometer placement) and the superior part of the sustentaculum tali, and for eversion strength between the fifth metatarsal head (dynamometer placement) and the superior part of the cuboid.

Isometric “make” tests were performed. During the make test, the participant applies a maximal force against the HHD, that is stabilized by the examiner or a belt. In contrast, the break test is performed by the examiner pushing the HHD against the participant’s extremity until the participant’s maximal muscular exertion is exceeded and the joint gives way. Resistance was held for three seconds. After one trial of a submaximal contraction was used to familiarize the subject with the task, three consecutive maximal contractions were performed by the subject which were recorded by an independent assessor. The tester, the subject and the assessor were blinded to the results from the previous day and to the results of the other tester. The mean of the three trials was used for further analysis. Participants rested for approximately one minute when changing between the test positions and for approximately three minutes between groups of inversion and eversion measurements. All participants were
measured barefoot. The foot (right/left) of the participant, the foot movement (inversion/eversion), and the position of the subject (supine, sitting, side-lying) were tested in a random order to avoid any effects of fatigue and habituation. Furthermore, the first tester (of the two testers) was selected at random. The participants were tested consecutively. The order of testing could not be randomized because of subjects’ individual availability. This testing procedure was preserved for the retest session. All data collection using the HHD took place at medicoreha Welsink Akademie GmbH, a school of physiotherapy education in the city of Neuss (Germany).

In order to investigate the validity of the measurements of hand-held dynamometry, isometric foot inversion and eversion strength was tested using an isokinetic dynamometer (Cybex II®, USA) and recorded by the corresponding software (HUMAC® 2008v8.5.3 Norm™, CSMi Medical Solutions, 101 Tosca Drive, Stoughton, MA). The Cybex II® is considered to be reliable and valid for strength testing of the lower extremity. Here, only 26 of the subjects participated and were considered for comparisons between HHD and isokinetic dynamometer measurements. Four participants were not available for this part of the study due to personal reasons. Participants were positioned according to the manufacturer's recommendations. They sat on the chair with the chair's backrest tilted (60°). The popliteal fossa of the tested leg lay on a cushion of a fixture and was fixed with a strap. The foot was placed on the ankle inversion-eversion footplate attachment at 10° of plantarflexion and fastened using hook-and-loop closures to avoid movement between the sole of the shoe and the surface of the footplate (Fig. 3). Participants wore their own athletic shoes. The midline of the foot was aligned with the midline of the patella when adjusting the dynamometer and the chair; positioning the calf in a nearly horizontal orientation. Data collected using the isokinetic dynamometer were performed at medicoreha Welsink Rehabilitation GmbH, an outpatient rehabilitation center in the city of Neuss (Germany).

**Statistical analysis**

Data were examined for the normal distribution using the Kolmogorov-Smirnov test and histograms, and normal distribution of data was confirmed, allowing use of parametric tests for analysis. For testing the homogeneity of variance of the dependent variable isometric muscle strength of foot inversion and eversion, the Levene test was performed. Intra-class correlation coefficients (ICC, model 2, k) and 95% confidence intervals (CI) were then used to determine intra- and inter-tester measurement reliability. Values < 0.50 represented poor reliability, values > 0.50 and < 0.75 indicated fair to good reliability, and values > 0.75 marked excellent reliability.15

A two-way repeated measures analysis of variance (ANOVA) was used to test the interaction between the factors of test position and tester on measurements of isometric foot inversion and eversion torques using the HHD. The level of statistical significance was set a priori at $\alpha < 0.05$. Post hoc tests with Bonferroni adjustment of $p$-values were used for multiple pairwise comparisons of maximal inversion and eversion torques between test positions (supine, sitting and side-lying) within testers. Concurrent validity between measurements detected by hand-held dynamometry and isokinetic dynamometry was determined by calculating the intra-class correlation coefficient (ICC, model 3, k) and 95% confidence intervals (CI) between measurements of both testers using HHD and the measurement using the isokinetic dynamometer. Furthermore, Bland-Altman plots were used to demonstrate the range of error and difference between HHD and isokinetic
RESULTS

Intra-tester reliability
For the maximal isometric inversion torque, intra-tester reliability for Tester 1 and Tester 2 was excellent in the supine position (Tester 1: ICC₂,k = 0.815, 95% CI: 0.615-0.912, p<0.001; Tester 2: ICC₂,k = 0.813, 95% CI: 0.608-0.911, p<0.001), good to excellent in the sitting position (Tester 1: ICC₂,k = 0.784, 95% CI: 0.551-0.897, p<0.001; Tester 2: ICC₂,k = 0.739, 95% CI: 0.455-0.876, p<0.001), and good in the side-lying position (Tester 1: ICC₂,k = 0.675, 95% CI: 0.319-0.845, p=0.002; Tester 2: ICC₂,k = 0.677, 95% CI: 0.336-0.844, p=0.001) (Fig. 4).

For the maximal isometric eversion torque, intra-tester reliability for Tester 1 and Tester 2 was good to excellent in the supine position (Tester 1: ICC₂,k = 0.625, 95% CI: 0.221-0.821, p=0.005; Tester 2: ICC₂,k = 0.813, 95% CI: 0.605-0.911, p<0.001), good to excellent in the sitting position (Tester 1: ICC₂,k = 0.645, 95% CI: 0.247-0.832, p=0.004; Tester 2: ICC₂,k = 0.819, 95% CI: 0.617-0.914, p<0.001), and fair to excellent in the side-lying position (Tester 1: ICC₂,k = 0.828, 95% CI: 0.641-0.918, p<0.001; Tester 2: ICC₂,k = 0.598, 95% CI: 0.146-0.810, p=0.009) (Fig. 4).

Inter-tester reliability
For the maximal isometric inversion torque, inter-tester reliability was good to excellent in the supine position when measured over two days (day 1: ICC₂,k = 0.656, 95% CI: 0.215-0.843, p<0.001; day 2: ICC₂,k = 0.824, 95% CI: 0.634-0.916, p<0.001). In the sitting position, inter-tester reliability was fair on day one (ICC₂,k = 0.519, 95% CI: 0.045-0.777, p=0.005) and excellent on day two (ICC₂,k = 0.879, 95% CI: 0.731-0.944, p<0.001). Measurements in the side-lying position revealed excellent inter-tester reliability on day one (ICC₂,k = 0.812, 95% CI: 0.604-0.911, p<0.001) as well as day two (ICC₂,k = 0.835, 95% CI: 0.655-0.921, p<0.001) (Fig. 5).

For the maximal isometric eversion torque, inter-tester reliability was excellent in the supine position.
demonstrated significant tester X test position interaction effects for inversion and eversion torques ($p<0.001$). Figure 6 shows the significance of simple effects (the effect of test position for each tester) on both days.

Furthermore, a significant day X test position interaction effect was noted for inversion torques measured by Tester 2 ($p<0.05$). The significant differences ($p$-values) between the post hoc tests of measurements in different test positions within testers on days one and two are presented in Table 1.

### Table 1. Mean ± standard deviation (SD) and standard error of measurement (SEM) for maximal isometric torques (Nm) of foot inversion and eversion in different subject positions using the HHD.

Significance of differences (Bonferroni adjusted $p$-values) of post hoc tests of measurements in different test positions (ab = supine vs. sitting, ac = supine vs. side-lying, bc = sitting vs. side-lying) within testers on days one and two

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Test condition, Tester 1, day 1</th>
<th>Test condition, Tester 2, day 1</th>
<th>Significance of differences between test positions, within tester</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HHD supine (a) [Mean ± SD (SEM)]</td>
<td>HHD sitting (b) [Mean ± SD (SEM)]</td>
<td>HHD side lying (c) [Mean ± SD (SEM)]</td>
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<tr>
<td>Inversion</td>
<td>7.3 ± 2.8 (0.5)</td>
<td>8.0 ± 2.4 (0.4)</td>
<td>8.9 ± 2.8 (0.5)</td>
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<tr>
<td>Eversion</td>
<td>6.2 ± 2.1 (0.4)</td>
<td>6.2 ± 2.2 (0.4)</td>
<td>11.0 ± 3.7 (0.7)</td>
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<td></td>
<td>HHD supine (a) [Mean ± SD (SEM)]</td>
<td>HHD sitting (b) [Mean ± SD (SEM)]</td>
<td>HHD side lying (c) [Mean ± SD (SEM)]</td>
</tr>
<tr>
<td>Inversion</td>
<td>5.9 ± 2.3 (0.4)</td>
<td>6.1 ± 2.3 (0.4)</td>
<td>8.8 ± 2.8 (0.5)</td>
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<tr>
<td>Eversion</td>
<td>5.8 ± 2.1 (0.4)</td>
<td>5.7 ± 2.2 (0.4)</td>
<td>10.4 ± 3.4 (0.6)</td>
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<td>HHD supine (a) [Mean ± SD (SEM)]</td>
<td>HHD sitting (b) [Mean ± SD (SEM)]</td>
<td>HHD side lying (c) [Mean ± SD (SEM)]</td>
</tr>
<tr>
<td>Inversion</td>
<td>7.0 ± 2.5 (0.5)</td>
<td>7.8 ± 2.7 (0.5)</td>
<td>9.4 ± 3.9 (0.7)</td>
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<tr>
<td>Eversion</td>
<td>5.8 ± 1.7 (0.3)</td>
<td>6.1 ± 2.1 (0.4)</td>
<td>10.5 ± 3.6 (0.7)</td>
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<td>HHD supine (a) [Mean ± SD (SEM)]</td>
<td>HHD sitting (b) [Mean ± SD (SEM)]</td>
<td>HHD side lying (c) [Mean ± SD (SEM)]</td>
</tr>
<tr>
<td>Inversion</td>
<td>6.5 ± 2.5 (0.5)</td>
<td>6.9 ± 2.6 (0.5)</td>
<td>9.8 ± 4.0 (0.7)</td>
</tr>
<tr>
<td>Eversion</td>
<td>5.8 ± 1.7 (0.3)</td>
<td>5.7 ± 1.9 (0.3)</td>
<td>10.2 ± 3.2 (0.6)</td>
</tr>
</tbody>
</table>

when measured on two days (day 1: ICC$^{2,k} = 0.829$, 95% CI: 0.643-0.918, $p<0.001$; day 2: ICC$^{2,k} = 0.773$, 95% CI: 0.519-0.892, $p<0.001$). In the sitting position, inter-tester reliability was excellent on day one (ICC$^{2,k} = 0.822$, 95% CI: 0.626-0.915, $p<0.001$) and on day two (ICC$^{2,k} = 0.794$, 95% CI: 0.573-0.901, $p<0.001$). Measurements in the side-lying position demonstrated excellent inter-tester reliability on day one (ICC$^{2,k} = 0.858$, 95% CI: 0.705-0.923, $p<0.001$) as well as day two (ICC$^{2,k} = 0.860$, 95% CI: 0.706-0.933, $p<0.001$) (Fig. 5).

### Comparability of the measurements in different test positions

The mean, standard deviation, and standard error of measurement for maximal isometric torques of foot inversion and eversion in different participant positions using the HHD are shown in Table 1. Two-way repeated measures analysis of variance (ANOVA) demonstrated significant tester X test position interaction effects for inversion and eversion torques ($p<0.001$). Figure 6 shows the significance of simple effects (the effect of test position for each tester) on both days.

Furthermore, a significant day X test position interaction effect was noted for inversion torques measured by Tester 2 ($p<0.05$). The significant differences ($p$-values) between the post hoc tests of measurements in different test positions within testers on days one and two are presented in Table 1.

### Concurrent validity

Strength measurements using the isokinetic dynamometer revealed considerably higher inversion [mean: 20.1 ± SD 6.1 Nm (SEM 1.2)] and eversion torques [mean: 18.9 ± SD 8.3 Nm (SEM 1.6)] than torques measured with the HHD in all positions.
Accordingly, little agreement between measurements using the HHD and isokinetic dynamometer was observed for maximal isometric inversion torques. The HHD measurement in the supine position vs. isokinetic dynamometry revealed an ICCs,k = 0.303 (95% CI: -0.555-0.687, p=0.187). The HHD measurement in the sitting position vs. isokinetic dynamometry showed an ICCs,k = 0.347 (95% CI: -0.457-0.707, p=0.147). A fair correlation was demonstrated between the measurement using the HHD in the side-lying position vs. the isokinetic dynamometer (ICCs,k = 0.562, 95% CI: 0.024-0.804, p=0.022).

For the maximal isometric eversion torque, similar results were observed for the comparison between the HHD measurement in the supine position, and the isokinetic dynamometer (ICCs,k = 0.205, 95% CI: -0.772-0.644, p=0.285). Low correlations between HHD and isokinetic measurements were observed in the sitting position (ICCs,k = 0.241, 95% CI: -0.693-0.660, p=0.248) and the side-lying position (ICCs,k = 0.427, 95% CI: -0.278-0.743, p=0.085). Bland-Altman plots show that measurements using the HHD do not agree with those using the isokinetic dynamometer (Fig. 7). The mean of the differences of measurements for inversion and eversion torques deviates considerably from zero, indicating that measurements using the isokinetic dynamometer produce higher values than measurements using the HHD. Furthermore, the plots consistently show that the greater the torques, the greater the deviation from zero. The difference in inversion torques using the HHD and the isokinetic dynamometer varied extensively with the 95% limits of agreement between 1.7 Nm and 24.9 Nm measured in supine position, between 1.5 Nm and 24.3 Nm assessed in sitting and between 0.4 Nm and 20.8 Nm assessed in side-lying. The difference in eversion torques using the HHD and the isokinetic dynamometer varied similarly with the 95% limits of agreement between -2.7 Nm and 28.7 Nm measured in supine position, between -2.7 Nm and 28.7 Nm measured in sitting and between -6.4 Nm and 23.0 Nm assessed in side-lying.

A post-hoc power analysis on the basis of \( \alpha < 0.05 \), the lowest identified effect size (\( \eta^2 = 0.44 \), i.e., \( f = 0.89 \)) from two-way ANOVA comparing measurements.
While the maximal torques between supine and sitting with the knees extended test positions were comparable, those carried out with supine/sitting and side-lying positions differed. When compared to measurements using an isokinetic dynamometer, the maximal torques differed as well.

Figure 7. Bland-Altman plots illustrating the difference (y-axis) compared with the mean (x-axis) of foot inversion and eversion torques (Nm) using a hand-held dynamometer (HHD) and isokinetic dynamometer. The middle line characterizes the mean difference between the HHD and isokinetic dynamometer. The upper and lower dashed lines demonstrate the 95% limits of agreement.

using HHD in different test positions, and a sample size of $n = 30$, revealed a test power of $> 90\%$.

DISCUSSION
The main findings of the present study were that measurements of foot inversion and eversion torques in different test positions using a belt-stabilized HHD were reliable when repeated by the same tester and when measured by different testers. The analysis of the reliability of foot inversion and eversion strength testing in healthy subjects is similar
Analysis of the inter-tester reliability of measurements demonstrated a higher agreement between the results of testers on the second day compared with the first day for the supine and sitting test positions, suggesting a learning effect for testers. For eversion torques, correlations between testers were excellent on both days for all of the test positions, especially for side-lying position. In this position, the belt was fixed with the foot of the tester standing on the ground, ensuring a total static resistance without the influence of resistance applied by the tester's body or body parts. This suggests that a belt-fixed method, where stabilization is provided by a static object, should be used for inversion and eversion strength testing.

Force values of measurements using a HHD have been previously reported to range from 19.5 kg (=191.3 N) to 22.0 kg (=215.8 N) for inversion and from 19.5 kg (=191.3 N) to 22.4 kg (=219.7 N) for eversion in healthy participants with a slightly higher mean age of 28.1 years. In the present study, the strength values in all positions are considerably lower. Furthermore, they differ similarly to the values reported for the healthy controls in the study by Carroll et al.1 (inversion: 127.5 N; eversion: 121.7 N). This is in contrast to the suggestion that forces or torques measured with a belt-stabilized HHD would reveal higher values than assessed manually as previously reported for the knee and the hip. Therefore, stabilizing the HHD using a non-elastic belt may not be optimal for replacing the manual resistance applied by the tester in HHD foot inversion and eversion measurements. However, this should be investigated in further studies.

The peak eversion torques of control subjects with a mean age of 43.1 years (subjects from Quebec) and 45.7 years (subjects from Lyon) in the study of Hébert et al.3 ranged from 17.9 Nm to 19.6 Nm. Furthermore, isometric pronator and supinator torques that were measured using a specific foot apparatus ranged from 17.5 Nm to 18.5 Nm and from 13.3 Nm to 14.8 Nm, respectively.9 However, the lever arm was not defined in either of the previous studies, so that differences might have been caused by a larger lever arm. Furthermore, the different position of participants9 might be another reason for different torque outputs.

The peak forces measured with the HHD in the present study were lower than foot inversion and eversion force values in patients with chronic ankle instability measured with a HHD prior to a training intervention.22 The force values in the study of Hall et al.22 ranged from 157.2 N to 187.5 N for inversion and from 141.2 N to 175.5 N for eversion. Therefore, it appears that results of inversion and eversion strength measurements using HHD depend on the test method rather than on the existing ankle instability.

In the present study, the torques tested in the supine and sitting positions were consistently lower than those measured in the side-lying position, indicating that gravity is not the crucial factor in strength measurements using HHD. The fixation of the dynamometer and the applied resistance appeared to be most reliable in the side-lying position. It is therefore obvious that the muscles need a constant static resistance in order to generate high forces and torques, which is consistent with the results of the aforementioned studies of the knee and hip.

Isometric eversion torques measured with the isokinetic dynamometer revealed lower values than eversion torques of healthy controls in the study of Kaminski et al. (30.14 Nm)31 who only tested male students, which could account for the higher values.
The SEMs for the measurements using HHD and isokinetic dynamometer in the present study were low, indicating that differences of strength levels between subjects appear to be identifiable. As previously reported for the shoulder, testing techniques with low SEM are considered to be important for accuracy of measurements, especially to predict risk of injury.40

Concurrent validity of inversion and eversion strength was low to fair compared with results of isokinetic dynamometry. This is consistent with the results from a study investigating plantarflexion strength. Measurements using HHD in a side-lying position demonstrated higher validity than measurements in supine and sitting positions, which supports the theory that strength testing could be better controlled in this position. Furthermore, Bland-Altman plots showed that the discrepancy between HHD measurements and measurements using the isokinetic dynamometer increased with higher torques produced by the stronger subjects, especially when carried out with subjects in supine and sitting positions. Consequently, it seems that both testers were not able to control the torques generated by stronger subjects, although the HHD was stabilized using a belt around the tester’s pelvis. The findings of 95% limits of agreement support these assumptions and are similar to those previously determined for plantarflexion force values.7 It seems that the torques measured with the belt-stabilized HHD with participants lying on the side are more similar to the torques obtained with the isokinetic dynamometer because the tester could stabilize the belt to a fixed object, the floor. Based on these findings from Bland-Altman analysis, physiotherapists should not use the HHD and the isokinetic dynamometer alternatively to identify deficits of foot inversion and eversion strength. The validity results should be interpreted with caution, however, because the isokinetic test position differed from the position used for measurements with HHD. Furthermore, during measurements with the isokinetic dynamometer, the participants wore their own shoes to ensure a safe fixation of the foot on the footplate of the device while strength measurements using HHD were performed barefoot to ensure comparability with results presented in literature.

There are further limitations of the study that need to be addressed. In measurements using the HHD, a limitation was that the dynamometer was fixed with the belt around the pelvis of the tester with the subject in the supine and sitting positions; therefore, the applied resistance depended on the tester. However, as this technique is often used in manual therapy interventions, it was expected that resistance could be controlled more effectively with the body weight of the tester than with resistance applied with the hand.26 For future investigations, a device to stabilize the belt to a fixed object introduced by Thorborg et al30 may help to improve the test methods and reduce variation.

CONCLUSION
Inversion and eversion strength measurements using HHD in different subject positions demonstrate good to excellent intra- and intertester reliability but only poor to fair validity when compared with isometric strength measurements using an isokinetic dynamometer. While the outcomes assessed in supine and sitting positions seem to be comparable, those measured in supine/sitting and side-lying positions differed. These results may be relevant for the measurement of foot inversion and eversion strength during the recovery from common and prevalent foot and ankle injuries.

REFERENCES


ABSTRACT

**Background:** Based on the frequency pushing and pulling patterns are used in functional activities, there is a need to establish an objective method of quantifying the muscle performance characteristics associated with these motions, particularly during the later stages of rehabilitation as criteria for discharge. While isokinetic assessment offers an approach to quantifying muscle performance, little is known about closed kinetic chain (CKC) isokinetic testing of the upper extremity (UE).

**Purpose:** To determine the intersession reliability of isokinetic upper extremity measurement of pushing and pulling peak force and average power at slow (0.24 m/s), medium (0.43 m/s) and fast (0.61 m/s) velocities in healthy young adults. The secondary purpose was to compare pushing and pulling peak force (PF) and average power (AP) between the upper extremity limbs (dominant, non-dominant) across the three velocities.

**Methods:** Twenty-four physically active men and women completed a test-retest (>96 hours) protocol in order to establish isokinetic UE CKC reliability of PF and AP during five maximal push and pull repetitions at three velocities. Both limb and speed orders were randomized between subjects.

**Results:** High test-retest relative reliability using intraclass correlation coefficients (ICC2,1) were revealed for PF (.91-.97) and AP (.85-.95) across velocities, limbs and directions. PF typical error (% coefficient of variation) ranged from 6.1% to 11.3% while AP ranged from 9.9% to 26.7%. PF decreased significantly (p<.05) as velocity increased whereas AP increased as velocity increased. PF and AP during pushing were significantly greater than pulling at all velocities, however the push-pull differences in PF became less as velocity increased. There were no significant differences identified between the dominant and nondominant limbs.

**Conclusion:** Isokinetically derived UE CKC push-pull PF and AP are reliable measures. The lack of limb differences in healthy normal participants suggests that clinicians can consider bilateral comparisons when interpreting test performance. The increase in pushing PF and AP compared to pulling can be attributed to the muscles involved and the frequency that pushing patterns are used during functional activities.

**Level of Evidence:** 3

**Keywords:** Closed kinetic chain, power testing, strength testing, upper extremity

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**Acknowledgements**

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**Conflict of Interest**

The principal investigator for this study is an Adjunct Clinical Instructor for Biodex Medical Systems (Shirley, NY).

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INTRODUCTION
Many activities of daily living (ADL), such as mowing the lawn and vacuuming, require pushing and pulling motions of the upper extremity. Several sports activities, including football, rugby, wrestling, jujitsu, and mixed martial arts, frequently use upper extremity motions of pushing and pulling. During upper extremity push and pull movements, multiple muscles at the shoulder girdle, shoulder, elbow, and wrist joints contribute to the torque production and stabilization effort. Based on the frequency that these movements are used in both ADL and sports activities, there is a need to establish an objective method of quantifying the muscle performance characteristics associated with pushing and pulling motions, particularly during the later stages of rehabilitation as a potential criteria for discharge.

There is an abundance of research supporting the reliability and quantification of the muscle forces contributing to torque production at each individual joint of the upper extremity through hand held dynamometry and isokinetic testing. In contrast, there has been far less research examining the forces produced during upper extremity pushing and pulling movements. The benefit of isokinetics, to offer accommodating resistance through the range of motion across the velocity spectrum, has been well established, and therefore would represent a safe way to assess pushing and pulling force production in patients. The lack of instrumentation available to assess linear movement patterns of the upper extremities may explain the dearth of research examining isokinetic characteristics of upper extremity pushing and pulling. One exception is the closed kinetic chain (CKC) testing attachment for the Biodex System Dynamometers (Biodex Medical System, Inc. Shirley, NY) which converts rotary motion of the dynamometer into linear motion, thereby allowing for testing and training of pushing and pulling movement patterns.

The majority of work investigating CKC isokinetic testing has considered quantification of scapular protraction and retraction muscle performance, one of the joints contributing to upper extremity pushing and pulling. The CKC attachment in conjunction with the Biodex System Dynamometer was found to be a reliable in assessing peak force and total work produced during scapular protraction and retraction at speeds of 0.122 m/s and 0.366 m/s. In healthy individuals, no significant differences were revealed between dominant and nondominant arms for both peak force and total work. In addition to demonstrating significant velocity effects, protraction and retraction forces were reported to be equal at the higher test velocity, whereas protraction was significantly greater than retraction at the slower testing velocity. Finally, patients with impingement symptoms were demonstrated to have significantly lower protraction high speed peak force and a significantly low velocity lower protraction/retraction ratio. Gorman studied peak forces produced by gross upper extremity flexion and extension by subjects using the CKC attachment on two separate testing sessions at speeds of 0.24 m/s and 0.81 m/s and reported moderate reliability. Specific to upper extremity pushing and pulling, Cale-Benzoo, et al. used the CKC testing attachment to observe strength adaptations to limited motion range of motion training and reported internal consistency measures of .875-.983. To date, there appears to be a void of research examining between session reliability of the CKC attachment to quantify muscle performance characteristics during isokinetic assessment of all joints contributing to full range of motion upper extremity pushing and pulling performance.

Given the protraction and retraction alterations in patients with shoulder impingement, understanding the muscle performance characteristics of pushing and pulling motions in healthy persons may begin to provide a framework to better understand upper extremity injury risk and the resulting sequelae during ADL and sport activity. In an attempt to understand the normal ratio between pushing and pulling muscle performance in healthy individuals, Negrete et al compared the number of push ups to pull ups able to be completed in 15 seconds. The results indicated the pushing musculature to be approximately 1.5 to 2.7 times stronger than the pulling musculature. While their results provide a low technology method of assessing pushing and pulling performance, it does not provide all of the muscle performance characteristics attained through an isokinetic assessment approach, nor does it allow for bilateral comparisons. Isokinetic testing protocols
are often conducted at several velocities to identify various aspects of muscle performance, suggesting that pushing and pulling performance differences between the dominant and nondominant limbs may need to be examined across a velocity spectrum.

Therefore, the primary purpose of this study was to determine the intersession reliability of isokinetic upper extremity measurement of pushing and pulling peak force and average power at slow (0.24 m/s), medium (0.43 m/s) and fast (0.61 m/s) velocities in healthy young adults. If reliable results were attained, a secondary purpose was to compare pushing and pulling peak force and average power between the upper extremity limbs (dominant, non-dominant) across the three velocities. It was hypothesized that the testing protocol would produce reliable results for both peak force and average power. Furthermore, it was hypothesized while there would be no limb differences, however there were be significant direction and velocity effects.

METHODS

Subjects
Twenty-four physically active college aged men (n=12, 24.1 ± 1.7 yrs, 1.8 ± 0.1 m, 83.2 ± 12.7 kg) and women (n=12, 23.3 ± 2.0 yrs, 1.6 ± 0.1 m, 64.9 ± 10.1 kg) volunteered to participate in the study. Participants were between the ages of 18 and 30 yrs and reported being physically active a minimum of three days per week (30 minutes per session) as per the American College of Sports Medicine guidelines.12 Participants were excluded from participation if they reported a history of any trunk or upper extremity injuries requiring surgery or medical attention within the previous year. Before participation, all subjects completed a basic health questionnaire and signed an informed consent form before participation that was approved by Armstrong State University's Institutional Review Board.

Experimental Approach
Dominant and nondominant limb pushing and pulling isokinetic testing was completed using the Biodex® System 3 Isokinetic Dynamometer (Biodex Medical Systems, Inc., Shirley, NY) with the CKC upper extremity attachment at three velocities, 0.24 m/s (120°/s), 0.43 m/s (210°/s) and 0.61 m/s (300°/s). Participants completed testing on two separate days (minimum of four day separation, range: 4 to 19 days) using an identical protocol for each session. Testing and limb order were determined at the first session by having the subjects randomly select cards. Two examiners performed all testing, 12 participants each, with the same examiner performing both sessions for a particular participant.

Assessment Protocol
Prior to the isokinetic assessment, participants first completed a five-minute warm-up on an upper body ergometer exercise at a rate of ninety rpm with a self-selected resistance that equated to a ten to twelve rating of perceived exertion. Three upper extremity dynamic stretches were performed that included thirty seconds each of forward arm circles, backward arm circles and shoulder horizontal abduction and adduction.

The CKC attachment was placed on the isokinetic dynamometer parallel to horizontal with the hand grip inserted into the attachment. Both the chair and dynamometer were rotated 45° so that a 90° angle was created between the chair and dynamometer shaft (Figure 1). Once the participant was secured in the seated position, chair height and travel location as well as the dynamometer travel location were

Figure 1. Isokinetic testing setup using the Biodex System 3 Isokinetic Dynamometer with the Closed Chain Attachment.
adjusted so the shoulder was in a neutral position with 90° of elbow flexion while grasping the hand grip (forearm neutral). By using this positioning and stabilization procedure, the shoulder abduction angle remained constant during testing. Straps were placed across the chest and waist to stabilize the participant firmly in the seat and to minimize trunk and scapular movements. Once the participant was positioned and stabilized appropriately, the chair height, chair travel and dynamometer travel measurements were recorded in order to reproduce an identical set-up during the subject’s second testing session. The pulling end range of motion limit was set with the shoulder neutral (anatomical position) and 90° of elbow flexion, while the pushing end range of motion limit was established at the point when the elbow was at full extension with the back remaining in contact with and stabilized by the chair back.

For each of the three velocities (0.24 m/s, 0.43 m/s, and 0.61 m/s), four gradient sub-maximal to maximal warm-ups were completed (25%, 50%, 75% and 100% of maximum volitional effort) followed by five maximal pushing and pulling repetitions. Participants were instructed to, “push and pull the hand grip throughout your full range of motion for five repetitions as hard and fast as you can”. Strong verbal encouragement was given to each participant throughout all trials in order to facilitate a maximal effort during testing. There was a thirty-five second rest period between each speed and three minutes rest between extremities.

Statistical Analysis
Exploratory analysis for normality was conducted by visual inspection of the box plots and Q-Q plots. Heteroscedasticity was examined by considering the relationships between the absolute differences and means for the session one and two scores. The majority of raw scores demonstrated positive correlations consistent with heteroscedasticity and so the data were natural log transformed prior to computing reliability statistics. To establish relative and absolute intersession reliability of peak force and average power, intraclass correlation coefficients (ICC$_{2,1}$), typical error expressed as a coefficient of variation, and ratio limits of agreement expressed as a percentage of the means were computed. Additionally, systematic differences between sessions one and two were evaluated with paired $t$ tests. Separate three factor (direction by velocity by limb) repeated measures analyses of variance were conducted on the session one raw peak force and average power data. In cases of sphericity violations, Greenhouse-Geisser degrees of freedom adjustments were used. Simple main effect and complex comparisons with Bonferroni adjustments were used to examine significant interactions. Statistical significance was considered apriori at $\alpha<0.05$.

RESULTS
Reliability
Across sessions, limbs, and velocities, pushing peak forces ranged from 572.6 to 599.2N, pulling peak forces ranged from 556.9 to 575.3N, pushing average power ranged from 615.1 to 632.1W, and pulling average power ranged from 592.9 to 615.1W. Pushing and pulling peak force and average power descriptive statistics by testing session, limb and velocity, as well as the corresponding intraclass correlation coefficients, coefficient of variation and ratio limits of agreement are summarized in Tables 1 to 4. No statistically significant systematic differences were evident between the two sessions, with peak force difference varying between -2.5% (nondominant slow velocity pull) to 1.7% (dominant slow velocity push) and average power differences varying between -3.9% (dominant medium velocity pull) to 2.6% (dominant fast velocity pull). Intraclass correlation coefficients ranged from .914 (dominant medium velocity pull) to .969 (nondominant medium velocity pull) for peak force and 0.851 (nondominant fast velocity pull) to .954 (dominant slow velocity pull) for average power. In contrast to the relative reliability, absolute reliability was better for peak force than average power. The peak force typical error ranged from 6.1% (nondominant medium velocity pull) to 11.3% (dominant medium velocity pull) while the average power typical error ranged from 9.9% (nondominant slow velocity pull) to 26.7% (nondominant fast velocity pull). Similarly, the ratio limits of agreement were better for peak force than average power. The ratio limits of agreement ranged from 16.9% (nondominant medium velocity pull) to 31.5% (dominant medium velocity pull) for peak force and from 21.3% (dominant slow velocity pull) to 73.9% (nondominant fast velocity pull).
Peak Force
As testing velocity increased, peak forces decreased (Figure 2), however velocity affected pushing peak force differently than pulling peak force. Post hoc comparisons of the significant velocity by direction interaction ($F_{2,46} = 36.7, p < .001$) revealed the slow ($p < .001$, 95% CI$_{diff}$: 67.3 to 114.4N) medium ($p < .001$, 95% CI$_{diff}$: 40.9 to 80.2N), and fast $p < .001$, 95% CI$_{diff}$: 28.9 to 64.5N) velocity pushing peak forces to be significantly greater than the pulling peak forces. As velocity increased, the difference between push and pull peak force became less. Results of post hoc complex comparisons revealed the fast velocity push-pull peak force difference to be significantly less than the medium velocity ($p = .001$, 95% CI$_{diff}$: 6.3 to 21.4N) and the medium push-pull difference to be significantly less than the slow velocity ($p < .001$, 95% CI$_{diff}$: 18.5 to 42.1N). There were no significant differences ($p > .119$) identified between the dominant and nondominant limbs as evidenced by the limb interactions and main effect.

Average Power
Pushing average power was significantly greater than pulling average power ($p < .001$, 95% CI$_{diff}$: 73.9 to 156.9W). Velocity had a significant effect on average power ($F_{2,46} = 14.0, p < .001$). Post hoc analysis yielded the medium velocity average power to be...
significantly greater than the slow velocity ($p < .001$, $95\% \text{ CI}_{\text{diff}}: 41.5 \text{ to } 117.2 \text{W}$) and the fast velocity average power to be significantly greater than the medium velocity ($p = .050$, $95\% \text{ CI}_{\text{diff}}: .046 \text{ to } 67.3 \text{W}$).

**DISCUSSION**

Based on the need to establish reliable methods for assessing upper extremity pushing and pulling muscle performance, the purpose of the study was to determine the reliability of isokinetically derived peak force and average power during pushing and pulling movement patterns at three velocities. With the exception of average power at the fast velocity (.61 m/s), the results support high reliability for both measures across limbs (dominant, nondominant), directions (pushing, pulling) and velocities (medium and slow). Supporting the hypothesis, pushing peak force and average power values were revealed to be significantly greater than the pulling values at all three velocities. Also consistent with the hypothesis were no significant differences between the dominant and nondominant extremities for

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**Table 3.** Means ± Standard Deviations and reliability statistics for the average power during pushing at linear speeds of .61m/s (Fast), .43m/s (Medium), and .24m/s (Slow).

<table>
<thead>
<tr>
<th></th>
<th>Session 1</th>
<th>Session 2</th>
<th>Session 1-2 Differences</th>
<th>Relative Reliability</th>
<th>Absolute Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD (W)</td>
<td>Mean ± SD (W)</td>
<td>% Diff</td>
<td>$p$ value</td>
<td>ICC</td>
</tr>
<tr>
<td>Dominant Fast</td>
<td>632.1 ± 59.6</td>
<td>629.7 ± 54.1</td>
<td>2.4</td>
<td>.573</td>
<td>.940</td>
</tr>
<tr>
<td>Medium</td>
<td>628.4 ± 54.9</td>
<td>629.8 ± 47.2</td>
<td>-1.3</td>
<td>.746</td>
<td>.930</td>
</tr>
<tr>
<td>Slow</td>
<td>619.2 ± 46.2</td>
<td>615.1 ± 45.2</td>
<td>4.2</td>
<td>.222</td>
<td>.936</td>
</tr>
<tr>
<td>Nondominant Fast</td>
<td>626.0 ± 69.0</td>
<td>629.8 ± 50.7</td>
<td>-3.7</td>
<td>.556</td>
<td>.871</td>
</tr>
<tr>
<td>Medium</td>
<td>628.9 ± 53.1</td>
<td>628.8 ± 45.0</td>
<td>0.1</td>
<td>.982</td>
<td>.946</td>
</tr>
<tr>
<td>Slow</td>
<td>617.3 ±46.0</td>
<td>619.8 ±40.3</td>
<td>-2.5</td>
<td>.399</td>
<td>.947</td>
</tr>
</tbody>
</table>

SD= standard deviation, W= Watt, Diff= difference, ICC= intraclass correlation coefficient, CI= confidence interval, CV= Coefficient of Variation (typical error), RLOA= ratio limits of agreement

**Table 4.** Means ± Standard Deviations and reliability statistics for the average power during pulling at linear speeds of .61m/s (Fast), .43m/s (Medium), and .24m/s (Slow).

<table>
<thead>
<tr>
<th></th>
<th>Session 1</th>
<th>Session 2</th>
<th>Session 1-2 Differences</th>
<th>Relative Reliability</th>
<th>Absolute Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD (W)</td>
<td>Mean ± SD (W)</td>
<td>% Diff</td>
<td>$p$ value</td>
<td>ICC</td>
</tr>
<tr>
<td>Dominant Fast</td>
<td>615.1 ± 57.7</td>
<td>612.5 ± 54.8</td>
<td>2.6</td>
<td>.488</td>
<td>.950</td>
</tr>
<tr>
<td>Medium</td>
<td>608.7 ± 56.1</td>
<td>612.6 ± 47.8</td>
<td>-3.9</td>
<td>.408</td>
<td>.904</td>
</tr>
<tr>
<td>Slow</td>
<td>596.6 ± 44.3</td>
<td>595.8 ± 43.5</td>
<td>0.8</td>
<td>.771</td>
<td>.954</td>
</tr>
<tr>
<td>Nondominant Fast</td>
<td>606.6 ± 67.7</td>
<td>610.2 ± 52.2</td>
<td>-3.6</td>
<td>.600</td>
<td>.851</td>
</tr>
<tr>
<td>Medium</td>
<td>607.3 ± 52.4</td>
<td>610.0 ± 44.5</td>
<td>-2.7</td>
<td>.471</td>
<td>.932</td>
</tr>
<tr>
<td>Slow</td>
<td>592.9 ± 44.1</td>
<td>595.6 ± 40.6</td>
<td>-2.7</td>
<td>.318</td>
<td>.951</td>
</tr>
</tbody>
</table>

SD= standard deviation, W= Watt, Diff= difference, ICC= intraclass correlation coefficient, CI= confidence interval, CV= Coefficient of Variation (typical error), RLOA= ratio limits of agreement
Either peak force or average power. Consistent with the concentric force-velocity relationship, as well as our hypothesis, peak force decreased as testing velocity increased while average power increased with increasing testing velocity.

High relative reliability using intraclass correlation coefficients were revealed for both peak force (.914 to .969) and average power (.851 to .954) across velocities, limbs and directions. There is limited research examining the reliability of upper extremity isokinetic push-pull CKC testing, consequently the search was expanded to include any upper extremity movement patterns that involved pushing-pulling or protraction-retraction patterns. Gorman showed moderate reliability for dominant and nondominant upper extremity isokinetic gross flexion (Intraclass correlation coefficient range: 0.67 to .86) and gross extension (Intraclass correlation coefficient range: 0.70 to .73) movements. Cale-Benzoor, et al. reported internal consistency measures of 0.875 to 0.983 for CKC isokinetic testing of peak force as part of a CKC limited range of motion training study. Cools, et al. reported reproducibility of isokinetic protraction and retraction peak force at two velocities for the non-dominant limb (Intraclass correlation coefficient range: 0.94 to 0.97) and for the dominant limb (Intraclass correlation coefficient range: 0.88 to 0.92). Thus, the relative reliability results demonstrated better outcomes which may be attributable to the movement pattern, test velocities, populations tested, subject stabilization and positioning, progressive gradient warm-up repetitions and testing protocols.

In addition, the typical error and ratio limits of agreement results support the absolute reliability of all limbs, directions, and velocities with the exception of the high velocity nondominant average power in both directions (push and pull). Based on the need to conduct data transformations secondary to heteroscedasticity, it should be noted that the typical error and ratio limits of agreement are reported as percentages. In this manner, the expected random measurement error can be computed relative to the attained values by computing the error magnitude and adding/subtracting it to the pretest scores to create an interval. When the retest values exceed the interval boundaries, the practitioner can be more certain the change is ‘real’ as opposed to performance/measurement fluctuations. Typical error represents the amount of fluctuation that can be expected from testing session to testing session. The ratio limits of agreement is a more conservative measurement error estimation, thereby explaining the larger values reported.

The third aspect of reliability considered was systematic change in performance across the two testing sessions. Isokinetic exercise and training is a novel motor task for many individuals and therefore slight performance improvements in subsequent testing sessions can occasionally occur. The results revealed no statistically significant changes in performance between the two sessions. The majority of the peak force percent differences were within ±2% which is similar to other investigations considering peak torque differences at the knee and shoulder joints. The slightly higher differences for the average power were expected, as average power involves force production through the range of motion.

Unfortunately because there are only a few previously performed studies using the CKC attachment, and none of them provide justification for the velocities selected for testing, the selection of the testing velocities was based upon several factors. First, consistent with isolated joint isokinetic testing, we

![Figure 2. Pushing peak forces (black line) were significantly greater than pulling peak forces (gray line) at each testing velocity. As testing velocity increased, the difference between pushing and pulling peak forces became significantly less. Error bars represent standard deviations. *significantly greater than medium velocity, †significantly greater than fast velocity, ‡push-pull difference significantly more than medium velocity, §push-pull difference significantly more than fast velocity.](image)
sought to perform velocity spectrum testing at a slow, medium and fast velocities to more completely examine muscle force producing capacities. Secondly, we wanted to have similar changes between consecutive velocities. The 300°/s maximal dynamometer shaft velocity capacity of the Biodex System, which corresponds to .61 m/s CKC attachment handle velocity, established the fast velocity. Based upon pilot testing healthy subjects and consideration of using the protocol with patients possessing various upper extremity pathologies, the choice to use .24 m/s (120°/s) as the slowest velocity was made to avoid excessive shear forces across the glenohumeral joint and minimize excessive strain to the muscle-tendon unit. These two limits then dictated the medium velocity as .43 m/s (210°/s). Further research is needed to determine the testing velocities that best indicate performance decrements following injury and pathology.

The increase in pushing peak force and average power compared to the pulling direction can be attributed to the muscles involved, familiarity of movement patterns, and testing position and stabilization. During the pushing movement, the anterior deltoid, pectoralis major, middle deltoid, infraspinatus, biceps, and triceps have been demonstrated to be active. Additionally, the serratus anterior, supraspinatus and coracobrachialis also likely contribute to the pushing motion. In contrast, during the pulling motion, the posterior deltoid, anterior deltoid, middle deltoid, infraspinatus, supraspinatus, biceps and triceps have been identified as the main muscles. Additionally, the teres minor, latissimus dorsi, teres major, middle trapezius and rhomboids also likely contribute to the pulling motion. Secondly, pushing patterns are performed more frequently than pulling patterns in activities of daily living and sport. On a daily basis, it is more common to use pushing motions than pulling motions to move objects such as shopping carts and lawn mowers. Thus, in persons who are recreationally active and not specifically training pulling motions, there is likely more stimulus for adaptation of the pushing pattern. Finally, partially explaining greater push peak force and power production could have been participant positioning and stabilization. Participants were positioned in the dynamometer chair with two padded straps diagonally crossing the torso. Thus, during the pushing motion, the chair backrest provided a broad and stable base whereas during the pulling motion, the two straps provided less stability with more focal pressure.

The lack of bilateral differences was consistent with the hypothesis and suggests clinicians can consider bilateral comparisons when evaluating performance. The hypothesis was based upon two factors. First, previous research reported similar bilateral scapular protraction and retraction performance in non-athletic populations. Additionally, most pushing and pulling motions in activities of daily living and sport involve simultaneous use of both limbs, thereby providing similar stimulus for adaptations. Thus, when conducting isokinetic pushing and pulling assessments in persons who are not heavily involved in unilateral upper extremity activities, clinicians can expect similar peak force and average power values for the dominant and nondominant limbs.

It is important to recognize several aspects of the study that influence the generalizability and clinical relevance. First, the participants included in this investigation were college aged and physically active but not currently involved with collegiate or club athletics. Whether similar results exist for older or younger participants or individuals involved with competitive athletics remains unknown. Secondly, all participants in the study were healthy and without recent (1 year) of upper extremity pathology. Further research is needed to examine the reliability and limb, velocity, and direction differences with individuals with shoulder pathology. Finally, the results only pertain to push and pull isokinetic testing with the Biodex System and CKC attachment. While some clinical practices have access to a Biodex Dynamometer, many do not have the CKC attachment.

CONCLUSIONS

Upper extremity isokinetic CKC push-pull testing was demonstrated to be a reliable measure of peak force and average power production. As pushing and pulling motions are very common patterns in many activities of daily living and sports, these results provide a basis for quantifying muscle performance during these movements. Pushing peak force and power
production were significantly greater than pulling force and power measures across all velocities and the dominant and nondominant limbs. There were no significant differences in push/pull outputs between the dominant and nondominant limbs supporting the use of bilateral comparison testing.

REFERENCES
ABSTRACT

Background: While physical therapy is an effective element in the rehabilitation of rotator cuff (RC) disease, the most effective sequence of exercise training interventions has not been defined.

Hypothesis/Purpose: The purpose of this study is to determine if there is a difference in pain or function in patients who are given RC strengthening prior to or after initiating scapular stabilization exercises.

Study Design: Level I randomized crossover trial

Methods: This was a prospective study of 26 men and 14 women with a mean age 51 who were diagnosed with subacromial impingement syndrome (SAIS). They were randomly assigned to one of two groups for a comprehensive and standardized rehabilitation program over six visits at an orthopedic outpatient clinic. One group was prescribed a 4-week program of scapular stabilization exercises while the other group began with RC strengthening exercises. The crossover design had each group add the previously excluded four exercises to their second month of rehabilitation.

Results: The results showed significant improvements in pain ($p < 0.001$), function ($p < 0.001$), and patient satisfaction ($p < 0.001$) at all follow-up times for both groups. There was not a statistically significant difference in pain or function at any follow-up period for initiating one group of exercise before the other ($p > 0.05$). There was a statistically significant interaction between the patient's global rating of change at the 4 week follow-up as compared to 8 weeks ($p = 0.04$) or 16 ($p < 0.001$).

Conclusion: Patients with SAIS demonstrate improvement in pain and function with a standardized program of physical therapy regardless of group exercise sequencing.

Level of Evidence: 1b

Keywords: Rotator cuff training, scapular stabilization, shoulder physical therapy

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INTRODUCTION
Subacromial impingement syndrome (SAIS) is the most common diagnosis of patients who present to outpatient orthopedic clinics with shoulder pain, encompassing up to 36% of cases. The etiology of SAIS can originate from several faulty mechanisms within the shoulder. Intrinsic degeneration from chronic tendon overload, osteophyte formation on the acromion, extrinsic compression by a hooked acromion, or poor dynamic humeral centering have all been implicated as possible means by which soft tissues occupying the subacromial space may become symptomatic. Trauma, overuse of the rotator cuff tendons, faulty force-coupling of the rotator cuff, scapular dyskinesis, and a tight posterior capsule of the glenohumeral joint are cited as mechanical causes contributing to SAIS.

Scapular dyskinesis can be caused from weakness of the trapezius, excessive thoracic kyphosis, weakness of the serratus anterior, tightness of the posterior capsule, and limited flexibility of the short head of the biceps or pectoralis minor. The Scapular Summit in 2013 further elucidated the correlation between scapular dyskinesis and subacromial impingement syndrome, specifically the tendency for patients who have subacromial impingement to also present with scapular dyskinesis. What is not known is whether scapular dyskinesis is a cause or a result of subacromial impingement. Furthermore, the incidence of scapular dyskinesis has been found to be nearly equivalent in populations of people with and without shoulder pain during elevation in the scapular and coronal planes.

Despite these inconsistencies, there is a preponderance of evidence in support of improving scapular mechanics for the treatment of subacromial impingement syndrome. Specifically, physical therapy intervention that is aimed to improve shoulder range of motion, glenohumeral joint mobility, and muscular strength of the rotator cuff, trapezius, and serratus anterior has been proven to be more effective than non-specific exercise interventions. Furthermore, scapular stabilization exercises in addition to traditional physical therapy treatment focusing only on the rotator cuff has proven to be more effective than standard physical therapy treatment alone. In theory, scapular stabilization exercises provide an additional benefit of a stable base and improved mechanics for unimpeded shoulder mobility.

Previous authors have speculated that optimizing scapular strength and motor control is necessary to improve function with patients who have scapular dyskinesis and subacromial impingement. At this time, there is no experimental evidence that has determined an optimal temporal sequence to strengthening exercises for subacromial impingement. While most place scapular emphasis at the beginning, some advocate that scapular exercises should be delayed until later in the rehabilitation program. The present study evaluates whether there is an optimal sequence for muscular retraining efforts. Consequently, the purpose of this study is to determine if there is a difference in pain or function in patients with subacromial impingement who are given rotator cuff strengthening prior to or after initiating scapula stabilization exercises. The hypothesis is that there will be no difference in outcome between groups based on the sequence of therapy intervention and timing of the scapular based rehabilitation program.

METHODS
Subjects
This prospective randomized crossover trial was designed to evaluate the effectiveness of a rehabilitation program beginning with axioscapular (scapular stabilization) strengthening exercises compared to one beginning with scapulohumeral (rotator cuff) strengthening exercises. The investigation utilized patients who presented for shoulder rehabilitation at an outpatient physical therapy clinic in a university medical center setting between 2012 and 2014. Forty subjects, 26 women and 14 men, aged 30-74 (mean 51.1 years) diagnosed with Neer Stage I/II subacromial impingement syndrome were referred for physical therapy by eight different primary care physicians and four orthopedic surgeons for participation in the study. Fifty subjects were initially enrolled but 10 did not complete the study protocol: four were subsequently diagnosed with a full-thickness rotator cuff tears, two withdrew consent secondary to time constraints involved with the physical therapy visit attendance, and four were lost to follow-up.

Inclusion criteria to participate in the study were 1) 18-80 years of age 2) diagnosis of Neer Stage I/
II subacromial impingement with a primary pain complaint in the shoulder and/or upper arm 3) presence of at least two of the following findings: painful arc, weakness in external rotation, positive impingement sign (Hawkins-Kennedy or Neer/Walsh tests), pain and/or weakness with resistance to internal rotation, external rotation, or scapular plane elevation. Radiological imaging and periodic MRI evaluation supplemented the diagnosis. The primary investigator verified these inclusion criteria for each subject upon entry into the study. Exclusion criteria were 1) concurrent medical co-morbidities including pregnancy, diabetes, and rheumatoid arthritis, 2) osteoarthritis greater than grade 2 on the Kellgren-Lawrence scale, 3) current diagnosis and/or previous history of glenohumeral instability or dislocation, 4) full-thickness rotator cuff tear, 5) adhesive capsulitis, 6) fractures of the scapula, clavicle or humerus, 7) peripheral nerve lesions, 8) shoulder surgery in past year, and 9) inability to speak the English language at a level sufficient to obtain informed consent.

Sample size was based on the primary outcome focus of change in self-reported function as measured by the American Shoulder and Elbow Scale (ASES) score by a true mean response difference of eight points to test the null hypothesis.13 Statistical power calculations were also based on a type I error probability level of alpha = 0.05, type II error probability level of beta = 0.20, and an anticipated dropout rate of 20%. Based on literature review, the anticipated standard deviation (SD) was set at 12 points on the ASES for the difference in response of matched pairs in a normally distributed population. Power calculations resulted in an estimated sample size of 36 participants (18 per arm of the trial) to detect a true difference in mean response from the interventions. This sample size is more than double the amount required for a crossover trial where both groups are exposed to both forms of exercise and the randomization was to the exercise sequence as opposed to the exercise treatment. The sample size is also similar to the number enrolled in another randomized controlled trial assessing a similar intervention strategy.8

Procedures
This study was designed as a prospective randomized control trial with crossover at four weeks. After ensuring appropriate evaluation of inclusion and exclusion criteria, subjects were randomly allocated by the primary investigator via blind draw to one of two groups after all baseline assessments were performed and informed consent was secured. The institutional review board at UT Southwestern Medical Center in Dallas, TX approved the study. A flow chart of the trial is provided in Figure 1.

All subjects received a comprehensive and standardized physical therapy treatment program over six visits during the first month that consisted of pathology education, postural advice, activity modification recommendations, manual therapy (no more than two units or less than 37 minutes per session) to the entire upper quarter including the cervicothoracic spine area, and standard flexibility and range of motion exercises. Care providers were not blinded to the subject's group allocation.

Subjects in one group (RC) were assigned four rotator cuff intensive exercises for the first four weeks with the addition of four scapular stabilization exercises in the next four weeks. The four exercises included 1) external rotation with the arm in a resting position supported by a towel roll; 2) 0-30° short arc military press; 3) internal rotation isolation with the forearm adjacent to the trunk; and 4) horizontal abduction at shoulder level. The short arc military press was progressed to a long arc scapular plane elevation maneuver as tolerated by each patient. See Appendix 1 for detailed explanations. Subjects from group two began with a program of scapular stabilization intensive exercises (SS) for the first four weeks and added the aforementioned rotator exercises during the next four weeks. The four SS exercises included 1) supine shoulder protraction punch; 2) wide grip rows at shoulder level in standing; 3) shoulder extension/scapular depression and retraction from an overhead position in standing; and 4) shoulder retraction with both shoulders in external rotation with the elbows at the side. These eight unique exercises were selected based on reported high electromyographical activity in target muscle groups as demonstrated in multiple studies.14-20 See Appendix 2 for detailed explanations. All therapeutic strengthening exercises were conducted using Theraband (The Hygenic Corporation; Akron, OH, USA) elastic resistance in
which a therapeutic dosage of two to three sets of 20 repetitions daily could be completed. Detailed instructions on exercise technique, compensatory or substitution tendencies, and criteria for progression were provided for each exercise. Tension adjustments were made by each subject within the exercises session to ensure muscular fatigue during the third set of each exercise throughout the study.

Both groups were instructed in their additional exercise regimen on their sixth visit at four weeks post-study enrollment. Both groups were performing all

Figure 1. Study Flow Chart
eight standardized exercises during the fifth through eighth week of the study. The only difference in treatment protocol was the order in which the exercises were initiated during the first four weeks. Thus, the independent variable under investigation was the temporal sequencing of the resistive training exercises aimed at the axioscapular stabilizers or scapulothoracal cuff muscles. Fourteen of the 40 subjects received (seven from each group) a corticosteroid subacromial injection during one of the follow-up assessment periods. Each subject was informed of their treatment protocol but remained blinded to other group assignments to minimize subject bias. The assessor was blinded at baseline and all follow-up sessions regarding group assignment, precise intervention protocols, and impairment measurements.

Assessment and treatment of all subjects was provided by one of four licensed physical therapists with one to two years of experience that were completing an accredited orthopedic physical therapy residency program. After enrollment, each subject completed a questionnaire that provided demographic information such as sex, age, height and weight, side of involvement, date of onset, handedness, and whether or not they had recently received a corticosteroid injection. In addition, they responded to a medical screen that included a thorough review of their current and past medical status and history of upper quarter injury or disease.

Outcome Assessment Dependent Variables
The primary variables used to assess treatment outcomes included numerical pain ratings, self-report of function utilizing the American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form (ASES) is a region-specific scale intended to measure functional limitations and pain of the shoulder. The original ASES consists of two portions, a medical professional assessment section and a patient self-report section. The self-report section, used in this study, is a short self-report survey tool consisting of questions regarding pain and the dimensions of activities of daily living. The pain score is calculated from the single pain question on a visual analog scale and the functional score from the sum of 10 questions addressing routine, everyday function. The pain score and function composite score are weighted equally (50 points each) and combined for a total score out of a possible 100 points with 100 representing a complete absence of pain and disability. The test-retest reliability (ICC = 0.84) and internal consistency (Cronbach α, 0.86) values are acceptable. The standard error of the measure is 6.7 points on the ASES scale. Construct and discriminant validity have been demonstrated with comparison to the University of Pennsylvania Shoulder Score and the Short Form–36 quality of life scale. Adequate responsiveness is demonstrated by a standardized response mean of 1.5 and an effect size of 1.4. The minimal detectable change is 9.7 points with a minimal clinically important difference of 6.4 points. This outcome measurement tool is considered to be reliable, valid, and responsive.22

The GPF was used to assess the patient's overall perception of shoulder function. Patients rated their shoulder function based on the following question: “How would you rate your current level of shoulder function on a scale of 0-100% with 100% being your level of shoulder function before your injury?” The patient's global rating of change (GROC) reflected the patient's satisfaction with the overall treatment plan and progress. The scale for response is designed to quantify a patient's perception of improvement or deterioration over time.
using a 15-point ordinal scale range from –7 to +7. -7 represents a “very great deal worse”, 0 represents no change in status, and +7 represents a “very great deal better”. This assessment tool has been shown reliable, valid, and responsive with a meaningful change represented by at least ±5 points.\(^{23}\)

**Statistical Analysis**

All data are presented as means ± SD unless otherwise stated. Significance testing of baseline characteristics was performed utilizing unpaired t-tests and chi square tests. The NPRS, ASES, GROC, and GPF dependent variables were assessed using two-way repeated measure analysis of variance (ANOVA), with a repeated factor of “time” (at four levels: baseline, follow-up one (four weeks), follow-up two (eight weeks), and follow-up three (16 weeks); only three levels for analysis of GROC and a non-repeated factor of “treatment” (two levels: treatment beginning with RC exercises versus treatment beginning with SS exercises). Results of the analysis will be presented in the form of an F-statistic (the variance between group means) and the determined \(p\)-value (the probability of this variance solely due to chance). For practical purposes, interpretations will be based off of the \(p\)-value. Post-hoc pairwise comparisons were performed to identify the individual differences within factors. In order to maintain the probability of a Type I error at 5% (set a priori), a stringent Bonferroni correction was used.

All data were analysed using SAS 9.4 for Windows (SAS 9.4, Cary, NC, USA) with normality and equal variance assumptions ensured prior to the analysis. In cases where the assumptions of sphericity were violated (Mauchly’s test), a Greenhouse-Geisser correction was used to interpret the results of the ANOVA. Intention to treat imputation was used for missing data, primarily at the follow-up two time interval; this provided a conservative estimate of the main effect size.

**Results**

This study was completed with 40 patients that met the inclusion criteria for SAIS. There were no significant differences between groups in regards to baseline characteristics of age, sex, size, and chronicity of injury. Also of note is that both groups had a very similar prevalence of shoulder girdle weakness at baseline (Table 1). A summary of the outcome variables at all follow-up intervals is presented in Table 2. No unintended effects or adverse events were reported by any of the subjects.

**ASES Functional Outcome Score**

The interaction between treatment and time on ASES outcome score was not statistically significant with \(F(3,114)=0.80\) and \(p = 0.47\). There was no statistically significant difference in the main treatment effect when initiating one group of exercise before the other with \(F(1,38) = 0.32\) and \(p=0.57\). Notably, the score between groups never exceeded the minimally clinically important difference. The main effect of time showed a statistically significant difference on ASES outcome score between time points with \(F(3,114) = 11.52\) and \(p<0.0001\). Analyzing pairwise comparisons, the improvement of functional scores at follow-up 1 (75.8±17.6), follow-up 2 (80.1±14.4), and follow-up 3 (78.4±20.1) were statistically different from baseline (64.2±18.5) but not from one another. There was no difference in mean score between treatment groups at baseline with \(p=0.91\) (RC: 63.8±15.5 vs. SS: 64.5±21.1, Figure 2).

**Numerical Pain Score**

The interaction between treatment and time on reported pain scores was not statistically significant with \(F(3,114)=1.35\) and \(p= 0.26\). There was not a difference in the main treatment effect of exercise sequencing with \(F(1,38) = 1.09\) and \(p=0.30\). Notably, the pain score between groups never exceeded the minimally clinically important difference at each time interval. The main effect of time showed a statistically significant difference on pain scores between time points with \(F(3,114) = 11.69\) and \(p<0.0001\). Pairwise multiple comparison analyses showed that the improvement of scores at follow-up one (2.7±2.8), follow-up two (2.3±2.7), and follow-up three (2.1±2.5) were statistically different from baseline (4.3±2.6) but not from one another. There was no difference of mean score between treatment groups at baseline with \(p=0.30\) (RC: 4.7±2.1 vs. SS: 3.9±2.9, Figure 3).

**Global Rating of Change Score (GROC)**

The interaction between treatment and time on reported GROC scores was statistically significant
with $F(2,76) = 3.67$ and $p = 0.03$. However, with further simple effects analysis there was no difference of treatment group at each follow-up period (follow-up one mean difference $= -1.15$, $p = 0.21$; follow-up two mean difference $= 0.1$, $p = 0.90$; follow-up three mean difference $1.15$, $p = 0.11$). In regards to comparison of the factor of time within the RC treatment group, there was no statistical difference in reported scores across time with all $p$ values $> 0.91$ (follow-up 1: $4.7 \pm 2.4$; follow-up 2: $5.0 \pm 2.7$; follow-up 3: $4.8 \pm 2.9$). Within the SS treatment group, on the other hand, there was a statistically significant increase of the reported GROC score from follow-up one compared to follow-up two with $p=0.04$ (follow-up one: $3.6 \pm 3.2$; follow-up two: $5.1 \pm 2.1$); follow-up one compared to follow-up three also showed a significant difference with $p<0.001$ (follow-up one: $3.6 \pm 3.2$; follow-up three: $5.9 \pm 1.2$). This increase within the RC treatment group was not statistically significant from follow-up two to follow-up three with $p=0.34$ (follow-up two: $5.1 \pm 2.2$; follow-up three: $5.9 \pm 1.2$, Figure 4).

**Global Percentage of Improvement (GPF)**

The interaction between treatment and time on reported percentage of improvement scores was not statistically significant with $F(2,76)=1.86$ and $p=0.16$. There was not a significant difference in the main treatment effect of exercise sequencing with $F(1,38)=0.33$ and $p=0.57$. Again, the main effect of time showed a statistically significant difference on percentage of improvement scores between time points with $F(2,76)=9.26$ and $p=0.0003$. Pairwise multiple comparison analyses showed that the improvement of scores at follow-up three of both treatment groups were statistically different from follow-up one with a mean difference of $21.7 \pm 6.1$ and $p=0.03$ (Figure 5).

### Table 1. Group Demographic Data.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>SS Group</th>
<th>RC Group</th>
<th>$p$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years) [(mean ± SD) (range)]</td>
<td>50.8 ± 11.1 (30-72)</td>
<td>49.4 ± 10.6 (33-74)</td>
<td>0.43</td>
</tr>
<tr>
<td>Side of involvement is dominant extremity</td>
<td>55%</td>
<td>60%</td>
<td>1.00</td>
</tr>
<tr>
<td>Sex (% female)</td>
<td>15/20 (75%)</td>
<td>11/20 (55%)</td>
<td>0.32</td>
</tr>
<tr>
<td>Body Mass Index [(mean ± SD) (range)]</td>
<td>28.5 ± 4.7 (17-49)</td>
<td>29.0 ± 7.5 (20-47)</td>
<td>0.66</td>
</tr>
<tr>
<td>Mean weeks since injury (mean ± SD)</td>
<td>40.0 ± 34.4</td>
<td>29.2 ± 29.9</td>
<td>0.83</td>
</tr>
<tr>
<td>Baseline Muscular Strength (% of subjects testing &lt; 4/5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder Flexion</td>
<td>0%</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>Shoulder Abduction</td>
<td>15%</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Shoulder External Rotation</td>
<td>15%</td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td>Shoulder Internal Rotation</td>
<td>0%</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>Supraspinatus Empty Can</td>
<td>27%</td>
<td>29%</td>
<td></td>
</tr>
<tr>
<td>Serratus Anterior</td>
<td>22%</td>
<td>33%</td>
<td></td>
</tr>
<tr>
<td>Middle Trapezius</td>
<td>58%</td>
<td>39%</td>
<td></td>
</tr>
<tr>
<td>Lower Trapezius</td>
<td>74%</td>
<td>83%</td>
<td></td>
</tr>
</tbody>
</table>

SS= Scapular stabilization training; RC= Rotator cuff exercise
DISCUSSION
For the first time to the authors' knowledge, this randomized controlled trial evaluates the ordering and timing prescription of the exercise protocol in patients diagnosed with SAIS. The results demonstrate that regardless of exercise sequencing, subjects experienced improvement in pain and function while demonstrating an overall satisfaction with treatment. It is likely that both forms of exercise contribute to these findings, and this randomized

<table>
<thead>
<tr>
<th>Variable</th>
<th>Time Frame</th>
<th>SS Group</th>
<th>RC Group</th>
<th>Group x Time Interaction Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASES</td>
<td>Baseline</td>
<td>64.5 ± 21.1</td>
<td>63.8 ± 15.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Week 4 (Follow-Up 1)</td>
<td>75.5 ± 19.3</td>
<td>77.0 ± 16.1</td>
<td>* p=0.47</td>
</tr>
<tr>
<td></td>
<td>Week 8 (Follow-Up 2)</td>
<td>81.6 ± 13.6</td>
<td>79.8 ± 14.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Week 16 (Follow-Up 3)</td>
<td>82.4 ± 15.5</td>
<td>75.0 ± 23.3</td>
<td></td>
</tr>
<tr>
<td>NPRS</td>
<td>Baseline</td>
<td>3.9 ± 1.9</td>
<td>4.70 ± 2.1</td>
<td>* p=0.26</td>
</tr>
<tr>
<td></td>
<td>Week 4 (Follow-Up 1)</td>
<td>2.7 ± 3.2</td>
<td>2.65 ± 2.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Week 8 (Follow-Up 2)</td>
<td>2.1 ± 3.0</td>
<td>2.45 ± 2.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Week 16 (Follow-Up 3)</td>
<td>1.3 ± 1.8</td>
<td>2.85 ± 2.9</td>
<td></td>
</tr>
<tr>
<td>GROC</td>
<td>Week 4 (Follow-Up 1)</td>
<td>3.6 ± 3.2</td>
<td>4.7 ± 2.4</td>
<td>* p=0.03</td>
</tr>
<tr>
<td></td>
<td>Week 8 (Follow-Up 2)</td>
<td>5.1 ± 2.2</td>
<td>5.0 ± 2.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Week 16 (Follow-Up 3)</td>
<td>5.9 ± 1.2</td>
<td>4.8 ± 2.9</td>
<td></td>
</tr>
<tr>
<td>GPI</td>
<td>Week 4 (Follow-Up 1)</td>
<td>52.1 ± 37.4</td>
<td>57.5 ± 33.2</td>
<td>* p=0.16</td>
</tr>
<tr>
<td></td>
<td>Week 8 (Follow-Up 2)</td>
<td>69.0 ± 31.4</td>
<td>63.2 ± 36.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Week 16 (Follow-Up 3)</td>
<td>83.5 ± 18.1</td>
<td>69.5 ± 33.9</td>
<td></td>
</tr>
</tbody>
</table>

ASES= American Shoulder Elbow Score; NPRS= Numerical Pain Rating Scale; GROC= Global Rating of Change; GPI= Global Percentage of Improvement

Figure 2. American Shoulder Elbow Score Outcomes.

Figure 3. Numerical Pain Rating Scale Outcomes.
controlled trial did not elucidate the need for a specific order or timing to the introduction of muscular training. Both groups of patients showed statistically significant improvement in pain levels and self-reported outcome scores at all follow-up time intervals.

Although not reaching a statistically significant difference, an interesting trend emerged in the RC treatment group. The rate of pain relief and functional improvement seemed to slow with the unsupervised therapy periods during the second month of care prior to discharge. This group also had a trend for a mild regression in their pain and functional levels after formal discharge at the eight-week mark following initiation of the interventions. This trend could imply that continuation of an exercise program may be more important in instances in which the early contractile emphasis is aimed at restoring rotator cuff strength and control; however, speculations regarding these trends cannot be affirmed without a control group.

It is unknown if initially establishing a scapular base from which the rotator cuff muscle group can exercise more effectively would explain this tendency. It is possible that proximal stability and neurodynamic anchoring of the rotator cuff muscular origins by the axioscapular muscle group has a more enduring or permanent value than rotator cuff training alone. It appears that care providers need to educate patients that perseverance with the exercise program will be beneficial, particularly if the initial therapeutic exercise emphasis is directed at restoring normal rotator cuff function. Nonetheless, all dependent variables showed a slight, but insignificant, trend towards superior outcomes at both the eight and 16-week follow-up interval with the earlier scapular stabilization emphasis. The relatively slow but substantial improvement in pain and function is further testament to the lack of immediate, but ultimately lasting improvement beyond a minimally clinically important difference as time passes. It is unknown if this trend continues after 16 weeks based on the results of this trial. Continued research is necessary to validate these findings, which were not statistically significant but worthy of further investigation.

This study has several limitations, including the absence of a control group to ensure that improvement was not attributable simply to the passage of time. However, numerous studies have shown the value of exercise therapy in this pathological population.\textsuperscript{,1,8,11-14,17} The study design did not include a placebo group because of the ethical dilemma of withholding a proven, standard of care intervention for patients with SAIS. Second, although the general inclusion criteria allow for liberal generalization of the results to a broad population, the subjects in

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure4.png}
\caption{Global Rating of Change Outcomes}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure5.png}
\caption{Global Percentage of Improvement Outcomes}
\end{figure}
this study were slightly older than typical patients with SAIS. Consequently, caution should be used in extrapolating these results to a younger, more athletic population. Third, it was difficult to utilize exercise techniques for each group that allowed only axioscapular or scapulohumeral muscular activation as these muscles typically work in a synergistic fashion. The exercises selected for each group were based upon EMG activation studies and chosen to emphasize one group of muscles over the other. Despite this rationale it is possible there was a cross-group activation during the performance of each exercise. Finally, the study intentionally did not exclude subjects who received corticosteroid injections after enrolling in the study; however, likely due to randomization, both treatment groups had seven subjects who received subacromial injections to alleviate symptoms and allow a more comfortable continuation of their prescribed rehabilitation protocol. The analysis of treatment groups without these 14 subjects would have decreased the power of the study. Post-hoc plotting of the 13 subjects in each group who completed the study without an injection resulted in nearly identical graphical results with all dependent variables (data not shown).

This study offers important insights as to the most desirable sequencing of exercise in patients with subacromial impingement syndrome, specifically that there is not a major difference between the order of therapeutic introduction for axioscapular vs. rotator cuff exercise training. Future research efforts should consider nesting experimental interventions by impairment classification, as this study did not account for baseline patterns of weakness that were present at the initial examination of the patient. Indeed, prior studies have indicated that prescribing specific interventions based on subcategories of a broader condition may result in superior outcomes. Additional future study design considerations could include longer follow-up times and/or an additional treatment group that received a customized exercise prescription incorporating both RC or SS exercise prescriptions based on unique impairments.

**CONCLUSION**

The results of this study suggest that patients with SAIS demonstrate improvement in pain and function with a standardized program of physical therapy for scapulohumeral and axioscapular muscles regardless of the order in which exercises are introduced to the treatment plan. Both groups of subjects were satisfied with their intervention program while realizing significant decreases in pain and improvement in function.

**REFERENCES**

Appendix 1. **Exercise Training Details**

**Rotator Cuff Strengthening**

1. **External Rotation**
   - Secure one end of band to a door or post.
   - Place a small towel roll under your arm close to your elbow.
   - Grasp the other end of the band with the palm facing in.
   - Rotate the forearm away from the body while keeping your trunk still. Keep your upper arm still and the elbow at a right angle.

2. **Short Arc Military Press**
   - Stand on one end of the band.
   - Hold onto the other end of band with elbow bent and by your side.
   - Push upwards a short amount until the hands are at the height of your ears.
   - DO NOT raise your hand above this landmark.

3. **Internal Rotation Isolation**
   - Attach the band at a point in front of you.
   - Grab one end of the band and pull the arms in towards the chest.
   - The upper arm remains still while the forearm rotates in towards the body.

4. **Shoulder Pull Apart**
   - Grasp both ends of the band with arms elevated to shoulder level.
   - Pull tubing apart as far as possible.
   - Return to the starting position slowly

**General Instructions**

☑ Perform each exercise slowly and carefully. Stop if the exercise increases your symptoms.

☑ Perform the above indicated exercises 3 times a day, 20 repetitions each time, 7 days/week.

☒ Do not increase the resistance unless you can correctly and easily complete the maximum number of repetitions prescribed.
Appendix 1. Exercise Training Details (continued)

**Scapular Stabilization Exercises**

1. Shoulder Punches: Resisted Scapular Protraction Supine
   - Grasp band while lying on your back with arm bent.
   - Punch arm up towards ceiling, keep your arm straight.
   - Your shoulder blade should LIFT OFF the table.

2. Wide Grip Rows
   - Secure the band in front of you at shoulder height.
   - Pull the elbows straight backward while squeezing the shoulder blades together.
   - Return to the starting position slowly.
   - Create the movement with your shoulder blades, not your arms.

3. Resisted Shoulder Extension
   - Secure band in overhead position.
   - Keep your elbows locked straight.
   - Squeeze your shoulder blades together.
   - Create the movement with your shoulder blades, not your arms.

4. Resisted Scapular Retraction
   - Grasp band with both hands, elbows bent.
   - Pinch you shoulder blades together, this will stretch the band.
   - Create the movement with your shoulder blades, not your arms.

**General Instructions**

- Perform each exercise slowly and carefully. Stop if the exercise increases your symptoms.
- Perform the above indicated exercises 3 times a day, 20 repetitions each time, 7 days/week.
- Do not increase the resistance unless you can correctly and easily complete the maximum number of repetitions prescribed.
### Appendix 2. Group Intervention Overview

<table>
<thead>
<tr>
<th>Session</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Session 1</td>
<td>Eligibility screening, baseline initial history and physical examination, random assignment, usual medical advice education, and instruction in home program of exercise according to group allocation</td>
</tr>
<tr>
<td>Sessions 2-5</td>
<td>Manual therapy, range of motion exercises, and assessment/modification of assigned home resistive strengthening exercises according to group allocation</td>
</tr>
<tr>
<td>Session 6 (at 4 weeks post-initial evaluation)</td>
<td>Reassessment of baseline findings and all dependent variables (pain, function, satisfaction, and fear of movement); Patients instructed in additional home exercise program of strengthening activities experienced by the other cohort.</td>
</tr>
<tr>
<td>Session 7 (at 8 weeks)</td>
<td>Reassessment of baseline findings and dependent variables</td>
</tr>
<tr>
<td>Session 8 (at 16 weeks)</td>
<td>Final assessment of baseline findings and dependent variables</td>
</tr>
</tbody>
</table>
ABSTRACT

Background: With shoulder pain and injury on the rise in overhead athletes, clinicians are often examining preventative exercises to address functional abnormalities. Because shoulder impingement is prevalent in overhead athletes, much focus is on scapular stability and the function of the stabilizing force couple of the upper and lower trapezius and serratus anterior.

Hypothesis/Purpose: The purpose of this study was to examine scapular muscle activation during a series of throws and holds (throwing without releasing) with two different ball weights (7oz and 12oz). It was hypothesized that the holds exercises would elicit greater activation of the scapular musculature than the throw, irrespective of ball weight.

Study Design: Case control laboratory study

Methods: Twenty-two NCAA Division I, right hand dominant, softball players (19.91 ± 1.04 years; 169.24 ± 7.36 cm; 72.09 ± 10.61 kg) volunteered to participate. Surface EMG was utilized to measure muscle activity in the upper, middle and lower trapezius and serratus anterior muscles during three different throwing activities.

Results: MANOVA results revealed no significant differences in muscle activity between throwing conditions, $F_{(16,82)} = 1.02, p = 0.446$, Wilks' $\Lambda = 0.696$, Cohen's $d = 0.44$ (7oz holds), 0.24 (12oz holds), power = 0.625.

Conclusion/Clinical Relevance: The results may provide some clinical insight in advocating the use of holds with different ball weights. The holds throw may be an effective step in shoulder strengthening that can more closely mimic the functional movement of throwing without the element of ball release.

Levels of Evidence: Level 3

Keywords: Baseball, injury, kinetic chain, rehabilitation, softball, upper extremity
INTRODUCTION
Shoulder pain and scapulohumeral dysfunction are common among overhead throwing athletes. Shanley et al. reported that the shoulder was the most frequently injured joint in high school softball and baseball players. Additionally, it has been reported that shoulder impingement is the most common cause of shoulder pain in overhead athletes. Many authors have suggested that scapular movement abnormalities are linked to inefficient strength and stability of the scapular stabilizing muscles and thus contribute to shoulder injury. As it is commonly known that the scapula plays an essential role in shoulder complex function, the stability of the scapula through muscular balance is fundamental. It has been generally accepted that the force couple of the serratus anterior (SA) and trapezius musculature acts to dynamically stabilize the scapula. When examining individuals with shoulder impingement, most have described greater activation of the upper trapezius (UT) combined with decreased activation of the lower trapezius (LT) and SA. Additionally, altered activation has been reported as a contributor to diminished scapular posterior tilt and upward rotation, which are needed to maximize the amount of subacromial space for the rotator cuff tendons to pass through. Therefore, due to the prevalence of shoulder injuries in overhead throwing athletes, there is a need to identify potential risk factors and also develop rehabilitation and strength training protocols that address scapular stability.

Traditionally, exercises targeting the scapular musculature have been limited to single planes of motion with the patient positioned prone, side lying or supine on a table; though recently, shoulder exercises aiming to incorporate the entire kinetic chain are becoming more common. The emphasis on the kinetic chain allows for the implementation of dynamic movement patterns throughout the rehabilitation process. These types of exercises are preferred by some, as proper kinetic chain sequencing of each interdependent body segment is needed to optimize the function of the most distal joint in the chain. It has been reported that restoration of the dynamic scapular stabilizing musculature requires proper kinetic chain function. Alterations at any other segment of the chain can affect the shoulder and dysfunction at the shoulder can impact the other segments of the chain as well. Therefore, by implementing exercises that utilize the entire kinetic chain during training or rehabilitation, clinicians may be able to improve dysfunction at multiple segments, in addition to the shoulder, and better prepare the athlete to return to play.

One approach that throwers commonly use in the clinical setting is performing a throwing motion without releasing the ball. Though this exercise of throwing holds has been utilized commonly in overhead athletes and has been recognized by athletes, coaches, and sports medicine clinicians, no researchers to date have validated this type of holds exercise. The use of a holds throwing exercise may be a suitable exercise for improving strength throughout the entire kinetic chain before returning to full throwing activity. Although holds exercises are used clinically, their ability to activate the scapular muscles has not been investigated. Thus, in attempt to analyze the scapular musculature, the purpose of this study was to examine scapular muscle activation during a series of throws and holds (throwing without releasing) with two different ball weights (7oz and 12oz). It was hypothesized that the holds exercises would elicit greater activation of the scapular musculature than the throw, irrespective of ball weight.

METHODS
Study Design
The objective of this study was to determine activation of selected scapular muscles during three throwing activities; independent variables: typical overhead throw with 7oz ball + release (7oz throw), an overhead throw without releasing a 7oz ball (7oz holds exercise), and an overhead throw without releasing a 12oz ball (12oz holds exercise). During these throwing activities muscle activity was recorded using surface EMG on the following muscles of the throwing limb; dependent variables: UT, middle trapezius (MT), LT, SA. Descriptive statistics (mean ± standard deviation) were used to determine muscle activations by calculating normalized surface electromyographic (sEMG) data as a percent of the participant's maximum voluntary isometric contraction (%MVIC).

Participants
Twenty-two NCAA Division I softball players volunteered to participate. Demographics are listed in Table
1. Participant criterion for selection was freedom from upper extremity injury within the past six months. Additionally, it should be noted that none of the participants reported any pain or stiffness in their upper or lower extremity following extensive throwing sessions within the previous six months. Additionally, no participants reported a history of upper extremity surgery. The Institutional Review Board of Auburn University approved all testing protocols. Prior to data collection, all testing procedures were explained to each participant and informed consent was obtained. All participants were tested during the off-season (four to six weeks following last competitive game) and had not thrown the day of testing.

<table>
<thead>
<tr>
<th>Table 1. Participant demographics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>19.91 ± 1.04</td>
</tr>
</tbody>
</table>

Procedures

Throwing arm LT, MT, UT and SA muscle bellies were identified through palpation using previously described placements by Noraxon (Noraxon USA, Inc, Scottsdale, Arizona). The identified locations were then shaved, abraded, and cleaned using standard medical alcohol swabs for electrode placement. The same investigator performed all surface preparation as well as electrode placement. Subsequent to surface preparation, adhesive BIO Protech bipolar, 4cm Ag/AgCl diameter disk shaped, surface electrodes (Bio Protech Inc., Tustin, California) were attached over the muscle bellies and positioned parallel to muscle fibers using previously published standardized methods. The selected inter-electrode distance was 25mm.

Electromyographic data were collected via a Noraxon Myopac 1400L 8-channel amplifier (Noraxon USA, Inc, Scottsdale, Arizona). Surface EMG data were visually monitored during the collection of data and sampled at a rate of 1000 Hz with an overall gain of 500. The raw signals were band-pass filtered with the low pass filter set to 80 Hz and the high pass filter set to 250 Hz. The common mode rejection ratio was set to >100 dB. The signal was full wave rectified and smoothed prior to analysis.

Following the application of surface electrodes, manual muscle testing (MMT) techniques as described by Kendall et al were conducted to determine the maximum voluntary isometric contraction to which all EMG data would be normalized. MMTs were performed as follows: (1) SA: Participant was lying supine with the humerus in 90° of flexion and neutral rotation with the fingers flexed into a fist. The investigator applied a downward force towards the participant's forearm and humerus. (2) UT: Participant sat upright with the scapula elevated and neck laterally flexed to the contralateral side. The investigator applied pressure to the shoulder girdle in the direction of depression. (3) MT: The participant was lying prone with the shoulder in 90° of abduction with the thumb pointed upward. The investigator applied pressure against the forearm in a downward direction toward the table. (4) LT: The participant was lying prone with the arm placed diagonally overhead in line with the lower fibers of the trapezius and the thumb pointed upward. The investigator applied pressure against the forearm in a downward direction toward the table. Two muscular contractions, lasting five seconds, were performed for each muscle and the first and last seconds were removed to obtain steady state results. The data for the two contractions were averaged and a rest period of 30 seconds was allotted between each contraction.

Following establishment of the MVIC, participants were instructed on the protocol consisting of three conditions: (1) 7oz throw, (2) 7oz holds, and (3) 12oz holds. The throwing condition consisted of performing a maximum effort overhand throw on a straight-line trajectory preceded by a “crow hop”. A crow hop is a lower extremity movement sequence that utilizes a skip and a hop prior to the throw being made. The holds exercises consisted of mimicking the same maximum effort overhand throw, however, participants were instructed to not release the ball. Each condition was performed three times in a randomized order for testing. After instruction, participants were given an unlimited time to perform their own specified pre-competition warm-up routine. While participants were allowed to perform their own warm-up routine, all of their selected warm-ups included both static and dynamic exercises. A standardized warm-up protocol was not implemented because of the variability in how each participant preferred to warm-up prior to throwing. The average warm-up time was ten minutes. Once participants deemed themselves
warm and ready for maximum effort throwing, they proceeded to perform the protocol described above. The muscular activity measured during the throwing motion was expressed as a %MVIC for all conditions and was examined as a single phase from maximum shoulder external rotation (Figure 1) to end of follow through (once the throwing hand crossed the midline of the body and came to a stop) (Figure 2). A single phase was chosen for the analysis since the objective was to quantify the overall average muscle activation throughout the throwing motion versus throughout multiple phases of the movement. For comparison purposes, low muscle activity was considered to be between 0-20% MVIC while moderate activity was 21-40%, high muscle activity was 41-60%, and very high activity was >60%.

**Statistical Analysis**

Surface EMG data from each muscle were normalized and expressed as a percent contribution of the MVIC. Statistical analyses were performed using IBM SPSS Statistics 22 (Armonk, New York, USA). Descriptive data were expressed as means and standard deviations. Effect size and statistical power were also calculated. A 2 (holds, release) x 3 (holds 7oz, holds 12oz, throw 7oz) x 4 (muscles) multivariate analysis of variance (MANOVA) was conducted to evaluate the differences between the different throwing conditions and activity of the UT, LT, MT, and SA.

**RESULTS**

Descriptive data for the UT, LT, MT, and SA are presented in Table 2. Activation for the LT increased from moderate to high activation (approximately 39%MVIC in the 7oz throw to 41%MVIC in the 7oz hold, and 43%MVIC in the 12oz hold); MT increased from moderate to high activation (approximately 31%MVIC in the 7oz throw to 60% in the 7z hold, and 41% in the 12oz hold); SA was very high, and increased from approximately 74% in the 7oz throw to 83% in the 7oz hold, and 82% in the 12oz hold; and UT activation was moderate to high, increasing from approximately 36% in the 7oz throw to 39% in the 7oz hold, and 45% in the 12oz hold. As reported, a general trend toward increase in activation was observed in both holds exercises when compared to the throw for all four muscles, however the overall results were not statistically significant. MANOVA results revealed no significant differences in muscle activity between throwing conditions, $F_{(16,82)} = 1.02$, $p = 0.446$, Wilks’ $\Lambda = 0.696$, Cohen’s $d = 0.44$ (7oz holds), 0.24 (12oz holds), power = 0.625.

**DISCUSSION**

Shoulder impingement is one of the most common causes of shoulder pain in overhead athletes and it
is often the result of functional abnormalities such as scapular muscle imbalances. The scapular muscle imbalance frequently observed in individuals with shoulder pain and impingement shows increased UT and decreased LT and SA muscle activation. Therefore, sports medicine professionals will often target these muscles when addressing either rehabilitation or injury prevention programs for overhead athletes in effort to reduce pain and improve shoulder function. Often in the clinical setting, injured baseball and softball players will perform holds exercises prior to the initiation of an interval throwing protocol in attempt to initiate scapular muscle activation prior to throwing.

The results of this study revealed that scapular muscle activations were similar between the three conditions in healthy NCAA Division I softball players. The lack of significant differences in muscle activation may help to support the use of the holds exercise in training and rehabilitation programs. The holds exercise produces similar muscle activations to that of a throw, but may not result in the same stresses being placed on the upper extremity that have been reported in the literature to occur at ball release and maximum internal rotation during a throw. By quantifying scapular muscle activation data for these exercises, future research may progress to better understand the kinetic differences between a throw and the holds exercises. It is known that the overhead throwing motion requires optimal function of the entire kinetic chain to transfer energy in addition to a great deal of neuromuscular efficiency. As a thrower advances through the training or rehabilitation process, they must progress from basic strengthening of the scapular musculature and surrounding shoulder musculature to more functional movements that mimic the throwing motion. As researchers and clinicians have gained a greater understanding of the importance of rehabilitating the kinetic chain as a whole, there has been a shift toward exercises that incorporate full body movement to retrain the body’s ability to transfer kinetic energy in an effective manner.

While no statistically significant differences between the three conditions were observed in this study, the results give insight into the use of potential holds exercises that target the scapular musculature for overhead throwing athletes. The examination of the level of activity for the LT, MT, SA, and UT is still pertinent. The results of this study revealed moderate (21%-40%), high (41%-60%), and very high (>61%) activations of the LT, MT, SA, and UT during all three of the examined conditions. It is speculated that these activations were a result of the LT, MT, SA, and UT functioning to control movement of the scapula. The values observed in the current study are similar to activations of the scapular musculature observed in previous shoulder rehabilitation studies examining scapular muscle activation during individual joint exercise and rehabilitation movements. Only one current study has examined lower trapezius, upper trapezius, and serratus anterior muscle activation during baseball pitching. In the abovementioned study, low activation was observed for the LT throughout the entire pitching motion and the UT and SA exhibited low activation between foot contact and maximum shoulder external rotation. Moderate and high activations of the SA and UT were observed during the acceleration and follow through phases of the pitch, respectively. By having similar levels of muscle activations observed in previously reported data during rehabilitation exercises, the holds exercises may be an alternative exercise that can be performed to best simulate the muscular demands of throwing when a player may not be medically cleared to throw. Therefore, the current results may further support the idea of a holds throw being an effective exercise that can more closely mimic the functional demands of throwing, when compared to traditional rehabilitation exercises, without the added risk of high forces about the shoulder that are produced at ball release.

Moderate activations were seen in LT and UT in the regulation weight ball holds condition and in LT, MT, and UT in the weighted ball holds exercises. It was hypothesized that greater scapular musculature activation would be observed in the weighted ball holds exercises compared to the regulation weight holds but significantly greater activation was not observed. Activation of the MT did however reach a moderate level in the 12oz holds exercise that was not observed in the 7oz holds exercise. It is speculated that the 12oz hold exercise may be more advantageous than traditional single-plane exercises because it requires the athlete to grip the ball throughout the entire holds throwing exercises.
While valuable data on sEMG data during throwing and a series of holds exercises were obtained it is important to note that some limitations do exist. The use of sEMG during a dynamic movement allows for the possibility of movement artifact due to movement of the muscle under the skin and thus the electrodes. Second, the current study examined healthy participants with no known upper extremity injury and the muscle activations observed in this study might not be indicative of those seen in athletes with injured shoulders. Another limitation of the study is that the participants were not evaluated for scapular dyskinesis, which may be present in a healthy and uninjured population. This was an exploratory descriptive study using healthy participants, and there is a need in the future to examine participants with scapular dyskinesis to see if the results would be similar. Future research should examine the use of a holds throwing exercises in affected participants who are transitioning from an upper extremity rehabilitation not to an interval long toss program and examine the effects of using balls of various weights for rehabilitative purposes. Additional kinetic analyses comparing throwing to holds throwing are needed to help determine if the forces about the upper extremity are impacted when not releasing the ball.

CONCLUSIONS

The results of the current study showed high activation of the LT (41.3%MVIC) and moderate activation for UT (39.8%MVIC) in the regulation weighted holds exercises and in LT (43.74%MVIC), MT (41.30%MVIC), and UT (44.93%MVIC) in the weighted ball holds exercises. The holds exercises also produced similar scapular muscle activations compared to those seen when throwing a softball. While definitive conclusions cannot be drawn, it is speculated that the holds exercises may be an alternative method for gaining similar muscle activation patterns compared to an actual throw. Thus, the use of a throwing holds exercise utilizes a sport specific movement that may bridge the gap between traditional scapular exercises and a subsequent return to throwing program.

REFERENCES


ABSTRACT

Background: Military physical therapists have been shown to have the necessary knowledge in musculoskeletal medicine in order to practice as a direct access provider. However, research about musculoskeletal knowledge in the civilian physical therapist (non-military) population is lacking.

Purpose: The purpose of the current study was to compare the knowledge in managing musculoskeletal conditions between civilian and military physical therapists using a validated and standardized musculoskeletal competency examination. Furthermore, this study aims to investigate the potential factors that may lead to increased musculoskeletal competency.

Study Design: Cross-sectional, electronic survey

Methods: This study involved a cross-sectional, electronic survey completed in August and September of 2014 in order to assess licensed physical therapists’ knowledge in identifying and managing musculoskeletal conditions. Only physical therapists practicing in orthopedics were permitted to be involved in the study. Descriptive statistics of the participants, and logistic regressions analyzing variables correlated with passing the musculoskeletal exam were calculated using SPSS 22.0. Frequencies were produced for multiple variables. Binary logistic regressions were used to correlate the frequency variables with performing at competency level on the musculoskeletal exam.

Results: A total of 22,750 surveys were sent to physical therapists in Arizona, Ohio, Texas, Maine and Wyoming. Two thousand sixty-five surveys were returned for a response rate of 10.6%. Of the 2,065 surveys completed, 408 responses were included for analysis. The average score for the respondents on the exam was 65.08% and only 28.2% of all respondents met the competency cutoff score (previously established to be 73.1%). Respondents who were orthopedic certified specialists (OCS) or sports certified specialists (SCS) were 3.091 times more likely to perform at the competency level on the examination with a p-value of < 0.001 and a confidence interval > 95%.

Conclusion: The current study utilized the results from a previous study for a comparison between the civilian and military physical therapist populations. The results indicate that civilian physical therapists in the current study (65.08%) scored lower than their military counterparts in the previous study (75.9%) on the musculoskeletal exam. Potential reasons for this include less autonomous practice responsibilities and a disparity in educational experiences. Board certifications may enhance civilian physical therapists ability to practice with greater autonomy as primary care clinicians when managing musculoskeletal conditions.

Level of Evidence: Level 4

Keywords: Board certifications, direct access, musculoskeletal competency

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INTRODUCTION
Musculoskeletal conditions are common, accounting for nearly 15-30% of encounters in a primary care practice setting. It has been estimated that 53.9 million people in the United States report having one or more musculoskeletal conditions and medical costs associated with these conditions average more than $3,578 per capita. Episodes of care that involved a physician referral increased costs by 123%, duration of care by 65%, office visits by 60%, and overall physical therapy claims by 67% compared to direct access services provided by physical therapists without a physician referral. At present, direct access services can be provided by physical therapists without a physician referral in all 50 states including the District of Columbia. Although direct access is legislated in all 50 states, there are varying levels: unrestricted, limited, or with provisions. Researchers have shown that not only does direct access physical therapy services reduce healthcare costs and duration of care, but also has shown to have similar or better discharge outcomes without increased risk.

 Nonetheless, the standard of care remains that physicians are the most common point of entry into the healthcare system for patients with musculoskeletal conditions. However, primary care physicians have continually shown to be lacking in their management, confidence, evaluation, and treatment of these patients. In 1998, Freedman and Bernstein developed a musculoskeletal assessment which tested basic knowledge of musculoskeletal conditions. The assessment was administered to 85 physicians in the first week of their internship following graduation from medical school; the mean score was 59.6%, well under the accepted competency level of 73.1% set forth by medical orthopedic residency program directors. Additionally, 82% of physicians failed to meet basic competency for managing musculoskeletal conditions in the primary care setting. The lack of confidence and inadequacy in the treatment of patients with musculoskeletal conditions is reflected by the lack of musculoskeletal exposure in medical school curricula. Currently, only 51 of the 122 American Medical schools have preclinical coursework devoted to musculoskeletal medicine.

Childs et al utilized the same assessment tool developed in the Freedman and Bernstein study to explore the level of knowledge of musculoskeletal conditions in military physical therapists. The results indicated that military physical therapists displayed higher levels of knowledge in the management of musculoskeletal conditions (mean score 75.9%) when compared to physicians in a multitude of specialties (mean score range 35%-61%), except orthopedists (mean score 94%). Additionally, physical therapists who are board-certified in orthopedics (OCS) or sports (SCS) from the American Board of Physical Therapy Specialists (ABPTS) demonstrated higher levels of knowledge than their counterparts who did not hold any advanced certifications. Jette et al further supported this sentiment and reported that physical therapists holding an OCS were almost two times more likely to make correct decisions for medical conditions and musculoskeletal conditions when presented with simulated paper cases. Ross et al concluded that military physical therapists demonstrated knowledge levels equal to or higher than physicians when evaluating patients with low back pain (LBP) and were able to recommend the correct drug treatments for patients with acute LBP. The results of these studies support the ability of military physical therapists to practice in direct access environments when encountering patients with LBP.

Since 1973, the military health care system has supported the use of physical therapists in the direct access environment. Furthermore, physical therapists in the uniformed services have shown to have the necessary knowledge in musculoskeletal medicine in order to practice as a direct access provider. Although this has been shown for physical therapists in the uniformed services, research about musculoskeletal knowledge in the civilian physical therapist (non-military) population is lacking. Even though direct access is legislated all fifty states, it is not utilized frequently secondary to reimbursement issues from third party payers. This limits civilian physical therapists’ exposure to direct access care. The purpose of the current study was to compare the knowledge in managing musculoskeletal conditions between civilian and military physical therapists using a validated and standardized musculoskeletal competency examination. Furthermore, this study aims to investigate the potential factors that may lead to increased musculoskeletal competency. The
authors hypothesize that civilian physical therapists will perform at similar levels as military physical therapists on a standardized examination that has been previously used to assess knowledge in managing musculoskeletal conditions. Furthermore, the authors hypothesize that civilian physical therapists who are board-certified in orthopedics (OCS) or sports (SCS) will perform at a higher competency level than those who are not. Finally, the authors hypothesize that civilian physical therapists who currently practice in direct access environments 50% of the time or greater will perform better than those who practice in direct access environments less than 50% of the time. This study has the potential to influence the utilization of physical therapists in managing musculoskeletal conditions without referral from a physician.

**METHODS**

**Design**

This study involved a cross-sectional, electronic survey completed in August and September of 2014 in order to assess licensed physical therapists' knowledge in identifying and managing musculoskeletal conditions. This study was approved by the Walsh University Human Subject Review Committee (14-24) prior to the recruitment of subjects and distribution of surveys. Informed consent was obtained from all subjects prior to completion of the survey.

**Survey**

The survey completed by subjects has been published elsewhere. This basic-competency examination in musculoskeletal medicine has been previously used in research by Freedman and Bernstein and then again by Childs et al and Matzkin et al. The scenarios addressed in this survey are frequently encountered in orthopedic practice and include arthritis, fractures, dislocations, and low back pain. This survey also includes situations in which the physical therapists would need to identify an immediate referral during medical emergencies for necessary medical care. There are 25 questions on the survey, which were designed to be open-ended in order to eliminate the possibility of subjects earning points for guesses and accurately assess the subject's knowledge of musculoskeletal conditions.

**Respondents**

Respondents were recruited via their valid email addresses on file with their respective state boards. The following five states were targeted to represent the five geographic regions as defined by the United States Census Bureau Regions: Arizona (West), Maine (Northeast), Ohio (Midwest), Texas (South), and Wyoming (West). Therefore, an accurate representation of the population by region was sampled. Although only five states were targeted, there were respondents from all fifty states. The authors speculate this to be due to participants moving out of the region in which the email address was obtained. However, the respondents from other states that were not targeted by the survey were not included within the final data set used for comparison based on pre-determined exclusion criteria. The following are the exclusion criteria: the respondent must be practicing in orthopedics, must be a non-military physical therapist, in clinical practice greater than one year, and must not have knowledge of the Freedman and Bernstein study. Civilian physical therapists (military physical therapists were previously studied regarding their knowledge of musculoskeletal conditions) who were licensed in their respective states as well as practicing in orthopedics for greater than one year were included in the study. While each physical therapist was currently licensed in his or her state, the subjects varied in professional degrees held and additional professional board certifications obtained. The professional degrees include Bachelor's of Science in Physical Therapy, Masters of Physical Therapy, and Doctorate of Physical Therapy. The additional professional board certifications were grouped as either being an OCS and/or SCS, or not holding either of those board certifications.

**Procedure**

The survey was distributed through SurveyMonkey, Inc. (US). Consistent with previous studies, a time limit was not enforced. The survey was open for five weeks with four follow up reminder emails sent during that period. The emails included a hyperlink to the survey. The responses were confidential and could not be traced back to the participant. Further risk of bias was reduced by coding each variable in an isolated fashion.
Data Analysis
Two civilian orthopedic physical therapists (MD and AH) graded the responses of participants. One is a fellowship trained manual therapist with eight years of experience teaching orthopedic content in an entry-level physical therapist program. The other therapist is board-certified in orthopedics and has earned a certification in manual therapy and has been teaching orthopedic content in entry-level physical therapist programs for six years. The senior author provided a training session on the scoring procedures. The two authors independently graded the responses using the answer key published in the Freedman and Bernstein study. Each question could receive a maximum score of one point; however, partial credit was given for some questions based on the criteria for partial credit provided in the Freedman and Bernstein study. Inter-rater reliability was performed on the first 100 responses. Substantial agreement or higher was reached for 21 out of 25 questions based on a kappa value of higher than 0.7. The two graders reached consensus through discussion for the four questions with kappa values <0.61. At this point, those questions were rescored independently and reliability statistics were re-run showing updated reliability of 0.666 to 1. In alignment with the previous Childs et al and Freedman and Bernstein studies, only one grader's data were used for analysis after acceptable reliability was shown. The one grader whose data were included for analysis was not the senior author and was unaware of the methods and results of previous studies. The previously established cut-off score of 73.1% was used to determine a passing score.

RESULTS
A total of 22,750 surveys were sent to physical therapists with valid email addresses on file with the state boards in Arizona, Ohio, Texas, Maine and Wyoming. Of those 22,750 surveys, 857 were not deliverable and 2,065 surveys were completed and returned resulting in a response rate of 10.6%. Of the 2,065 surveys completed, 408 responses were included for analysis. Of the 1,657 surveys that were not included in analysis: 997 surveys were eliminated for therapists that worked in settings other than outpatient orthopedics, 466 surveys were eliminated for incomplete data, 84 surveys were eliminated for therapists that had previous knowledge of the Freedman and Bernstein study, 52 surveys were eliminated for therapists that had been practicing less than one year (in order to maintain consistency with Childs et al study design), 30 surveys were eliminated for respondents who received assistance during the exam, 25 surveys were eliminated for therapists who were practicing in the military, and three surveys were eliminated for respondents who were physical therapy assistants.

Table 1 describes the sample in detail. Fifty-four percent of all respondents were doctorally trained, 19.6% of all respondents were either OCS or SCS board-certified, 91.9% of all respondents indicated they felt qualified to practice direct access, only 4.9% practiced direct access at least 50% of the time, and only 28.2% of all respondents met or exceeded the cutoff score. The average score for civilian physical therapists was 65.08%, which was below the competency cut-off score of 73.1%. The average score of OCS/SCS board-certified physical therapists was 72.76% (compared to 63.21% for those without an OCS/SCS board certification).

Table 2 indicates the number of respondents who met or exceeded the cutoff score by variable, with
the associated p-values reported. Of the 408 total respondents, 115 met the competency cutoff score (28.2%). The only significant variable was OCS/SCS board certification. Of the 80 total respondents that were OCS/SCS board certified, 39 met or exceeded the cutoff score (48.7%). In contrast, of the 272 respondents who were not OCS/SCS board certified, only 64 met the competency cutoff score (23.5%).

Table 1. Demographic Information of the Survey Sample.

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<th>Frequency (percentage)</th>
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</tr>
<tr>
<td>Frequency of direct access practice?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-49%</td>
<td>207</td>
<td>50.7%</td>
</tr>
<tr>
<td>50-100%</td>
<td>20</td>
<td>4.9%</td>
</tr>
<tr>
<td>Missing value</td>
<td>181</td>
<td>44.4%</td>
</tr>
<tr>
<td>APTA Membership</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>211</td>
<td>51.7%</td>
</tr>
<tr>
<td>No</td>
<td>194</td>
<td>47.5%</td>
</tr>
<tr>
<td>Missing value</td>
<td>3</td>
<td>0.7%</td>
</tr>
<tr>
<td>Musculoskeletal exam competency score</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below cut-off score</td>
<td>293</td>
<td>71.8%</td>
</tr>
<tr>
<td>Met cut-off score</td>
<td>115</td>
<td>28.2%</td>
</tr>
</tbody>
</table>
Figure 1 depicts a visual comparison of the average scores on the musculoskeletal competency examination among physical therapists in the present study, and data from previous studies identifying military physical therapists, physician interns, physician residents, medical students, and a multitude of physician subspecialties.

**DISCUSSION**

The purpose of the current study is to compare the knowledge in managing musculoskeletal conditions between civilian and military physical therapists using a validated and standardized musculoskeletal competency examination. Furthermore, this
The study aims to investigate the potential factors that may lead to increased musculoskeletal competency. The authors hypothesized that 1) civilian physical therapists would perform at similar levels as military physical therapists on the standardized examination, 2) civilian physical therapists who are board certified in orthopedics and/or sports would perform at a higher competency level than those who are not, and 3) civilian physical therapists who currently practice in direct access environments 50% of the time or greater would perform better than those who practice in direct access environments less than 50% of the time.

The current findings suggest that although obtaining either an OCS and/or SCS board certification increases the likelihood of meeting competency on the musculoskeletal examination by three-fold, civilian physical therapists did not perform at the same level as military physical therapists. However, civilian physical therapists performed at higher levels when compared to previous data for all physician subspecialties except for orthopedics. Furthermore, the percentage of practice time in direct access environments did not correlate to increased musculoskeletal competency. To the authors’ knowledge, this is the first study to examine the competency of civilian physical therapists with a validated examination tool measuring musculoskeletal knowledge. The authors believe that it is worth examining this population compared with military physical therapists, due to perceived differences in typical practice.

Civilian providers scoring lower than their military counterparts has been previously documented. Matzkin et al. studied physicians, residents and medical students who averaged 57.7% on this examination. The military physicians, residents, and medical students in the study averaged 62% compared to 55% for the civilian participants. Childs et al. further sup-

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**Figure 1.** Depiction of the overall scores on the musculoskeletal competency examination among civilian physical therapists in the present study along with comparison data from previous studies for military physical therapists, physical therapist students, physician interns, residents, medical students, and a multitude of physician subspecialties. Military physical therapists and physical therapist students’ data were derived from Childs et al. The physician data were derived from Matzkin et al. Physician intern data were derived from Freedman and Bernstein.

*PT = physical therapist, Phys = physician, OCS = Orthopedic Clinical Specialist, SCS = Sports Clinical Specialist, DPT = doctoral physical therapist program trained, Masters = Masters physical therapist program trained, FP = family practice, GS = general surgery, Res = resident, Peds = pediatrics, Med = internal medicine, Med stu = medical student, OB = obstetrics-gynecology, Psy = psychiatry.*
ported this finding when studying physical therapists in the military. The military physical therapists in the study achieved an average score of 75.9% on the musculoskeletal competency examination while the overall passing rate was 67% (the other participants in the Childs et al study were physical therapy students in the terminal phase of the curriculum). Additionally, military physical therapists who were board-certified in orthopedics (OCS) or sports (SCS) achieved an average score of 81% on the examination. In comparison to the civilian physical therapist population in the present study, the military physical therapists in previous studies achieved higher scores. Civilian physical therapists achieved an average score of 65.08% with an overall passing rate of 28.2%. Civilian physical therapists who were board-certified in orthopedics (OCS) or sports (SCS) achieved an average score of 72.76%. When speculating as to reasons between military and civilian physical therapists performance, the military physical therapists are routinely granted privileges that many civilian physical therapists are not granted. Examples include: direct-access practice, ability to order medications and laboratory tests, and referring to specialists. In addition, military physical therapists are viewed as physician extenders and the musculoskeletal expert on the team while enjoying a close working relationship with physicians that involves mutual respect. Multiple studies performed in the military population provide evidence to support that physical therapists have the requisite knowledge and skills to practice safely and effectively in the direct access environment. Evidence in the civilian population is less prevalent, but promising. Boissonnault et al reported that civilian physical therapists participating in a pilot direct access program in a large academic medical center made appropriate decisions of referring or initiating treatment in 100% of the reviewed cases as determined by physicians. The overall success of this pilot program led to the implementation of the direct access model in all of the hospital system’s outpatient clinics. Additionally, Ludvigsson et al supported the use of physical therapists as primary assessors of musculoskeletal disorders in the primary care practice setting. The authors found that only a few patients assessed via direct access required additional assessment by a physician, and patients with confirmed serious pathologies were identified. While there is evidence of effective and safe direct access care by civilian physical therapists, the prevalence of this model continues to be limited in the civilian population.

In addition to expanded practice responsibilities, another potential reason for the disparity in scores between military and civilian physical therapists include educational experiences. Forty-three percent of the military physical therapists who completed the musculoskeletal examination attended The US Army-Baylor Physical Therapy Program. This program emphasizes a strong musculoskeletal curriculum to meet the high prevalence of musculoskeletal injuries encountered in the military health system. Additionally, fifty-five percent of the military respondents in the Childs et al study had attended the Colonel Doug Kersey Neuromusculoskeletal Evaluation Course. This is a two-week post-professional continuing education course offered to military physical therapists that focuses on differential diagnosis and primary care management of patients with musculoskeletal conditions. It is not known whether the civilian participants attended an entry-level program with an emphasis on musculoskeletal management and/or a post-professional continuing education courses focusing on primary care management.

Another potential reason for the disparity in scores may lie with professional legislation. Although professional legislation acknowledges physical therapists as primary care providers, there are multiple barriers to practicing direct access for civilian providers. These barriers include limitations from third-party payer reimbursement, limitations from facility bylaws, and lack of consumer knowledge. Childs et al found that masters and doctoral physical therapy students achieved average scores of 64% and 68% respectively. These average scores nearly mirror the average scores of civilian physical therapists from the current study, which were about 65%. The proximity of these numbers may indicate that without the opportunity to practice in direct access environments, the musculoskeletal knowledge measured on this examination does not increase beyond what was learned in physical therapy education; in fact some decline may begin.
Civilian physical therapists with an OCS or SCS in the current study were three times more likely to demonstrate higher levels of knowledge (achieve a passing score) in managing musculoskeletal conditions compared to those without an OCS or SCS. This finding is echoed by Jette et al.10 who found that physical therapists with an orthopedic specialization were almost twice as likely to make correct decisions for critical medical and orthopedic conditions when presented with simulated paper cases. Additionally, Childs et al.8 found that board-certified physical therapists scored significantly higher than their non board-certified colleagues on the musculoskeletal competency examination (81% versus 74%), however these data are limited to the military population. Possible associations between the increased musculoskeletal competency and obtaining an OCS may lie within clinical decision-making models. Orthopedic certified specialists have been shown to possess superior levels of clinical decision-making which has been identified as a central component to expertise.20 Furthermore, physical therapists who obtain an OCS have been attributed to increased efficiency of care using fewer visits, less cost, and decreased treatment procedures compared to non-OCS clinicians.21 Although support for superior levels of clinical decision-making is limited to the OCS clinicians in the literature, these decision-making models may be present in other certified specialists such as SCS clinicians. The evidence from the aforementioned studies support the importance of obtaining board specialization in orthopedics and/or sports for practicing with greater competency in the direct access environment.

The authors feel that the lower pass rate of civilian physical therapists may be due to the nature of the questions and answers. Civilian physical therapists do not always need to know the detail required for this particular examination, just when to refer out. For example, some of the questions inquired about specific laboratory tests and medical interventions. The military physical therapists may have outperformed civilians on these types of questions due to their role in combat as well as their close working relationship with physicians in non-combat situations. Physical therapists in combat situations practice autonomously to manage musculoskeletal conditions and tend to minor wounds which allows the orthopedic surgeons and emergency department physicians to manage patients with more complex surgical and medical issues.22

A surprising observation was the discrepancy between those feeling qualified to practice direct access with those who actually passed the examination. While the purpose of the examination was not to measure readiness for direct access, the nature of the questions and “correct” answers can potentially account for this discrepancy. In many situations, it would be appropriate for a physical therapist to just know when to refer out versus knowing the relevant medical test or intervention to perform. Unfortunately, this assessment did not measure the physical therapist’s ability to know when to refer out. Physical therapists who practice in direct access environments greater than 50% of the time did not outperform those who practiced direct access less than 50% of the time. The authors believe this is due to a very low sample of those who actually practiced direct access greater than 50% of the time (n = 4).

Although discrepancies lie within the scores between civilian and military physical therapists, civilian physical therapists in this study performed at a higher level compared to previously reported data for many physician subspecialties. Civilian physical therapist averages (65.08%) are above that of physician interns (60%)5 and all physician specialties (ranges from 61% - 35%) except for orthopedics (94%).6 It can be speculated that physical therapists (military and civilian) have greater knowledge in managing musculoskeletal conditions based on the comparison of the data since the identical examination was administered to both physicians and physical therapists. The transition to a doctoral level physical therapy degree and emphasis of musculoskeletal diagnoses and management in physical therapy curricula support that physical therapists are well prepared to manage musculoskeletal conditions. Furthermore, it has been estimated that less than 3% of medical school curricula is dedicated to musculoskeletal medicine and only 41.8% of medical schools have preclinical coursework devoted to musculoskeletal medicine.9,23 The significant differences in musculoskeletal curricular time coupled with the results from the current study support physical therapists’ role as primary care pro-
viders with musculoskeletal impairments. However, this assertion requires further research with direct comparisons between providers.

There are limitations to this study. Although the authors intended to target a geographical representation with the survey, it was limited to five states due to convenience and cost reasons. This may limit the generalizability of the results to physical therapists residing in other states or outside of the United States. In addition, the authors are not sure that the sample is representative of the entire physical therapy population. For example, the percentage of doctorally trained physical therapists who participated in the study was 54%, while the percentage of doctorally trained physical therapists in the United States is about 23%. The response rate in this study was 10.6%, which is below the average response rate of 32.52%. The authors attribute the low response rate to the length of time required to complete the examination, which was estimated to be thirty minutes. Again, the low response rate can possibly limit the representativeness of the results. As indicated previously, some of the correct responses according to Freedman and Bernstein are more medically based treatments that are out of the scope of physical therapy practice and may not represent common physical therapist knowledge. In those instances physical therapists would need to understand there is an issue that requires further consult from a physician and refer, rather than knowing specific medical treatment interventions and/or tests. Finally, the respondents who completed the study may be more invested professionally and therefore have a greater desire for professional growth towards autonomous practice. This may have been represented by the larger percentage of doctorally trained physical therapists.

CONCLUSION

The results of this study indicate that civilian physical therapists in the current study performed at lower levels compared to previous data for military physical therapists on an examination assessing musculoskeletal knowledge. Although military physical therapists had higher average scores on the validated exam (75.9%), civilian physical therapists were not far off from their military counterparts (65.08%). Furthermore, civilian physical therapists scored higher on the musculoskeletal examination compared to physician interns (60%) and most physician subspecialties (ranges from 61% - 35%) except for orthopedics (94%). Additionally, physical therapists’ knowledge in managing musculoskeletal conditions greatly increases with an ABPTS board certification in either sports and/or orthopedics compared to those who do not possess a board certification (72.76% versus 63.21%). The study indicates that board certifications may enhance civilian physical therapists ability to practice with greater autonomy as primary care clinicians when managing musculoskeletal conditions.

REFERENCES


ABSTRACT

Background: Musculoskeletal pain can be an important sign of overuse injury in elite athletes. However, its prevalence and whether it is associated with aspects of training in marathon runners who compete at the elite level is still not clear.

Purpose: The purpose of this research was to assess the prevalence, location and intensity of running-related musculoskeletal pain over the previous 12 months in marathon runners who compete at the elite level and to verify whether certain training characteristics are associated with musculoskeletal pain.

Design: Cross sectional study.

Methods: One hundred and ninety-nine elite marathon runners were verbally interviewed regarding their personal demographics, training routines, and the presence, location and intensity of musculoskeletal pain.

Results: The prevalence of any running-related musculoskeletal pain in elite distance runners was 75%, and the most frequently reported location was the lower leg (19.1%). The presence of pain was independent of age, experience, and volume of training.

Conclusions: Running-related musculoskeletal pain is highly prevalent in marathon runners who compete at the elite level.

Clinical Relevance: Studies about prevalence and location of musculoskeletal pain and factors-related in this population are important to contribute to the development of educational and preventive strategies.

Evidence Level: 2

Keywords: Athletic performance, lower extremity, overuse injury, running injury,
INTRODUCTION

Running is a popular sporting activity that can be done everywhere and by almost everyone. For these reasons, it is considered one of the most accessible sporting activities, in terms of cost and ease of implementation, with the number of athletes from recreational to elite levels growing. The positive effects of running on cardiovascular risk factors, mental and social aspects are well known; however, running is not an activity without risk and has also been associated with musculoskeletal injuries. The number of studies assessing the prevalence of injuries in runners has been increasing and typically focus on the time that the athlete is unable to participate in sports activities. However, according to Bahr (2009) it is also important to describe the incidence of pain related to overuse injuries in those who continue to compete.

Runners who compete at the elite level, defined as those competing at international and/or national level, are a minority of the total number of participants in running events, however, they represent an important population to be studied because they are responsible for breaking records and also for the best performances. Their training is characterized by a high training volume, with weekly training loads of up to 160 km/week, which is also considered a risk factor for running-related injuries. Moreover, it has been postulated that the pain perception in athletes is different from the pain perception in normally active persons and can influence the threshold at which pain is reported, especially by elite level athletes.

Despite several studies that have been conducted on running injuries, the prevalence of musculoskeletal pain in marathon runners who compete at the elite level is unclear. Therefore, assessing musculoskeletal pain before a race in elite runners would improve the understanding regarding the perception of musculoskeletal pain of these athletes and clarify two major questions: 1) Do elite distance runners compete despite the presence of musculoskeletal pain? and, 2) If they do, what is the threshold of pain intensity they report before a competition? Addressing these behavioral questions could contribute to the development and implementation of educational interventions that aim to prevent overuse injuries in populations of elite athletes.

The purpose of this study was to assess the prevalence, location and intensity of running-related musculoskeletal pain over the previous 12 months in marathon runners who compete at the elite level and to verify whether certain characteristics of their training are associated with musculoskeletal pain.

METHODS

All runners were recruited during the period of packet pick-up in the week prior to the marathon events staged in 2011. The eligibility criteria were as follows: 1) completion of a marathon in the past 18 months with a time under 2:35:00 for men and 3:00:00 for women, according to the competition regulations for the elite category; 2) enrollment in the elite category. The athletes were assessed only once even if they had participated in more than one event. All athletes who agreed to participate in the study gave written informed consent prior to enrollment. The study protocol was approved by the local human research ethics committee (protocol number 6411/11) in accordance with guidelines for research involving humans.

To assess the prevalence of musculoskeletal pain over the previous 12 months, the runners were verbally interviewed about the presence of musculoskeletal pain by using a previously used questionnaire. The International Association for the Study of Pain (IASP) considers pain as an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage. Those runners who answered “yes” were asked to mark the place (or more than one place, if necessary) of pain on a figure that had 28 points (Figure 1). They were allowed to note more than one location of pain. Next, the runners scored the pain intensity, using a visual analogue scale ranging from zero (no pain) to ten (intolerable pain), at each location noted on the figure. According to the reported score, the pain intensity was classified as mild (1 or 2), moderate (3 to 7), or intense (8 to 10). Subjects also answered questions regarding personal information and training volume, specifically, experience in marathons, weekly training volume, and best time in a marathon.

All information was obtained through verbal interviews conducted by a trained team of health care
professionals. To avoid misunderstanding, the researchers were previously trained to read the questions to the athletes and to repeat them when necessary, i.e., when the athlete did not understand in the first reading. Subjects reported pain by pointing out the body location where they usually experienced pain.

**Statistical analyses**

Descriptive analysis was performed using simple frequency distribution. Categorical data were expressed in percentages. Continuous data were described in measures of central tendency and dispersion. The evaluation of the normality of the continuous data (age, experience, frequency, weekly training volume and fastest time in the marathon) was calculated by the Kolmogorov-Smirnov test. Normal distribution data were presented as the mean and standard deviation, and non-normal distribution data were reported using the median and a 25%-75% interquartile range. The comparison of variables between groups of athletes with and without self-report of pain was performed using Chi-Square and Mann Whitney test for non-normal distribution. The significance level was set at p<0.05. SigmaPlot 12.1 (San Jose, CA, USA) statistical software was used for all analyses.

**RESULTS**

One hundred and ninety-nine athletes participated in the study. The mean age of the runners in this sample was 34 years (30-39 years). Subjects reported running an average of 180 km/wk (160-200 km/wk) (Table 1). There was no difference between the runners with and without pain in demographic measures or training behaviors (Table 1).

Among the 199 respondents, 149 (75%) reported the presence of musculoskeletal pain in the last 12 months, and the most frequently reported locations of running-related musculoskeletal pain were as follows: lower leg (19.1%), knee (15.3%), Achilles tendon (14.5%) and the thigh (12.8%). The shoulder, clavicle, and thoracic spine were the least reported locations, representing 4.8% of the total complaints (Table 2). Fifty-eight individuals (38.6%) reported two distinct locations of pain, 23 (15.3%) reported three locations of pain, and six (4%) reported more than four locations of pain (Table 2).

Regarding the pain intensity assessed by a visual numerical scale (from 0 to 10), 58 athletes (29%) reported intense pain (from 8 to 10), 83 (42%) reported moderate pain (from 3 to 7), 58 (29%) reported mild pain, and 50 (25%) reported the absence of pain (from 0 to 2). Independent of the pain intensity, the prevalence of pain was more commonly reported (61.7%) in four segments of the lower limbs; however, there was no statistical difference among them (Figure 1).

**DISCUSSION**

To the best of the authors' knowledge this is the first study to describe the prevalence of running-related musculoskeletal pain in marathon runners who compete at the elite level. In this study, the areas

| Table 1. Characteristics of the training routine among athletes and comparison between the athletes with and without pain |
|---|---|---|---|
| **Gender (M/F)** | All (n=199) | Pain (n=149) | No pain (n=50) |
| | 164/35 | 128/21 | 36/14 |
| **Age (years)** | 34 (30-39) | 34 (30-39) | 34 (30-39) |
| **Running experience (years)** | 11 (8-16) | 11 (8-16) | 11 (8-17.5) |
| **Running distance (km/wk)** | 180 (160-200) | 180 (160-190) | 180 (160-200) |
| **Personal best time in marathon** | 2h:28min (2h:12min-2h:50min) | 2h:29min (2h:12min-2h:48min) | 2h:29min (2h:14min-2h:48min) |

Continuous data are presented as the mean with the 95% confidence interval (in parenthesis). The categorical data are expressed in number of runners.

M=male, F=female, km= kilometer, h= hours, min=minutes.
Figure 1. Points of musculoskeletal pain (numbers reported on the body region) and prevalence (% reported in arrow boxes) of those most frequently reported by the runners. All areas of pain were reported using a 10cm visual analog scale (shown below).

Table 2. Anatomical locations* of reported pain, according to intensity of pain

<table>
<thead>
<tr>
<th>Location of pain</th>
<th>Mild</th>
<th>Moderate</th>
<th>Intense</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower leg</td>
<td>1</td>
<td>29</td>
<td>15</td>
<td>45</td>
</tr>
<tr>
<td>Knee</td>
<td>3</td>
<td>19</td>
<td>14</td>
<td>36</td>
</tr>
<tr>
<td>Calcaneus tendon</td>
<td>2</td>
<td>13</td>
<td>19</td>
<td>34</td>
</tr>
<tr>
<td>Thigh</td>
<td>3</td>
<td>23</td>
<td>4</td>
<td>30</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>--</td>
<td>13</td>
<td>7</td>
<td>20</td>
</tr>
<tr>
<td>Ankle</td>
<td>1</td>
<td>12</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>Inguinal region</td>
<td>1</td>
<td>6</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>Feet/toes</td>
<td>1</td>
<td>4</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>Hip</td>
<td>1</td>
<td>7</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Pelvic/sacral/gluteus</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Shoulder/clavicle</td>
<td>--</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Thoracic spine</td>
<td>1</td>
<td>2</td>
<td>--</td>
<td>3</td>
</tr>
<tr>
<td>Neck/cervical spine</td>
<td>--</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Sternum/ribs</td>
<td>1</td>
<td>1</td>
<td>--</td>
<td>2</td>
</tr>
<tr>
<td>Wrist</td>
<td>1</td>
<td>--</td>
<td>--</td>
<td>1</td>
</tr>
</tbody>
</table>

Data are presented as number of runners reporting pain.

Mild = 1 or 2 on visual analog scale; Moderate = 3 to 7 on visual analog scale; Intense = 8 to 10

*Athletes were allowed to report as many regions of pain as they experienced.
with highest prevalence of musculoskeletal pain were the lower legs, knees, calcaneal tendon, and thigh. In addition, most athletes reported moderate pain, as reported and assessed by a visual analog scale. The presence of pain was not associated with age, quantity of training and running experience.

Based upon the high prevalence of musculoskeletal pain observed in this population, it would be important to adopt interventions focusing on the athletes’ education aiming to promote more information about the risks and consequences of continuing training despite the presence of pain. This could help to decrease the prevalence of overuse injuries and contribute to the development of injury-prevention strategies. However, this hypothesis needs to be confirmed in future studies.

The prevalence of pain among the elite marathon runners assessed in this study was nearly four times higher than that in another study that assessed musculoskeletal pain in recreational runners (39 ± 11 years old and BMI of 24.3 ± 2.8 kg/m²) who ran an average of 30 kilometers per week. A possible explanation for this difference could be the higher training volume undertaken by the marathon runners who compete at the elite level. In recreational runners, musculoskeletal pain has been associated with weekly training volume and the number of years of running; however, this association was not observed in this study, likely because the sample was homogeneous in terms of the training volume and the number of years of running. Others factors such as preferred running surface and use of different running shoes, atypical foot pronation and inadequate hip muscle stabilization have been identified as causative factors for overuse running injuries and may also be associated with musculoskeletal pain. However, these factors were not assessed in this study.

Assessing the prevalence of musculoskeletal pain in elite marathon runners seems important considering the frequent association between several influences such as biomechanical factors and training conditions and a predisposition to injury. Accordingly, although the pain locations and intensities reported by the runners may suggest musculoskeletal overuse injuries, further investigations are required to further describe the possible interaction between musculoskeletal pain and excessive physical exertion. The areas where the marathon runners who compete at the elite level reported the greatest musculoskeletal pain were the lower legs, knees, calcaneal tendon and thigh. These findings were expected, given the high prevalence of musculoskeletal injuries in the lower limbs that have been described in long-distance runners. The high frequency of pain in the lower limbs may have occurred mainly due to the impact of running on joints, which varies from one and a half to three times the body weight, and the related forces that contribute to soft tissue injuries that range from inflammation to structural degeneration.

There are several limitations to this study that should be noted. First, other domains, such as impairment, disability, strength, amplitude of movement, agility, coordination and balance were not assessed. However, based on the authors’ previous experience with elite athletes, the inclusion of such evaluations would not be well accepted prior to competition because most athletes claim that they must rest and be focused. Second, the reports of musculoskeletal pain were obtained retrospectively, introducing the possibility of memory bias. Third, it is not possible to infer causation from any of the variables assessed because this was a cross-sectional study. Last, the athletes were not queried regarding how much time, if any, was missed from their training due to pain level.

CONCLUSION

Three-quarters of the marathon runners who compete at the elite level reported running-related musculoskeletal pain. Studies on musculoskeletal pain in elite athletes are particularly important because such studies may reveal the ways in which these athletes respond to musculoskeletal pain. Consequently, the findings may contribute to the development of educational and preventive strategies.

REFERENCES

3. Rauh MJ, Barrack M, Nichols JF. Associations between the female athlete triad and injury.


ABSTRACT

Background: Disc golf is rapidly increasing in popularity and more than two million people are estimated to regularly participate in disc golf activities. Despite this popularity, the epidemiology of injuries in disc golf remains under reported.

Purpose: The purpose of the present study was to investigate the prevalence and anatomic distribution of injuries acquired through disc-golf participation in Danish disc golf players.

Methods: The study was a cross-sectional study conducted on Danish disc-golf players. In May 2015, invitations to complete a web-based questionnaire were spread online via social media, and around disc-golf courses in Denmark. The questionnaire included questions regarding disc-golf participation and the characteristics of injuries acquired through disc golf participation. The data was analyzed descriptively.

Results: An injury prevalence of 13.3% (95% CI: 6.7% to 19.9%) was reported amongst the 105 disc-golf players who completed the questionnaire. The anatomical locations most commonly affected by injury were the shoulder (31%) and the elbow (20%). Injuries affecting the players at the time of completion of the questionnaire had a median duration of 240 days (IQR 1410 days), and the majority (93%) had a gradual onset.

Conclusions: A 13.3% point prevalence of injury was reported. Most injuries occurred in the shoulder and elbow regions, and were gradual in onset. Injuries affecting the players at the time of data collection had median symptomatic duration of 240 days.

Levels of Evidence: 3b

Keywords: Disc golf, epidemiology, frisbee golf, injury, overuse

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Ethics: Observational studies require no ethical approval, in accordance to Danish law.

Conflicts of interest: None of the authors has any financial interest in the results presented. No sources of funding were sought or received. R. O. Nielsen was personally salaried by his institution, but no specific salary was set aside or given for the paper.

Acknowledgements: The authors would like to give thanks to the Danish Disc Golf Union and DGI Disc Golf, for their support spreading invitations to the study, both online and on courses around Denmark.
INTRODUCTION
Disc golf is rapidly increasing in popularity as a sport and leisure activity, with an average annual growth rate of more than 11% since 2005. Today, the Professional Disc Golf Association (PDGA) estimates, that more than two million people around the world regularly participate in disc-golf activities, of which an estimated 80,000 reside in Scandinavia. Accordingly, the number of disc-golf courses across the world has doubled to more than 4700 between 2007 and 2014, further emphasizing the increasing interest in the sport.

Formalized in the 1970's, the rules and terminology of disc golf is similar to regular golf, but contrary to the use of golf balls and clubs, disc golf is played with specially designed frisbees, called discs, which are thrown aimed at elevated baskets. In disc golf, the goal is to complete a round of usually 9 or 18 baskets in the fewest throws possible, using a combination of driver-, midrange- and putter-style discs. Each course, and even each hole, presents with its distinct barriers, including terrain, elevation, curvature, obstacles and wind conditions. The player then seeks to overcome these barriers using a variety of different types of throws, of which the backhand and the forehand throws are the most common.

Recreational disc golf appeals to a large portion of the population, as the vast majority of courses are public, and the sole requirement to play is a single disc that costs approximately fifteen dollars. Disc golf is a viable option for those who wants to remain active and competitive in middle age, because of the low-intensity non-contact nature of the sport and the social component, inherent to golf-type sports. In fact, more than 30% of the registered PDGA players are above 40 years of age. Disc golf also utilizes the handicap system, which facilitates high-level competition across differences in skill.

Epidemiologic knowledge regarding injuries in disc golf, however, is sparse. A related frisbee-sport, ultimate, has received more scientific attention, but as more than 40% of injuries in ultimate occurs acutely through player to player contact, the injury pattern is likely incomparable to disc golf. Instead, overuse injuries may be prevalent, owing to the repetitive forceful movements of throwing the discs, similar to the injury pattern of regular golf. One study including disc-golf players was recently conducted by Nelson and colleagues, revealing an 81.8% all-time prevalence of injury sustained through disc golf. However, in their study no definition of injury was provided. In other sports, varying injury definitions has shown to affect the number, and even location, of injuries reported. Therefore, more studies on injury occurrence in disc golf are needed using well-defined injury definitions.

The purpose of the present study was to investigate the prevalence and anatomic distribution of injuries acquired through disc-golf participation in Danish disc golf players.

METHODS
Study design
The study was designed as a cross-sectional, epidemiological study. Data collection was conducted during a six-week timeframe beginning in May 2015, using a web-based questionnaire developed by the authors. In accordance to Danish legislation, no ethical approval was sought because of the observational design.

Participants
Invitations to complete the web-based questionnaire were uploaded to the website of the Danish Disc Golf Union (DDGU), and were sent by e-mail to all members of DGI disc golf organization (n = 80). Online invitations were shared on the social media site Facebook, at 17 Danish disc-golf groups. Posters were put up at five popular disc golf courses nationwide, two of which hosted the Danish disc-golf tour during the data collection phase. A participant needed to have played disc golf at least once, and be at least 18 years of age to be included in the study. Participation in the study was voluntary and all participants gave informed written consent, after reading the purposes and procedures of the study.

Data collection
The questionnaire included details of demographics (gender, age, body mass), disc-golf characteristics (e.g. hours of weekly disc-golf participation, tournament participation, experience, warm-up routines, score), and details of disc-golf injuries (e.g. anatomic region, duration/time to recovery, acute/gradual onset, treatment, workdays lost) sustained throughout the player’s
entire disc-golf career. Score was defined as the number of throws ± par used on a typical 18-basket course, as a substitute for handicap, as many recreational players may not be aware of their actual handicap. Participants were also asked to allocate themselves to either of four groups; “Novice”, “Amateur”, “Intermediate” and “Professional”, inspired by the PDGA player classifications. In the present study, the “Novice” group was pooled to the amateur group, since only few (n=4) were classified as Novice. Due to the self-reporting and retrospective design of the study, only anatomic region of the injury and not specific diagnosis was collected. Prior to the study, the questionnaire was pilot-tested on a small group of disc-golf players with various disc-golf experience (range < one to eight years) and adjusted in accordance to responses. The questionnaire and database system have previously been used in epidemiologic studies.13,14

Outcome

The primary outcome measure was disc-golf injury, defined as “any physical pain or complaint sustained through disc-golf activities that resulted in full stop or modification of usual disc-golf participation, for 7 days or more”. This definition was inspired by Jacobsson and colleagues,15 and modified to include a time-loss period of seven days. The injury definition was visualized to the participant at the injury section of the questionnaire. Both data on point prevalence, defined as “currently suffering from a disc-golf injury” (current injuries), and career prevalence; “any injury previously sustained during disc-golf participation” (previous injuries, which no longer affected the player), were collected.

Exposures

The exposures hypothesized to be associated with injury risk included the following continuous variables: age (years), body mass index (BMI), experience (years), warm-up (minutes), discs carried during play (quantity), tournaments played (quantity), score (+/- 0). In addition, one categorical exposure was included: group for amateur, intermediate, or professional.

Statistical analysis

Continuous variables are presented as median and interquartile range (IQR), as several variables were non-normally distributed, tested by histograms and quantile plots. Categorical variables are presented by counts and percentages. An exploratory analysis was conducted to measure the association between exposure variables and injury status (Binary: Career injury ‘yes’, n = 41; Career injury ‘no’, n = 64). Subgroups of the exposure variables of interest were created according to terciles,16,17 and were analyzed using binominal regression. Main estimates of proportions and relative risks are presented with 95% confidence interval. All statistical analyses were performed using STATA v.13 (StataCorp LP, TX, USA), and statistically significant differences were considered at $p < .05$.

RESULTS

One hundred and five disc-golf players, 102 males and three females completed the questionnaire. The majority of participants (76.2%) had been playing disc golf for more than one year, 16.2% between six and twelve months, and 7.6% less than six months (they had played disc golf a median of 5.5 times, IQR 16.5). Seventy-one players (67.6%) reported membership to an organized disc-golf club, while six players (5.7%) reported previous membership. Participant demographics and disc-golf related characteristics are presented in Table 1.

Forty-one players reported 55 injuries during their entire disc-golf career, which elicits a disc-golf career injury prevalence of 39% (95% CI 29.6% to 48.5%). Six players reported two injuries, while four players reported three. The 38 amateur players reported five previous and three current injuries, the 56 intermediate players reported 30 previous and seven current injuries, while the 11 professional players reported five previous and five current injuries. As one player was affected by two current injuries, fourteen players reported five previous and three current injuries. The 38 amateur players reported five previous and three current injuries, the 56 intermediate players reported 30 previous and seven current injuries, while the 11 professional players reported five previous and five current injuries. As one player was affected by two current injuries, fourteen players reported five previous and three current injuries. The 38 amateur players reported five previous and three current injuries, the 56 intermediate players reported 30 previous and seven current injuries, while the 11 professional players reported five previous and five current injuries. As one player was affected by two current injuries, fourteen players reported five previous and three current injuries. The 38 amateur players reported five previous and three current injuries, the 56 intermediate players reported 30 previous and seven current injuries, while the 11 professional players reported five previous and five current injuries. As one player was affected by two current injuries, fourteen players reported five previous and three current injuries. The 38 amateur players reported five previous and three current injuries, the 56 intermediate players reported 30 previous and seven current injuries, while the 11 professional players reported five previous and five current injuries. As one player was affected by two current injuries, fourteen players reported five previous and three current injuries. The 38 amateur players reported five previous and three current injuries, the 56 intermediate players reported 30 previous and seven current injuries, while the 11 professional players reported five previous and five current injuries. As one player was affected by two current injuries, fourteen players reported five previous and three current injuries. The 38 amateur players reported five previous and three current injuries, the 56 intermediate players reported 30 previous and seven current injuries, while the 11 professional players reported five previous and five current injuries. As one player was affected by two current injuries, fourteen players reported five previous and three current injuries. The 38 amateur players reported five previous and three current injuries, the 56 intermediate players reported 30 previous and seven current injuries, while the 11 professional players reported five previous and five current injuries. As one player was affected by two current injuries, fourteen players reported five previous and three current injuries. The 38 amateur players reported five previous and three current injuries, the 56 intermediate players reported 30 previous and seven current injuries, while the 11 professional players reported five previous and five current injuries. As one player was affected by two current injuries, fourteen players reported five previous and three current injuries. The 38 amateur players reported five previous and three current injuries, the 56 intermediate players reported 30 previous and seven current injuries, while the 11 professional players reported five previous and five current injuries. As one player was affected by two current injuries, fourteen players reported five previous and three current injuries. The 38 amateur players reported five previous and three current injuries, the 56 intermediate players reported 30 previous and seven current injuries, while the 11 professional players reported five previous and five current injuries. As one player was affected by two current injuries, fourteen players reported five previous and three current injuries. The 38 amateur players reported five previous and three current injuries, the 56 intermediate players reported 30 previous and seven current injuries, while the 11 professional players reported five previous and five current injuries.

Of all fifty-five injuries, the most common injury regions were the shoulder (31%) and the elbow (20%), as presented in Table 2. Thirty-six injuries occurred in the extremities, of which the vast majority (92%) occurred on the throwing side. All injuries...
also falls (9%) and inaccessible throwing positions (5%) were reported. Injury characteristics of previous and current injuries are presented in Table 3.

Fifteen (27%) of the 55 injuries received medical attention, including physiotherapists, chiropractors and general practitioners. One injury was treated surgically. Self-treatment such as painkillers, bandages and internet-inspired exercises were used for 27% of all injuries, while nearly half (48%) of injuries received no treatment.

Less than half of the participants (43%) received technical supervision or guidance during their first

Table 1. Demographic and disc golf related characteristics of 105 Danish disc golf players. Data is presented as median and (IQR)

<table>
<thead>
<tr>
<th>Variable</th>
<th>All (n = 105)</th>
<th>Amateur (n = 38)</th>
<th>Intermediate (n = 56)</th>
<th>Professional (n = 11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (year)</td>
<td>29 (12)</td>
<td>27 (12)</td>
<td>31 (12.5)</td>
<td>34 (13)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>182 (9)</td>
<td>182 (9)</td>
<td>183 (7)</td>
<td>180 (9)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>83 (16)</td>
<td>84 (19)</td>
<td>85 (18)</td>
<td>80 (14)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>25.5 (4.7)</td>
<td>25.6 (6.2)</td>
<td>24.9 (5.4)</td>
<td>26.2 (3.4)</td>
</tr>
<tr>
<td>Experience (years)</td>
<td>3 (4.5)</td>
<td>1.3‡ (1.3)</td>
<td>4§ (4) *</td>
<td>10 (7) *†</td>
</tr>
<tr>
<td>Preceeding month</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours per week</td>
<td>4 (6)</td>
<td>3 (2)</td>
<td>5 (6.3) *</td>
<td>6 (7) *</td>
</tr>
<tr>
<td>Throws per week</td>
<td>120 (244)</td>
<td>70 (120)</td>
<td>153 (243) *</td>
<td>240 (340) *</td>
</tr>
<tr>
<td>Score (± 0)</td>
<td>2 (8)</td>
<td>8 (8)</td>
<td>0 (5) *</td>
<td>-3 (5) *†</td>
</tr>
<tr>
<td>Tournaments (#)</td>
<td>10 (25)</td>
<td>2 (6)</td>
<td>13 (24) *</td>
<td>100 (75) *†</td>
</tr>
</tbody>
</table>

IQR= Interquartile range, BMI= body mass index, Experience= years of disc golf participation, Score= number of throws above or below 0 on a typical 18 basket course, Tournaments= number of tournaments with entrance fee played.
* p<0.05 Different from amateur
† p<0.05 Different from intermediate
‡ Data from 8 subjects missing (all 8 reported <6 month experience)
§ Data from 1 subject missing

Table 2. Anatomic region and characteristics of all 55 disc golf injuries

<table>
<thead>
<tr>
<th>Region</th>
<th>All injuries (n = 55)</th>
<th>Onset (Gradual)</th>
<th>Throwing side (Yes)</th>
<th>Medical attention (Yes)</th>
<th>Current injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder</td>
<td>17 (30.9)</td>
<td>12 (71)</td>
<td>17 (100)</td>
<td>5 (29)</td>
<td>7 (46.5)</td>
</tr>
<tr>
<td>Elbow</td>
<td>11 (20)</td>
<td>6 (55)</td>
<td>11 (100)</td>
<td>2 (18)</td>
<td>1 (6.7)</td>
</tr>
<tr>
<td>Hip</td>
<td>5 (9.1)</td>
<td>2 (40)</td>
<td>-</td>
<td>1 (20)</td>
<td>1 (6.7)</td>
</tr>
<tr>
<td>Knee</td>
<td>5 (9.1)</td>
<td>2 (40)</td>
<td>3 (60)</td>
<td>1 (20)</td>
<td>2 (13.3)</td>
</tr>
<tr>
<td>Lower back</td>
<td>3 (5.5)</td>
<td>3 (100)</td>
<td>-</td>
<td>1 (33)</td>
<td>1 (6.7)</td>
</tr>
<tr>
<td>Upper back</td>
<td>3 (5.5)</td>
<td>2 (67)</td>
<td>-</td>
<td>2 (67)</td>
<td>1 (6.7)</td>
</tr>
<tr>
<td>Achilles</td>
<td>1 (1.8)</td>
<td>1 (100)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>1 (6.7)</td>
</tr>
<tr>
<td>Ankle</td>
<td>1 (1.8)</td>
<td>0 (0)</td>
<td>1 (100)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Buttocks</td>
<td>1 (1.8)</td>
<td>1 (100)</td>
<td>-</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Wrist</td>
<td>1 (1.8)</td>
<td>1 (100)</td>
<td>1 (100)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Neck</td>
<td>1 (1.8)</td>
<td>0 (0)</td>
<td>-</td>
<td>1 (100)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Others</td>
<td>6 (10.9)</td>
<td>3 (50)</td>
<td>-</td>
<td>2 (33)</td>
<td>1 (6.7)</td>
</tr>
<tr>
<td>Total</td>
<td>55</td>
<td>33 (60)</td>
<td>33 (92)</td>
<td>15 (27)</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 3. Anatomic region and characteristics of all 55 disc golf injuries

<table>
<thead>
<tr>
<th>Region</th>
<th>Onset (Gradual)</th>
<th>Throwing side (Yes)</th>
<th>Medical attention (Yes)</th>
<th>Current injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder</td>
<td>12 (71)</td>
<td>17 (100)</td>
<td>5 (29)</td>
<td>7 (46.5)</td>
</tr>
<tr>
<td>Elbow</td>
<td>6 (55)</td>
<td>11 (100)</td>
<td>2 (18)</td>
<td>1 (6.7)</td>
</tr>
<tr>
<td>Hip</td>
<td>2 (40)</td>
<td>-</td>
<td>1 (20)</td>
<td>1 (6.7)</td>
</tr>
<tr>
<td>Knee</td>
<td>2 (40)</td>
<td>3 (60)</td>
<td>1 (20)</td>
<td>2 (13.3)</td>
</tr>
<tr>
<td>Lower back</td>
<td>3 (100)</td>
<td>-</td>
<td>1 (33)</td>
<td>1 (6.7)</td>
</tr>
<tr>
<td>Upper back</td>
<td>3 (67)</td>
<td>-</td>
<td>2 (67)</td>
<td>1 (6.7)</td>
</tr>
<tr>
<td>Achilles</td>
<td>1 (100)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>1 (6.7)</td>
</tr>
<tr>
<td>Ankle</td>
<td>0 (0)</td>
<td>1 (100)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Buttocks</td>
<td>1 (100)</td>
<td>-</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Wrist</td>
<td>1 (100)</td>
<td>1 (100)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Neck</td>
<td>1 (100)</td>
<td>0 (0)</td>
<td>1 (100)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Others</td>
<td>3 (50)</td>
<td>-</td>
<td>2 (33)</td>
<td>1 (6.7)</td>
</tr>
<tr>
<td>Total</td>
<td>33 (60)</td>
<td>33 (92)</td>
<td>15 (27)</td>
<td>15</td>
</tr>
</tbody>
</table>

at the non-throwing side (n = 3; 8%) occurred in the lower extremities.

The fifteen current injuries were reported to have affected the players for a median duration of 240 days (IQR 1410) prior to the point of the assessment, while a median time to recovery of 14 days (IQR 45) were reported for the 40 previous injuries. Two players reported having lost two and 10 workdays, respectively, due to injury. Of all 55 injuries, 33 (60%); 95% CI 46.6% to 73.4%) had a gradual onset, while 22 (40%; 95% CI 26.6% to 53.4%) had an acute onset. Most acute injuries occurred during drives (59%), but also falls (9%) and inaccessible throwing positions (5%) were reported. Injury characteristics of previous and current injuries are presented in Table 3.

Fifteen (27%) of the 55 injuries received medical attention, including physiotherapists, chiropractors and general practitioners. One injury was treated surgically. Self-treatment such as painkillers, bandages and internet-inspired exercises were used for 27% of all injuries, while nearly half (48%) of injuries received no treatment.

Less than half of the participants (43%) received technical supervision or guidance during their first
The exploratory analysis (Table 4) indicated, that players reporting scores of five or more, were less likely to report an injury, than players reporting scores of zero or less (RR = 0.37; 95% CI 0.18 to 0.76). Further, the results revealed players of the intermediate or professional group to face a significantly higher risk of injury, than players of the amateur group (RR = 2.71; 95% CI 1.32 to 5.57 and RR = 2.96; 95% CI 1.25 to 6.99). In addition, injury status tended to be associated with both a warm-up duration ≥10 minutes (RR = 1.82; 95% CI 0.95 to 3.46) and carrying 20 or more discs when playing disc golf (RR = 1.85; 95% CI 0.96 to 3.54).

### Table 3. Previous and current injury characteristics.

Data is presented as counts and (%)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Previous injury</th>
<th>Current injury</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n=40 n%</td>
<td>n=15 n%</td>
</tr>
<tr>
<td>Injury duration (days)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 1 month</td>
<td>29 (72.5)</td>
<td>5* (33.3)</td>
</tr>
<tr>
<td>&gt; 1 &lt; 12 months</td>
<td>10 (25)</td>
<td>4* (26.7)</td>
</tr>
<tr>
<td>≥ 12 months</td>
<td>1 (2.5)</td>
<td>6* (40)</td>
</tr>
<tr>
<td>Onset of injury</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute</td>
<td>21 (47.5)</td>
<td>1 (7)</td>
</tr>
<tr>
<td>Gradual</td>
<td>19 (47.5)</td>
<td>14 (93)</td>
</tr>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical attention</td>
<td>11 (27.5)</td>
<td>4 (27)</td>
</tr>
<tr>
<td>Self-treatment</td>
<td>9 (22.5)</td>
<td>6 (40)</td>
</tr>
<tr>
<td>No treatment</td>
<td>20 (50)</td>
<td>5 (33)</td>
</tr>
</tbody>
</table>

Self-treatment= use of painkillers, bandages, and/or exercises from the internet.
*Prior to point of assessment, with the injury continuing.

### Table 4. Exploratory analysis of potential risk factor

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Injured</th>
<th>RR</th>
<th>95% CI</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (Years)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18 - 27</td>
<td>43</td>
<td>14</td>
<td>1.37</td>
<td>[0.75; 2.49]</td>
<td>.31</td>
</tr>
<tr>
<td>28 - 36</td>
<td>27</td>
<td>12</td>
<td>1.27</td>
<td>[1.07; 2.49]</td>
<td>.35</td>
</tr>
<tr>
<td>37 - 68</td>
<td>35</td>
<td>15</td>
<td>1.23</td>
<td>[1.07; 2.49]</td>
<td>.35</td>
</tr>
<tr>
<td><strong>BMI (Kg/m²)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20.2 - 23.5</td>
<td>36</td>
<td>12</td>
<td>1</td>
<td>[0.71; 2.34]</td>
<td>.41</td>
</tr>
<tr>
<td>23.6 - 26.9</td>
<td>35</td>
<td>15</td>
<td>1.29</td>
<td>[0.71; 2.34]</td>
<td>.41</td>
</tr>
<tr>
<td>27.0 - 38.0</td>
<td>34</td>
<td>14</td>
<td>1.24</td>
<td>[0.67; 2.28]</td>
<td>.50</td>
</tr>
<tr>
<td><strong>Disc golf experience (Years)</strong>†</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5 - 1.5</td>
<td>26</td>
<td>9</td>
<td>1</td>
<td>[0.64; 2.32]</td>
<td>.55</td>
</tr>
<tr>
<td>1.6 - 4</td>
<td>38</td>
<td>16</td>
<td>1.22</td>
<td>[0.77; 2.72]</td>
<td>.24</td>
</tr>
<tr>
<td>4.1 - 36</td>
<td>32</td>
<td>16</td>
<td>1.44</td>
<td>[0.67; 2.28]</td>
<td>.50</td>
</tr>
<tr>
<td><strong>Score (+/- 0)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>-8 - 0</td>
<td>43</td>
<td>23</td>
<td>1</td>
<td>[0.45; 1.30]</td>
<td>.32</td>
</tr>
<tr>
<td>1 - 4</td>
<td>27</td>
<td>11</td>
<td>0.76</td>
<td>[0.18; 0.76]</td>
<td>.007*</td>
</tr>
<tr>
<td>5 - 28</td>
<td>35</td>
<td>7</td>
<td>0.37</td>
<td>[0.18; 0.76]</td>
<td>.007*</td>
</tr>
<tr>
<td><strong>Warmup (min)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 - 2</td>
<td>35</td>
<td>9</td>
<td>1</td>
<td>[0.84; 3.50]</td>
<td>.14</td>
</tr>
<tr>
<td>3 - 9</td>
<td>25</td>
<td>11</td>
<td>1.71</td>
<td>[0.84; 3.50]</td>
<td>.14</td>
</tr>
<tr>
<td>10 - 15</td>
<td>45</td>
<td>21</td>
<td>1.82</td>
<td>[0.95; 3.46]</td>
<td>.07</td>
</tr>
<tr>
<td><strong>Discs (#)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 - 11</td>
<td>35</td>
<td>9</td>
<td>1</td>
<td>[0.84; 3.38]</td>
<td>.14</td>
</tr>
<tr>
<td>12 - 19</td>
<td>30</td>
<td>13</td>
<td>1.69</td>
<td>[0.84; 3.38]</td>
<td>.14</td>
</tr>
<tr>
<td>20 - 35</td>
<td>40</td>
<td>19</td>
<td>1.85</td>
<td>[0.96; 3.54]</td>
<td>.06</td>
</tr>
<tr>
<td><strong>Tournaments (#)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 - 2</td>
<td>41</td>
<td>8</td>
<td>1</td>
<td>[1.20; 5.12]</td>
<td>.01*</td>
</tr>
<tr>
<td>3 - 12</td>
<td>29</td>
<td>14</td>
<td>2.47</td>
<td>[1.20; 5.12]</td>
<td>.01*</td>
</tr>
<tr>
<td>13 - 150</td>
<td>35</td>
<td>19</td>
<td>2.78</td>
<td>[1.39; 5.56]</td>
<td>.004*</td>
</tr>
<tr>
<td><strong>Group</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amateur</td>
<td>38</td>
<td>7</td>
<td>1</td>
<td>[1.32; 5.57]</td>
<td>.006*</td>
</tr>
<tr>
<td>Intermediate</td>
<td>56</td>
<td>28</td>
<td>2.71</td>
<td>[1.25; 6.99]</td>
<td>.01*</td>
</tr>
<tr>
<td>Professional</td>
<td>11</td>
<td>6</td>
<td>2.96</td>
<td>[1.25; 6.99]</td>
<td>.01*</td>
</tr>
</tbody>
</table>

RR= risk ratio, Discs= number of discs carried while playing, Group= designation per Professional Disc Golf Association categories.
*p <0.05, †n = 96, as only categorical data was collected for < 6 month year of disc golf and the median time spend on warm-up prior to disc-golf participation were five minutes (IQR 9). The median proportion of back-hand, forearm, and overhead throws during the previous month were 85% (IQR 25), 10% (IQR 21) and 1% (IQR 5), respectively.
DISCUSSION

The results of the present study indicate that 13.3% of the study population currently suffered from a disc-golf related injury, while 39% reported having sustained at least one injury during their disc-golf career. The majority of the current injuries affected the shoulder region, while the shoulder and elbow were the most affected anatomic regions of previous injuries. These results indicate that despite being a low-intensity non-contact sport, injuries in disc golf do occur.

This is the first study to report data on point prevalence and duration of injuries in the sport of disc golf. Nelson and colleagues reported a 81.8% all time prevalence of injury,5 which is in great contrast to the 39% all time prevalence of injury found in present study. This difference may partly be due to the conservative seven-day time-loss definition utilized in present study, as less severe injuries would not be included.12 As the present study recruited players both online and on disc golf courses, it is also possible, that the included players are less experienced and exposed to disc golf, than players being recruited directly from the PDGA website,5 an argument further supported because >50% of players reported six or more years of disc golf experience.5 Despite this discrepancy, the results of the present study indicate that the shoulder and elbow are the main regions of injury in disc golf players, supporting the findings of Nelson and colleagues.5

The actual Danish disc-golf population is unknown,3 and therefore the authors are unable to compare the current sample population with relation to the entire population. However, as an estimate of 500 disc-golf club members in Denmark has recently been suggested,18 the 71 club members in the current sample would represent 14% of the entire club-population in Denmark. In addition, as the registered Danish PDGA member-base consists of 158 members,1 a cross reference revealed that 50 of these PDGA members participated in the current study, which strengthens the representativeness of the sample. Finally only three females (3%) participated in the study which, despite being a proportion lower than the 7.1% females in the study of Nelson and colleagues,5 and the 8% member demographic in PDGA,2 illustrates a highly male-dominated sport.

The current data indicates that most injuries in disc golf occurs to the shoulder and elbow of the throwing arm (Table 2), supporting the initial assumption of a different injury pattern than ultimate frisbee.19 Injuries to these regions are common in sports with elements of overhead motion, such as badminton and the throwing events of athletics, and may be associated with the repetitive overhead motions, during which the shoulder are abducted and externally rotated.19 Interestingly, the data indicates that only 1% (IQR 5) of throws are overhead-throws, which suggests that other explanations of the injury pattern must be considered. It is possible, that these regions are particular susceptible to injury a result of the likely substantial biomechanical forces generated, when driving the ~175gram discs distances up to 263 meters.20 The kinetic chain has been extensively investigated as a key mechanism to maximize force development in the large segments of the legs and trunk, and to transfer energy to the smaller, distal, segments of the shoulder, arm and hand.21–23 Assuming a similar mechanism is present in disc golf, the injury pattern observed in present study could be due to a suboptimal kinetic chain, forcing players to increase force generation in the relatively smaller segments of the shoulder and elbow, potentially leading to higher risk of injury in these segments.24 In addition, even though gradual onset injuries are poorly understood, they are presumably caused by cumulative micro-damage to the tissues, following a period of excessive loading of the tissues or insufficient recovery.25 As intermediate and professional players perform more throws and participate in greater number of hours per week of disc golf than amateurs (Table 1), such accumulation could potentially occur during the many repetitive forceful throws and ultimately lead to injury, even in players with highly developed kinetic chain functional strategies. Future biomechanical studies are warranted to elucidate the specific injury mechanisms.

Point prevalence measures may be influenced by seasonal variance,26 and one must note that the current study was conducted in the beginning of the Danish disc golf tournament season, during which more injuries are prone to occur.27,28 In fact, this tendency is likely to influence the results, as five (33.3%) of the current injuries observed in the present study, had a duration of a month or less (Table 3). Therefore, it is likely that point prevalence observed from studies conducted during the later season, may differ from the current findings. Despite the seemingly low point prevalence,
these data show that 66.7% of the 15 current injuries affected the players for at least a month (Table 3), which in a recent consensus statement marked the point of a serious severity injury.29 The median duration of current injuries were 240 days (IQR 1410 days), further indicating that some injuries may adversely affect disc golf players for prolonged periods of time. The vast majority of these current injuries (93%) had a gradual onset (Table 3), and as the symptoms of gradual onset injuries may appear transient, players in other sports commonly continue to participate, despite their injury.30 All 14 players reporting being currently injured played at least 1 hour of disc golf per week during the last month (not reported), and therefore it is possible the continual participation may aggravate or prolong the injury duration.31,32

Ultimately, two notable observations deserves attention. First, only 43% of the disc-golf players received any means of technique-oriented guidance during their first year playing disc golf. Without proper initial technical guidance, new players may fail to properly develop the kinetic chain, forcing the player to generate more energy at the distal segments,22 or adapt potentially deleterious motor patterns, any of which may predispose the player to injury.33 Second, the disc-golf players warmed up for a median of five minutes (IQR 9), before playing disc golf. As the authors of a recent meta-analysis found that warm-up programs tended to reduce the risk of injuries,34 a structured warm-up routine may potentially be of benefit to disc-golf players.

The exploratory analysis indicated that reporting a low score, and therefore having a higher skill-level, was associated with a higher likelihood of reporting an injury. A high skill-level is a commonly identified risk factor in many sports,35,36 and could be partially explained by the high-skill players’ likely increased exposure to the sport,37 a tendency also observed in the present study (Table 1). As the high-skill players participated in more tournaments than players of lesser skill (Table 1), and as the number of tournaments played may be associated with higher risk of reporting an injury (Table 4), it is also possible the increased demands of tournament play may influence the risk of injury.38 The exploratory analysis also revealed a tendency of association (p = 0.07) between injury status and a warm-up duration of 10 or more minutes. This was unexpected as warm-up programs are assumed to reduce the risk of injury.34 As the retrospective design prevents assessment of temporal relationships, a potential explanation could be that players with previous or current injuries are more attentive towards warm-up procedures, not to risk recurrence of previous or aggravate current injury, than uninjured players. Another tendency (p = 0.06) of association was found when carrying 20 or more discs during rounds of disc golf (RR = 1.85; 95% CI 0.96 to 3.54). As carrying the golf bag is associated with a higher risk of injury in regular golf,39 the same pattern may exist in disc golf. Also, as disc-golf courses often includes obstacles and areas with inaccessible terrain,4,40 falls may be more frequent or severe when carrying a heavy bag. Though the explorative analysis indicates potential preliminary risk factors in disc golf, the authors stress that the present analysis identifies only association and not causation. These results are likely subject to confounding factors,41 as the statistical model used was crude, and thus the authors warrant caution during interpretation. To overcome the limitations of the present study, future research may benefit from using a prospective design, and a statistical analysis adjusted to potential confounding factors or taking into account the possibility for effect-measure modification or interaction.

A major limitation of the present study is the recall bias, inherent to the retrospective design. Gabbe et al.42 found that only 61% of football players could correctly recall their 12-month injury history, and as injury history was collected from the participants' entire disc-golf career, a recall bias indisputably influences the results. To limit this bias, the study could have assessed only current injuries, as previous injuries might be more difficult to recall.43 However, had the authors focused solely on current injuries it is likely that the results would have failed to identify the elbow as a highly exposed injury region as seen in Table 2, and would have missed the plenty of acute injuries, as seen in Table 3. As such, the presentation of both previous and current injuries is performed, acknowledging that the data regarding previous injuries may be flawed. Another major limitation of the study is the small sample size, and the results must be gauged accordingly. More participants would have provided additional reliability to the findings, and would have allowed for a more comprehensive subsequent analy-
A further limitation of present study is the self-evaluation method used to collect data as it cannot be verified that players reported the truth, deliberately or not (i.e. if a participant forgets an injury), which might affect the validity of the present results. In addition, data was not collected on potential aggravating factors outside of disc golf, such as occupation or participation in other sports, which may also affect the validity of the present findings. Ultimately, a participation bias might be present, as even though the study was advertised on both disc golf courses and online, the retrospective design may fail to include players whom prior to this study withdrew from disc golf due to an injury, which could lead to an underestimation of the injury prevalence. It is also possible however, that players with no history of injury will choose to ignore the study invitation, or that previously injured players would be keener to participate, both of which would cause us to overestimate the injury prevalence.

Following the injury prevention model of van Mechelen et al., future studies should attempt to identify causes of injury, including risk factors or injury mechanisms, preferably using prospective cohort studies. Studies may benefit from utilizing the injury recording method of Clarsen et al., as most current injuries were gradual in onset and traditional methodologies of gradual onset injury registration may not be optimal. Ultimately, large-scale studies are warranted, as even though the present study was conducted nationwide, disc golf in Denmark is still a young and relatively unknown sport.

CONCLUSION
A 13.3% point prevalence of injury was reported with the greatest number of injuries occurring in the shoulder and elbow regions. The vast majority of injuries affecting the players were gradual in onset, and showed a median symptomatic duration of 240 days prior to the assessment.

REFERENCES
17. Pieber K, Angelmaier L, Csapo R, Herceg M. Acute injuries and overuse syndromes in sport climbing and bouldering in Austria: A descriptive
   *Frederiksborg Amts Avis*, p. 3. February 17, 2015:3.


ABSTRACT

Background: Therapeutic modalities (TM) are used by sports physical therapists (SPT) but how they are used is unknown.

Purpose: To identify the current clinical use patterns for cryotherapy among SPT.

Study Design: Cross-sectional survey.

Methods: All members (7283) of the Sports Physical Therapy Section of the APTA were recruited. A scenario-based survey using pre-participation management of an acute or sub-acute ankle sprain was developed. A Select Survey link was distributed via email to participants. Respondents selected a treatment approach based upon options provided. Follow-up questions were asked. The survey was available for two weeks with a follow-up email sent after one week. Question answers were the main outcome measures.

Results: Reliability: Cronbach's alpha = >0.9. The SPT response rate = 6.9% (503); responses came from 48 states. Survey results indicated great variability in respondents' approaches to the treatment of an acute and sub-acute ankle sprain.

Conclusions and Clinical Relevance: SPT applied cryotherapy with great variability and not always in accordance to the limited research on the TM. Continuing education, application of current research, and additional outcomes based research needs to remain a focus for clinicians.

Level of Evidence: 3

Key Words: Best practice, cryotherapy, injury management
INTRODUCTION
Cryotherapy, the therapeutic application of cold, has been recognized “as an integral part of physical medicine, physical therapy, athletic therapy, and sports medicine”1(p. 96) for several decades. Despite the common application of cryotherapy, the evidence for its usage is lacking. Bleakley et al.2 concluded in their systematic review that insufficient evidence exists to support the use of cryotherapy clinically, and Hubbard and Denegar state that “the exact effect of cryotherapy on more frequently treated acute injuries has not been fully elucidated.”3(p. 279)

Numerous attempts have been made to supply proof for the use of cryotherapy, but studies have failed to either provide concrete evidence to support cryotherapy usage and/or fully dispel misconceptions about its application. For example, Selkow et al. observed no decrease in blood flow and blood volume of the calf during the application of an ice bag, even though intramuscular temperature did decrease.4 Otte et al.5 observed cooling times associated with cryotherapy application were affected by adipose tissue thickness. More recent data suggests that target tissue depth may be another explanation for the results of Otte et al.6 Ideal cryotherapy applications have also been debated. When seeking the most rapid anesthesia, ice massage appears to be most effective, but cold water immersion may have longer lasting effects.7,8 The nature of these “longer lasting effects” is also under scrutiny. Bleakley and Hopkins report that within animal models, target tissue (e.g., the tissue in the immediate proximity to the injury) temperatures must reach 5 – 15°C in order to decrease metabolic function. It should be noted that no studies on humans exist that address this same issue. Bleakley and Hopkins did not find a single study that reported superficial muscle temperatures being changed to less than 21°C, meaning that the tissues targeted with the cryotherapy likely do not become cold enough for a decrease in metabolism.9 It is apparent from the references cited that a great deal of confusion exists with respect to utilization of cryotherapy and the parameters for application of cold modalities.

From this perspective, one might question whether clinicians are practicing according to evidence (or the lack thereof) or if decisions are being made based on historical factors, such as therapeutic modality availability, ease of application, familiarity with a given modality, and tradition. Therefore, the purpose of this research was to identify the current clinical use patterns for cryotherapy among sports physical therapists (SPT). It was hypothesized that there would be a general consensus amongst the respondents as to how to treat each condition. It was also anticipated that different approaches would be selected depending on the scenario provided. To the authors knowledge, this is the first study of this type to ascertain how SPT would approach these type of injuries.

METHODS
An survey was developed based on available therapeutic modality research.5,6,11-17 The authors of this study wrote the survey, drawing upon greater than two decades of clinical experience and several research studies conducted on therapeutic modalities. The authors received feedback concerning the content of each scenario, treatment options, and the specific parameters of each treatment from five physical therapists (all practicing in the clinical setting at the time of survey development, two trained in master’s programs and three via doctoral programs) and five certified athletic trainers (all with previous clinical athletic training experience teaching at the time of survey development) within an athletic training curriculum (three with PhDs, one with an EdD, and one working towards an EdD).

The survey was sent via a blast email to SPT that are part of the Sports Physical Therapy Section of the American Physical Therapy Association. This section was selected because of it being the section that has members who participate in “a specialized practice that focuses on the prevention, evaluation, treatment, rehabilitation, and performance enhancement of the physically-active individual.”10 Utilizing the blast email method, all members of the Sports Physical Therapist section (7,283 – included physical therapists, physical therapist assistants, and physical therapy students) received an email with a request to participate in the study and a link to the survey. This group received a follow-up reminder email one week after the initial survey request for participation had been sent. The study was approved by the Institutional Review Board at Illinois State
University and informed consent was obtained prior to data collection. The instructions within the email stated that by clicking on the link to the survey the respondents were providing their consent to participate in the study.

Based upon available research and the feedback received, the survey was scaled back from five scenarios to the two included. The number of treatment options and specific parameters were also decreased, with the ones selected chosen based upon regularity of use and availability to the population to whom the survey would be distributed. These ten individuals also took the survey. The feedback received at each stage (during development and after actually having taken the survey) served as the development of content validity for the survey. The reliability of the survey was determined by evaluating the internal consistency of answers between similar questions among the study participants. A frequency analysis was used to assess the number and percent of responses for each question. Pearson correlation coefficients were also computed to see whether relationships existed between the participants and their answers.

The survey focused on the treatment of acute (Scenario 1) and sub-acute (Scenario 2) ankle sprains. The treatment options included ice packs, ice immersion, and Game Ready (CoolSystems, Inc., Concord, CA). Cryokinetics (the use of cold to facilitate exercise) was also included as an option for ice immersion in both scenarios and as an additional option with ice packs and Game Ready in Scenario 2. Respondents were asked to describe their treatment approach, including parameters for their application, for the following scenarios:

- **Scenario 1**: The center on the men's basketball team went up for a rebound and landed awkwardly during practice. An initial evaluation was performed and it was determined that he suffered a Grade II lateral ankle sprain. He was pulled from practice to begin treatment. Which treatment do you perform?

- **Scenario 2**: The basketball player with a Grade II lateral ankle sprain has moved past the acute care phase (0 – 4 days) and is now moving into the sub-acute phase (4 – 14 days). You begin a before practice rehabilitation protocol to remove any swelling that is left over from the injury and to facilitate range of motion exercises. The athlete is full weight bearing and is able to walk unassisted. Which cryotherapy modality would you choose for the rehab?

These two scenarios and the treatment options identified were selected based on their common occurrence and typical usage in sports medicine clinics, allowing for a common reference point for data collection concerning evidence based therapeutic modality selection.

If the SPT would not use one of the approaches provided in survey, they had the option to input their own approach or to select “none of the above.” Descriptive demographic information (sex, age, years practicing, route to practice, where therapeutic modality knowledge was gained, how often therapeutic modalities were used each day) was also sought from each respondent as well as an overview of the equipment available for their use in their given clinical setting.

**RESULTS**

The reliability of the survey was calculated as being good18 (Cronbach's alpha > 0.9 for each question assessed). Five hundred and three members of the Sports Physical Therapy section (6.9% response rate) responded to the survey. The majority of respondents were male, 52% had a doctorate degree, and 77% gained their therapeutic modality experience as a combination of classroom education and clinical experience (Table 1). Additionally, 71% of respondents had an ice machine, and 92% had hydrocollator packs and an ultrasound machine. Other common therapeutic modalities available in their clinics are listed on Table 2.

The predominant choice demonstrated great variability in both cryotherapy selection and parameters of application for the treatment of an acute ankle sprain, where 42% selected RICES with an ice pack, 35% selected Game Ready, 14% selected ice immersion with cryokinetics, and 9% selected “other” (Table 3) and a sub-acute ankle sprain where 24% selected ice pack, 23% selected Game Ready, 14% selected “other”, and 12% selected Game Ready...
+ cryokinetics (Table 4). There was no correlation between degree type (Scenario 1 = .000; Scenario 2 = -.010), years practicing (Scenario 1 = -.020; Scenario 2 = .027), or for where the respondents gained their therapeutic modality knowledge (Scenario 1 = -.009; Scenario 2 = .015) and the treatment selected for either scenario. The choices selected for the two scenarios exhibited a medium strength of correlation however (Pearson correlation = .321, significant at the .01 level).

### DISCUSSION

The purpose of this study was to determine the current clinical use patterns with regards to cryotherapy by SPT in the treatment of an acute and sub-acute ankle sprain. Variability was observed in the selected cryotherapy methods and parameters (Tables 3 & 4), but the selection for Scenario 1 was moderately correlated with the selection for Scenario 2. The variability of treatment approaches may be attributed to a lack of available research associated with cryotherapy and its therapeutic application. Since evidence based practice guidelines do not exist with respect to the use of cryotherapy to treat acute and sub-acute ankle sprains, the results obtained will be compared to research available concerning aspects of cryotherapy usage. Adjustments to practice are recommended where appropriate.

### Scenario 1

Scenario 1 queried the respondents’ approach to the treatment of an acute ankle sprain. This scenario was written to determine how a SPT would choose to cool the tissue in order to limit pain and secondary

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**Table 1. Participant demographics (# (% of total)) for the sports physical therapists who responded to the survey.**

<table>
<thead>
<tr>
<th>Demographic Category</th>
<th># (% of total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>157 (39)</td>
</tr>
<tr>
<td>Male</td>
<td>247 (61)</td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
</tr>
<tr>
<td>≤ 25</td>
<td>14 (3)</td>
</tr>
<tr>
<td>26 – 35</td>
<td>165 (41)</td>
</tr>
<tr>
<td>36 – 45</td>
<td>128 (31)</td>
</tr>
<tr>
<td>&gt; 45</td>
<td>99 (24)</td>
</tr>
<tr>
<td>Years Practicing (years)</td>
<td></td>
</tr>
<tr>
<td>≤ 5</td>
<td>125 (31)</td>
</tr>
<tr>
<td>6 – 10</td>
<td>79 (20)</td>
</tr>
<tr>
<td>11 – 15</td>
<td>67 (17)</td>
</tr>
<tr>
<td>16 – 20</td>
<td>47 (12)</td>
</tr>
<tr>
<td>&gt; 20</td>
<td>87 (21)</td>
</tr>
<tr>
<td>Route to Practice</td>
<td></td>
</tr>
<tr>
<td>Bachelors</td>
<td>83 (20)</td>
</tr>
<tr>
<td>Masters</td>
<td>110 (27)</td>
</tr>
<tr>
<td>Doctorate</td>
<td>212 (52)</td>
</tr>
<tr>
<td>Where therapeutic modality knowledge gained</td>
<td></td>
</tr>
<tr>
<td>Classroom</td>
<td>66 (16)</td>
</tr>
<tr>
<td>Working clinically</td>
<td>28 (7)</td>
</tr>
<tr>
<td>Combination</td>
<td>311 (77)</td>
</tr>
<tr>
<td>How often therapeutic modalities used each day</td>
<td></td>
</tr>
<tr>
<td>With every patient</td>
<td>14 (3)</td>
</tr>
<tr>
<td>With most patients</td>
<td>198 (49)</td>
</tr>
<tr>
<td>With few patients</td>
<td>142 (35)</td>
</tr>
<tr>
<td>Rarely</td>
<td>53 (13)</td>
</tr>
</tbody>
</table>

**Table 2. Therapeutic modalities present in the sports physical therapy clinics surveyed (# (% of total)).**

<table>
<thead>
<tr>
<th>Therapeutic Modalities</th>
<th># (% of total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice machine</td>
<td>291 (71)</td>
</tr>
<tr>
<td>Whirlpool (cold)</td>
<td>64 (16)</td>
</tr>
<tr>
<td>Whirlpool (warm)</td>
<td>78 (19)</td>
</tr>
<tr>
<td>Game Ready</td>
<td>154 (37)</td>
</tr>
<tr>
<td>Other cryocompression device</td>
<td>137 (33)</td>
</tr>
<tr>
<td>Hydrocollator packs</td>
<td>381 (92)</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>381 (92)</td>
</tr>
<tr>
<td>Diathermy</td>
<td>11 (3)</td>
</tr>
<tr>
<td>Paraffin</td>
<td>187 (45)</td>
</tr>
<tr>
<td>Fluidotherapy</td>
<td>79 (19)</td>
</tr>
<tr>
<td>Laser</td>
<td>88 (21)</td>
</tr>
</tbody>
</table>
tissue injury. Of note, the SPT picked what they would do, not necessarily what they thought was the best thing to do, from the available treatment options presented in the survey. As mentioned previously, 42% of respondents chose to accomplish this goal using RICEs while 35% of respondents chose to use a Game Ready (Table 3). Marketing for the use of Cold/compression devices (e.g., Game Ready) base their performance claims on the notion that they can do what an ice pack and an elastic wrap can do, but do it better. This claim is made due to the added benefit of being able to provide intermittent compression to the body part, something that cannot be done with an elastic wrap.19 Not only did roughly one third of the respondents select the Game Ready to manage an acute ankle sprain (Table 3), but approximately one quarter selected it for the management of a sub-acute ankle sprain (Table 4) as well. The

<table>
<thead>
<tr>
<th>Table 3. Management strategy of sports physical therapists of an acute ankle sprain (# (% of total)).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment Option</td>
</tr>
<tr>
<td>RICEs with an ice pack</td>
</tr>
<tr>
<td>How long initially iced</td>
</tr>
<tr>
<td>≤ 10 min</td>
</tr>
<tr>
<td>11 – 15 min</td>
</tr>
<tr>
<td>16 – 20 min</td>
</tr>
<tr>
<td>&gt; 20 min/Until numb</td>
</tr>
<tr>
<td>What ice applied with</td>
</tr>
<tr>
<td>Elastic wrap</td>
</tr>
<tr>
<td>Plastic film</td>
</tr>
<tr>
<td>Other/Nothing</td>
</tr>
<tr>
<td>Barrier present</td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>Ice immersion with cryokinetics</td>
</tr>
<tr>
<td>Toe Cap</td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>How long initially iced</td>
</tr>
<tr>
<td>≤ 10 min</td>
</tr>
<tr>
<td>11 – 15 min</td>
</tr>
<tr>
<td>&gt; 15 min/Until numb</td>
</tr>
<tr>
<td>Game Ready</td>
</tr>
<tr>
<td>How long initially iced</td>
</tr>
<tr>
<td>≤ 10 min</td>
</tr>
<tr>
<td>11 – 15 min</td>
</tr>
<tr>
<td>16 – 20 min</td>
</tr>
<tr>
<td>&gt; 20 min/Until numb</td>
</tr>
<tr>
<td>Pressure of the machine</td>
</tr>
<tr>
<td>No pressure</td>
</tr>
<tr>
<td>Low</td>
</tr>
<tr>
<td>Medium</td>
</tr>
<tr>
<td>High</td>
</tr>
<tr>
<td>How many “snow flakes”*</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>Between 1 &amp; 3</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>Other</td>
</tr>
</tbody>
</table>

*Game Ready indicates how cold a treatment is based on the number of “snow flakes” selected – one snow flake is not as cold as three.

<table>
<thead>
<tr>
<th>Table 4. Management strategy of sports physical therapists of a sub-acute ankle sprain (# (% of total)).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment Option</td>
</tr>
<tr>
<td>Ice pack</td>
</tr>
<tr>
<td>Ice pack + Cryokinetics</td>
</tr>
<tr>
<td>Ice immersion</td>
</tr>
<tr>
<td>Ice immersion + Cryokinetics</td>
</tr>
<tr>
<td>Game Ready</td>
</tr>
<tr>
<td>Game Ready + Cryokinetics</td>
</tr>
<tr>
<td>Other</td>
</tr>
<tr>
<td>None of the above</td>
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</table>
propensity for this use is not supported by data. In a 2012 study, Hawkins et al.\textsuperscript{11} observed that an ice pack with an elastic wrap and ice immersion both cooled the sinus tarsi area of the ankle to a greater extent than a Game Ready machine on medium setting, and maintained that cooling longer. Again, if cooling is the goal, the use of a Game Ready machine may not be best practice. If this in indeed the case, less than half of respondents in this case appear to be practicing accordingly.

Beyond determining the most appropriate cooling modality it is also important to discuss treatment parameters, in particular: treatment time, the use of a barrier, and how the selected method of cryotherapy is to be held in place (elastic wrap vs. plastic film). Forty-nine percent of respondents chose to apply RICEs for 11-15 minutes while 38% chose 16-20 minutes. These were the two most popular responses. Generally speaking, it is unknown how long is sufficient to apply cryotherapy in an acute situation. However, based on the work of Otte et al\textsuperscript{1} the respondents treated the acute ankle sprain for an adequate amount of time to see a 7° C decrease in temperature (12 minutes). Jutte et al\textsuperscript{12} have added further clarity to this issue by applying the Otte et al recommendations to commonly treated body parts. The results of their study indicated that an ankle should be treated for 15 minutes.

In the clinical environment, the use of reusable cryotherapy approaches (e.g., chemical gel packs) is common. Should a non-reusable approach be taken, ice packs made from crushed ice are safe to be applied directly to the skin.\textsuperscript{20} Chemical gel packs are generally considered to be unsafe for application directly to the skin as they can actually maintain a temperature that is several degrees below zero, increasing the risk of frostbite.\textsuperscript{21,22} Applying a non-reusable ice pack made of crushed ice directly to the skin is supported by available research since including a barrier (elastic wrap or towel) will insulate the treatment area, decreasing the effectiveness of the cryotherapy treatment.\textsuperscript{13,14} As noted in Table 3, the majority of respondents (78%) selected to use a barrier during the application of an ice pack. If the respondents were using a chemical gel pack as their “ice pack”, this response is appropriate. Whether they were using a chemical gel pack or not cannot be ascertained from the data however.

When ice was selected for application, it was applied with an elastic wrap 57% of the time (Table 3). This is supported by available research. Tomchuk, et al.\textsuperscript{15} compared the difference between an elastic wrap and flexi wrap (plastic film) on tissue cooling. Both held the ice pack in place, but the elastic wrap facilitated a decrease in temperature that the flexi wrap did not. The elastic wrap does this by compressing the underlying tissue closer together. Tissues that are closer together more readily conduct heat, or in this case, the removal of heat from the body part. As such, if the goal is to decrease tissue temperature, applying the ice pack under an elastic wrap is optimal.

It bears noting that no data from randomized clinical trials exist to suggest that decreasing temperature change after injury causes a change in outcomes in actual patients with respect to limiting pain and secondary injury. Furthermore, the rationale for use of cryotherapy in the specific manner provided above is based on the results from a few papers. Ideally there would be multiple papers that have established good evidence. This fact is highlighted to emphasize the need to gather further evidence with respect to the acute management of musculoskeletal conditions before definitive statements can be made regarding the correct choice, application strategies, and duration and regarding the treatment effectiveness of any given intervention on athletes with injury.

**Scenario 2**

Scenario 2 queried the respondents’ approach in treating a sub-acute ankle sprain. A common goal of cryotherapy in a scenario such as this is to cool the area to the point of numbness which will in turn facilitate pain free range of motion exercises and allow for active muscle pumping to assist with removal of residual swelling. This is known as cryokinetics.\textsuperscript{21,22} Numbness has been reported to occur in 15 – 20 minutes with various methods of ice application.\textsuperscript{16} Longer applications, meaning applications beyond numbness, are not believed to be any more beneficial.\textsuperscript{21,22} As such, selecting either “16 – 20 minutes” or “until numb” appears to be the best response to this question, making sure to take into account adiposity\textsuperscript{5,17} as well as target tissue depth.\textsuperscript{9} The respondents most commonly selected an ice pack (24%) and Game Ready (23%) to accomplish this
goal (Table 4). The use of cryokinetics was not commonly chosen (7%-ice pack + cryokinetics, 8%-ice immersion + cryokinetics, and 12% -Game Ready + cryokinetics) by the respondents.

The parameters associated with the cryotherapy selections outlined in Table 4 (sub-acute ankle sprain) were purposefully not reported. Since no one treatment approach had greater than 24% of the total responses it was believed that this fact was more telling than any specific aspect of the treatment. Once a patient moves out of the acute phase where a decrease in temperature may help with pain and secondary injury, movement and mobility via exercise is the key. The approach a therapist takes to get their patient cold to facilitate exercise (if needed) may be less important than the fact the patient is able to exercise. This appears to be the case with the responses reported in Table 4, and there is no evidence to support the use of one treatment approach over the other.

The need for additional study of cryotherapy interventions is further substantiated in the number of “Other” selections made in both scenarios. The question was open ended, allowing for the 35 “Other” responses (9%) for Scenario 1 and the 45 (14%) for Scenario 2 unique in their own way. The responses were most commonly a combination of the answer options provided in the surveys but also included different methods of manual therapy, notably massage and the use of instrument assisted soft tissue mobilization. It was clear that personal preference or experience guided these answers; and some responses have more evidence for their use than others.

Limitations
A major limitation of this study is the low response rate. The data received is enlightening and does shed light on how cryotherapy is used, but may not represent fully the SPT group due to the lack of participants. A second limitation is the fact that the entire SPT section received the survey. As the section also includes sports physical therapy assistants and sports physical therapy students who are not decision makers, the results may not fully represent the SPT group. Ideally only practicing SPT would have received the survey, but the Sports Physical Therapy section would not distribute the survey that way. A third limitation is associated with the survey responses themselves. From the number of “other” responses it is clear that the respondents would have deemed numerous other approaches appropriate. Although the provided survey responses were deemed appropriate by the authors and ten reviewers of the survey, they apparently did not encompass the possibilities of treatment. Fourth, the survey scenarios themselves, as well as the specific wording, could have influenced the choices made by the respondents. Finally, there is a lack of research evidence to support the use of cryotherapy as well as the parameters for application of the types of cryotherapy offered as interventions, as referenced throughout this manuscript. Without clear evidence it is nearly impossible to determine what an appropriate “correct” choice would be.

Clinical Implications
Within the two scenarios presented in this article lies the primary uses of cryotherapy clinically, to treat acute and subacute injuries. The most common methods of cryotherapy application are also highlighted, with the exception being ice massage. Ice massage was purposefully left off of the list due to the boney nature of the ankle. Regardless of the specific form of cryotherapy used or the injury it is applied on, efforts need to be made to substantiate the evidence beyond cryotherapy application.

Conclusions
A great deal of variability existed in the approaches that were selected by SPT for treatment of an acute and sub-acute ankle pathology using cryotherapy. These results demonstrate the lack of clear consensus for choices or treatment guidelines for cryotherapy. The greatest implication of this study is that the data to substantiate the use of cryotherapy and create treatment guidelines exists and needs to be gathered, quantified, and disseminated so evidence-based guidelines for cryotherapy can be created. Further, it is evident that certain aspects of the application of cryotherapy (creation of a therapeutic goal and how to best accomplish it, treatment time, use of barrier, and how the modality is held in place) should also be further studied.

REFERENCES


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