LITERATURE REVIEW

THE ROLE OF MASSAGE IN SPORTS PERFORMANCE AND REHABILITATION:
CURRENT EVIDENCE AND FUTURE DIRECTION

Jason Brummitt, MSPT, SCS, ATC*

ABSTRACT

Background. Massage is a popular treatment choice of athletes, coaches, and sports physical therapists. Despite its purported benefits and frequent use, evidence demonstrating its efficacy is scarce.

Purpose. To identify current literature relating to sports massage and its role in effecting an athlete's psychological readiness, in enhancing sports performance, in recovery from exercise and competition, and in the treatment of sports related musculoskeletal injuries.

Methods. Electronic databases were used to identify papers relevant to this review. The following keywords were searched: massage, sports injuries, athletic injuries, physical therapy, rehabilitation, delayed onset muscle soreness, sports psychology, sports performance, sports massage, sports recovery, soft tissue mobilization, deep transverse friction massage, pre-event, and post exercise.

Results. Research studies pertaining to the following general categories were identified and reviewed: pre-event (physiological and psychological variables), sports performance, recovery, and rehabilitation.

Discussion. Despite the fact clinical research has been performed, a poor appreciation exists for the appropriate clinical use of sports massage.

Conclusion. Additional studies examining the physiological and psychological effects of sports massage are necessary in order to assist the sports physical therapist in developing and implementing clinically significant evidence based programs or treatments.

Key Words: sports massage, sports rehabilitation, sports performance, sports recovery

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INTRODUCTION
Massage has been utilized in the treatment of illness and injury for thousands of years by health care practitioners.\(^1\) Chinese writings dating back to 2500 BC describe the use of this modality for a variety of medical purposes.\(^1,3\)
Massage has been promoted as a treatment of choice for numerous conditions such as musculoskeletal injuries, cancer, stress, relaxation, and pregnancy.\(^2,4\)

Physical therapists who specialize in sports medicine often utilize massage techniques to aid an athlete’s recovery from intense exercise or as a treatment option when performing clinical rehabilitation.\(^5\) Sports massage has been suggested as a means to help prepare an athlete for competition, as a tool to enhance athletic performance, as a treatment approach to help the athlete recover after exercise or competition, and as a manual therapy intervention for sports-related musculoskeletal injuries.\(^2,3,5\)

While massage is frequently performed by physical therapists (and other healthcare or alternative medicine practitioners) and is popular with athletes and coaches, its actual efficacy is questionable.\(^5,6\)

The purpose of this paper is to review and present the current literature relating to sports massage and its roles in effecting an athlete’s psychological readiness, in enhancing sports performance, in recovery from exercise and competition, and in the treatment of sports-related musculoskeletal injuries. Recommendations are discussed highlighting the need for additional research in sports massage.

METHODS
Selection of Papers
The following electronic databases were used to identify papers relevant to this review: Medline (from 1950-present), CINAHL (1982-present), PsycINFO (1985-present), Cochrane Database of Systematic Reviews, and SPORTDiscus (1830-present). Table 1 presents the Medical Subject Headings (MeSHs) and textwords (tw) utilized in the search strategy for this paper. If fewer than 300 articles were identified by a search strategy, the study abstracts were reviewed from that category in order to identify potentially relevant papers. The reference list of each of the selected papers was also reviewed in order to identify additional relevant publications.

Study Selection
Inclusion Criteria
1) The report’s study design must have been one of the following: randomized controlled trial, quasi-experimental, single-case design, non-randomized historical cohort comparisons, case-series, or case report.
2) The report was published in a scientific peer-reviewed journal.
3) The sports massage protocol described in the report must have included at least one or more of the following techniques: effleurage, petrissage, or deep transverse friction massage (also known as cross-friction massage).
4) The purpose of the massage intervention was to impact one or more of the following facets of athletics: pre-event (warm-up and psychological readiness), sports performance, recovery from exercise and competition, or the treatment of sports-related injuries.

Exclusion Criteria
1) Papers that were not published within a peer-reviewed scientific journal.
2) Reports that detailed the use of massage for non-sports related injuries or functions.

The rationale for these inclusion and exclusion criteria was to identify papers that investigate the use of massage in all facets of athletic care. The massage techniques included for review in this paper were based upon their prevalence within the literature and their preference among physical therapists.\(^7\) In specific situations where there was paucity in the literature, complementary paper(s) were presented (but not included in the overall review). Massage protocols investigating efficacy for non-sports related injuries or chronic conditions were considered beyond the scope of this review.

Description of Selected Massage Techniques
Sports massage is defined as a collection of massage techniques performed on athletes or active individuals for the purpose of aiding recovery or treating pathology.\(^8\)

Three forms of massage are frequently reported in the sports medicine literature: effleurage, petrissage, and deep transverse friction massage (DTFM).\(^7\)

Effleurage techniques are performed along the length of the muscle, typically in a distal to proximal sequence.\(^1,3,8\)
These techniques are executed throughout a massage routine, with the strokes performed slowly utilizing light or gentle pressure.\(^1,3,8\)
The petrissage techniques include kneading, wringing, and scooping strokes.\(^1,3,8\)
techniques are generally performed with deeper pressure to patient tolerance.\textsuperscript{1-3,8} Deep transverse friction massage (also known as cross-friction massage) is performed by using the fingers to apply a force moving transversely across the target tissue.\textsuperscript{1-3,8,9}

**Description of Tables**

The information about to be presented is summarized in Table 3-6. Part of each of these tables includes a column called “level of evidence.” The definition of these levels is defined in Table 2. The reader should refer to Table 2 when referring to the information on Tables 3-6.

**Efficacy of a Pre-Event Massage**

Athletes routinely prepare both physically and psychologically prior to competition. Athletes typically incorporate one or more of the following pre-competition preparation strategies: static stretching,\textsuperscript{10,11} dynamic stretching,\textsuperscript{10,13} warm-up drills, game simulations, and mental imagery.\textsuperscript{14} A pre-event massage has been suggested as a strategy to decrease pre-competition anxiety and to prepare the muscles for competition.\textsuperscript{2} Currently a paucity in the literature exists addressing the effects of a pre-event massage in order to reduce injury risk or enhance psychological readiness (Table 3).

**Effect on Blood Pressure**

Camborn et al\textsuperscript{15} investigated the effect of massage on a recipient's blood pressure (BP). Twenty five massage therapy students provided massage treatments to 150 current massage therapy clients.\textsuperscript{15} The length of the massage and the techniques performed by the students were not controlled, but were instead based upon the students' perception of the clients' needs.\textsuperscript{15} The massages ranged in time from 30 to 90 minutes. Six different massage techniques were used including Swedish, deep tissue, myofascial release, sports, trigger point, and craniosacral. The authors defined sports massage as “a more vigorous type of massage used to prepare athletes for peak performance and uses a combination of techniques including joint mobilization, stretching and/or postisometric relaxation, cross-fiber friction, and pressure point massage.”\textsuperscript{155}

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**Table 1. Search Strategy**

<table>
<thead>
<tr>
<th>MeSH or tw</th>
<th>MeSH or tw Defined</th>
<th>Number of Articles Identified</th>
<th>Number of Articles Determined as Potentially Relevant</th>
<th>Number of Articles Included in Critical Appraisal</th>
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</thead>
<tbody>
<tr>
<td>1) MeSH or tw Massage</td>
<td>14032</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
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<tr>
<td>2) MeSH or tw Sports Injuries</td>
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<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>3) MeSH or tw Athletic Injuries</td>
<td>227875</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>4) MeSH or tw Physical Therapy</td>
<td>53602</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>5) MeSH or tw Rehabilitation</td>
<td>169190</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>6) MeSH or tw Delayed Onset Muscle Soreness</td>
<td>764</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>7) MeSH or tw Sports Psychology</td>
<td>1512</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>8) MeSH or tw Sports Performance</td>
<td>1423</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>9) MeSH or tw Sports Massage</td>
<td>253</td>
<td>22</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>10) MeSH or tw Sports Recovery</td>
<td>90</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>11) MeSH or tw Soft Tissue Mobilization</td>
<td>46</td>
<td>6</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>12) MeSH or tw Deep Transverse Friction Massage</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>13) MeSH or tw Pre-event</td>
<td>312</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>14) MeSH or tw Post Exercise</td>
<td>2099</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
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</tbody>
</table>

1 and 2 | 34 | 2 | 1 |
1 and 3 | 81 | 4 | 1 |
4 and 9 | 5 | 0 | 0 |
5 and 9 | 6 | 0 | 0 |
6 and 9 | 8 | 4 | 4 |
7 and 9 | 1 | 1 | 1 |
8 and 9 | 11 | 4 | 4 |
9 and 10 | 8 | 4 | 2 |
9 and 11 | 0 | 0 | 0 |
9 and 13 | 0 | 0 | 0 |
9 and 14 | 5 | 2 | 2 |

MeSH: Medical Subject Heading
tw: textword
n/a: not assessed
The authors found that clients receiving Swedish massage (effleurage and petrissage) experienced the greatest reduction in blood pressure, whereas those who had received trigger point therapy and sports massage experienced an increase in blood pressure. While this research provides findings that may have clinical significance, the study design challenges the overall strength of the findings. A large sample size was collected (n = 150), but 25 massage therapy students performed the non-uniform interventions to clients who were already receptive to this form of treatment. The study also lacked controls for the duration of the massage (30 to 90 minutes) and the massage techniques performed.

Although this study did not directly focus on an athletic population, a vigorous massage may be less desirable than a “Swedish” (or relaxation) type of massage in specific situations. Theoretically, an athlete who is experiencing pre-game anxiety or stress may increase his or her risk of sustaining an injury or of having a sub-par performance. Future investigations should be performed with specific athletic populations receiving massages just prior to participating in a stressful simulation or actual competition.

Effect on Mood and Anxiety
Leivadi et al. evaluated the effects of massage on mood and anxiety states in female dancers (mean age = 20.1 years, SD = 1.8 years). The dancers were randomly assigned to either a massage therapy (n = 15) group or a relaxation therapy (n = 15) group. The massage therapy group received a 30-minute treatment twice a week for a five week period. The massages consisted of effleurage, petrissage, and friction techniques with a treatment emphasis on the upper torso. Those assigned to the relaxation therapy group performed a series of muscle tensing and relaxation exercises while listening to a recorded tape. Both groups demonstrated significant effects between the first and last treatment sessions for lowered anxiety levels and improved mood scores (as measured by the State Anxiety Inventory and the Profile of Mood States (POMS) respectively). The massage treatment group also demonstrated significantly lower cortisol levels compared to the relaxation group. Limitations in study design threaten the strength of the findings. This investigation lacked a true control group. The subjects in the relaxation therapy group were required to independently perform the program on their own at home. To ensure that dancers fully complied with the relaxation program, each relaxation session should have been performed under the supervision of an examiner.

Micklewright et al. investigated the effects of a pre-performance massage on mood state. Sixteen subjects (10 male and 6 female university students) participated in the study. Each subject completed the POMS questionnaire to establish baseline mood state prior to receiving the treatment intervention. During the first session a subject received either 30 minutes of massage or rested 30 minutes on his or her back. The subjects served as their own controls between the two sessions. After the treatment intervention subjects completed a standard Wingate anaerobic cycling test. The POMS questionnaires were also completed after the treatment intervention and after the cycling test.

The investigators found that cycling performance was better after the massage compared to the control group, but this improvement was unrelated to changes in mood state. The authors hypothesized that pre-performance psychological factors other than one’s mood state may enhance performance.

Additional studies have investigated how massage effects an athlete’s perception of recovery and regeneration. While these investigations support the beneficial psychological effects of massage; overall study design threatens the strength of the conclusions.

EFFECTS OF MASSAGE ON SPORTS PERFORMANCE
Athletes and coaches are constantly fine tuning their training strategies in order to develop a competitive edge. The use of therapeutic modalities, such as thermal agents, electrical stimulation, and massage are often performed for this purpose. Despite the frequency that
<table>
<thead>
<tr>
<th>Study (Year)</th>
<th>Study Design</th>
<th>Level of Evidence</th>
<th>Participants</th>
<th>Professional(s) Conducting the Intervention</th>
<th>Techniques</th>
<th>Treatment Time</th>
<th>Results and Authors’ Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cambron et al 2015</td>
<td>Quasi-experimental pre-test post-test design</td>
<td>3</td>
<td>150 massage therapy clients (mean age 42.5 years, range 19-79)</td>
<td>25 massage therapy students; 12 in their 2nd trimester and 13 in their 3rd (final) trimester</td>
<td>Swedish, deep tissue, myofascial release, sports, trigger point, craniosacral</td>
<td>One treatment session, 30 – 90 minutes per practitioner preference</td>
<td>1) Nonsignificant decrease in systolic blood pressure (BP): average 1.8 (range: -24-34) mmHg and an average increase in diastolic BP of 0.1 (range: -53-18). 2) No association between BP and any of the following variables: duration, amount of pressure, and the massage therapy internship experience. 3) Swedish massage was associated with a nonsignificant decrease in systolic BP. 4) Systolic BP increased with trigger point and sports massage. When the two techniques were performed in combination both systolic and diastolic BP increases were statistically significant.</td>
</tr>
<tr>
<td>Leivadi et al 2018</td>
<td>Randomized controlled trial: Pre-test/Post-test group design</td>
<td>2</td>
<td>30 female adult dance majors (mean age 20.1 years, SD 1.8)</td>
<td>“Different trained massage therapists”</td>
<td>Effleurage, petrissage</td>
<td>Two sessions a week for 5 weeks, 30-minute sessions.</td>
<td>1) Significant pre-test/post-test treatment measures for anxiety levels, less depressed moods, less neck and shoulder pain, less low back pain for both groups. 2) Significant decrease in cortisol levels for the massage intervention group. 3) Those receiving massage treatment experienced a significant improvement in neck extension and shoulder abduction at the end of the study.</td>
</tr>
<tr>
<td>Micklewright et al 2019</td>
<td>Within subjects experimental design with counterbalanced design</td>
<td>3</td>
<td>16 university and students (10 male 6 female) mean age 22 years, SD 4.8</td>
<td>One massage therapist</td>
<td>Effleurage, petrissage</td>
<td>30-minute standardized massage protocol</td>
<td>The massage treatment prior to Wingate Anaerobic Cycling Test significantly enhanced performance but had no effect on mood state.</td>
</tr>
<tr>
<td>Hemmings et al 2020</td>
<td>Within subjects experimental design with counterbalanced design</td>
<td>3</td>
<td>Eight amateur boxers (mean age 24.9 years, SD 3.8)</td>
<td>Sports massage therapist</td>
<td>Effleurage, petrissage</td>
<td>20-minute standardized protocol consisting of 8-minutes for the legs, 2-minutes for the back, and 10-minutes for the shoulders and arms</td>
<td>1) No significant difference between groups for performance. 2) Massage program significantly increased perceptions of recovery. 3) No statistical difference in blood lactate or glucose levels after either intervention. 4) Blood lactate concentration was significantly higher after the massage program.</td>
</tr>
<tr>
<td>Hemmings 2021</td>
<td>Within subjects experimental design with counterbalanced design</td>
<td>3</td>
<td>Nine Royal Navy boxing squad members (mean age 22 ± 3.1 years)</td>
<td>Sports massage therapist</td>
<td>Effleurage, petrissage</td>
<td>20-minute standardized</td>
<td>1) After massage, boxers’ perceived recovery was significantly greater than resting and the touching control. 2) Massage did not affect saliva flow.</td>
</tr>
<tr>
<td>Hemmings 2022</td>
<td>Within subjects experimental design with counterbalanced design</td>
<td>3</td>
<td>Nine Royal Navy boxing squad members (mean age 22 ± 3.1 years)</td>
<td>Sports massage therapist</td>
<td>Effleurage, petrissage</td>
<td>20-minute standardized protocol</td>
<td>1) After massage intervention, significant main effects were found in the fatigue subscale and a trend towards significance in the tension subscale. 2) No main effects noted in the vigor, depression, and anger subscales.</td>
</tr>
<tr>
<td>Study (Year)</td>
<td>Study Design</td>
<td>Level of Evidence</td>
<td>Participants</td>
<td>Professional(s) Conducting the Intervention</td>
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<tr>
<td>et al27</td>
<td>Randomized controlled trial: pre-test/post-test group design</td>
<td>2</td>
<td>30 female adult dance majors (mean age 20.1 years, SD 1.6)</td>
<td>“Different trained massage therapists”</td>
<td>Effleurage and petrissage techniques</td>
<td>2 sessions a week for 5 weeks. 30-minute sessions</td>
<td>1) Significant pre-post treatment measures for anxiety levels, less depressed moods, less neck and shoulder pain, less low back pain for both groups. 2) Significant decrease in cortisol levels for the massage intervention group. 3) Those receiving massage treatment experienced a significant improvement in neck extension and shoulder abduction at the end of the study.</td>
</tr>
<tr>
<td>et al23</td>
<td>Experimental design (mean age 21 massage not significantly change sit and reach</td>
<td>3</td>
<td>11 male volunteers</td>
<td>One massage therapist</td>
<td>Effleurage, petrissage</td>
<td>30-minute standardized massage protocol</td>
<td>The massage treatment prior to Wingate Anaerobic Cycling Test significantly enhanced performance but had no effect on mood state.</td>
</tr>
<tr>
<td>et al47</td>
<td>Randomized controlled trial: pre-test/post-test and female), mean age therapy student techniques</td>
<td>2</td>
<td>18 volunteers (male and female)</td>
<td>Effleurage, petrissage</td>
<td>20-minute routine consisting of 8-minutes for the legs, 2-minutes for the back, and 10-minutes for the shoulders and arms</td>
<td>1) No significant difference between groups for performance. 2) Massage program significantly increased perceptions of recovery 3) No statistical difference in blood lactate or glucose levels after either intervention. 4) Blood lactate concentration was significantly higher after the massage program.</td>
<td></td>
</tr>
<tr>
<td>et al25</td>
<td>Randomized controlled trial: pre-test/post-test volunteers (consisting of lying prone for increased hamstring flexibility as group design volleyball players</td>
<td>2</td>
<td>45 healthy male volunteers (mean age 19.8 ± 3.7, range 15 to 31).</td>
<td>Two physiotherapists</td>
<td>Effleurage, knodding</td>
<td>2) Significant decrease in cortisol compared to the control group. 3) Those receiving massage</td>
<td>1) Both massage types significantly improved hamstring strength following treatment. 2) There was no statistical maintenance over a 24-hr time period for either group.</td>
</tr>
<tr>
<td>Barlow et al20</td>
<td>Experimental design (mean age 21 years ± 3)</td>
<td>3</td>
<td>11 male volunteers (mean age 21 years ± 3)</td>
<td>Massage therapist</td>
<td>Effleurage, petrissage</td>
<td>One 15-minute massage</td>
<td>One massage to the hamstrings did not significantly change sit and reach performance.</td>
</tr>
<tr>
<td>et al24</td>
<td>Randomized controlled trial: pre-test/post-test field hockey players (consisting of 8-minute classic improved hamstring length</td>
<td>2</td>
<td>35 competitive female field hockey players (mean age 19.8 ± 3.7, range 15 to 31).</td>
<td>Two physiotherapists</td>
<td>Effleurage, petrissage</td>
<td>1. “Classic” massage consisting of effleurage, knodding, picking up, shaking) 2. Dynamic soft tissue mobilization (DSTM) that consisted of classic massage and “dynamic” longitudinal and cross-fibre strokes</td>
<td>1) Significant pre-post treatment measures for anxiety levels, less depressed moods, less neck and shoulder pain, less low back pain for both groups. 2) Significant decrease in cortisol levels for the massage intervention group. 3) Those receiving massage treatment experienced a significant improvement in neck extension and shoulder abduction at the end of the study.</td>
</tr>
<tr>
<td>et al19</td>
<td>Controlled trial: majors (mean age massage therapists “petrissage techniques for 5 weeks. measures for anxiety levels, less</td>
<td>3</td>
<td>30 female adult dance majors (mean age 20.1 years, SD 1.6)</td>
<td>One massage therapist</td>
<td>Effleurage, petrissage</td>
<td>1) Significant slowing in shuttle run time for either group. 2) Significant changes in vertical jump displacement, perceived soreness, and algometer levels for the massage group.</td>
<td></td>
</tr>
<tr>
<td>Leivadi et al28</td>
<td>Randomized controlled trial: pre-test/post-test women basketball and vibration standardized protocol times for the control group.</td>
<td>2</td>
<td>22 NCAA Division I women basketball and volleyball players (mean age 20 ± 0.93 years).</td>
<td>Two massage therapists</td>
<td>Effleurage, petrissage, vibration</td>
<td>17-minute standardized protocol</td>
<td>1) Significant slowing in shuttle run times for the control group. 2) Significant changes in vertical jump displacement, perceived soreness, and algometer levels for the massage group.</td>
</tr>
<tr>
<td>Mancinelli et al26</td>
<td>Randomized controlled trial: pre-test/post-test</td>
<td>2</td>
<td>18 volunteers (male and female), mean age 20.4 ±1.0</td>
<td>A senior physical therapy student</td>
<td>Classic Swedish techniques (effleurage, percussion, petrissage)</td>
<td>20 minute standardized protocol</td>
<td>1) The massage protocol did not impact any of the following variables: range of motion, peak torque, neutrophil count, mood, or unpleasantness of soreness. 2) The massage protocol led to a significant decrease in intensity of soreness (Differential Descriptor Scale) in the massage group as compared to the control group.</td>
</tr>
</tbody>
</table>
Massage treatments are performed, only a few studies exist in the literature that have investigated the effect of massage on sports performance (Table 4).

**Massage Effects on Flexibility**

A common perception held by athletes and coaches is that adequate flexibility will decrease the risk of injury and enhance performance. While these claims may be debatable (and beyond the scope of this paper), massage has been investigated as a strategy to increase range of motion.

Barlow et al.23 investigated the immediate effects of massage on hamstring flexibility in physically active young men. Eleven active men (mean age 21 ± 3 years) were randomly assigned to attend two testing sessions each separated by one week. The subjects either received a 15-minute massage (performed by a massage therapist) consisting of effleurage and petrissage strokes to the hamstring muscles bilaterally or a 15-minute supine rest. Three pre-test and post-test sit and reach measurements were performed with the best one recorded. Investigators were blinded to who had received which intervention. The subjects were also blinded when performing the sit and reach test to avoid subject bias threats to validity. The authors concluded that a single bout of hamstring massage did not have a significant effect upon sit and reach scores. Although the authors found no significant change among the small sample size, they did find that those who had low pre-test reach scores (less than 15 cm) had a higher percentage of change in reach versus those who had a 15-cm or greater reach. This led the authors to suggest a larger sampling should be performed with a “tighter” population.23 Also, future studies should investigate the effect on flexibility when massage is applied both proximally and distally to the target tissue.

While Barlow et al.23 failed to demonstrate a statistically significant change in flexibility, Hopper et al.24 found massage made significant short term changes in hamstring flexibility. Female field hockey players from Western Australia’s Premier League were recruited for the study. Thirty-nine players met the study’s inclusion criteria of experiencing knee extension range of motion, and having full ankle less than 70º during a straight leg raise (SLR), having full a stretching sensation on the posterior thigh at an angle.24 The DSTM program was also performed for 8-minutes.24 The passive straight leg raise (PSLR) and passive knee extension (PKE) tests were used to measure hamstring length prior to the treatment intervention, immediately after the massage, and 24 hours later. Both techniques immediately created statistically significantly changes in hamstring lengths as measured by the PKE test. The flexibility changes though were not maintained at 24 hours in either group.24

In a subsequent investigation by Hopper et al.,25 they reported significant increases in hamstring flexibility after performing the DSTM program when compared to a classic massage approach or a control group. In this investigation, the subject sample was 45 healthy males (mean age = 23.7 years, SD = 4.6, range = 18 to 35 years), whereas, the previous study’s population consisted of female athletes.24 The “classic” massage protocol utilized effleurage, kneading, picking up, and shaking techniques performed for 5-minutes.25 The DSTM program was similar to the one described in Hopper et al.24 The DSTM group demonstrated significantly greater increases in hamstring flexibility as compared to the classic approach or the control group. While the DSTM protocol had a greater effect on immediate hamstring flexibility gains (post-test measurements conducted 90-seconds after treatment), the clinical significance of these results is difficult to extrapolate.

While it appears that some athletes may experience improvements in hamstring flexibility after one massage, these changes appear to be transient. If a short term goal is to increase an athlete’s flexibility, more efficient methods may exist (especially in the absence of an adequately staffed sports medicine team).26 Future research should investigate which athletes are ideal candidates for massage intervention, how long each massage intervention should be performed, and what duration is necessary to establish permanent flexibility changes.
**Massage Effects on Strength**

Brooks et al. assessed the effects of massage on power grip performance after maximal exercise in healthy adults. The authors conducted a pre-test and post-test study design with subjects randomized to one of four intervention groups. The testing protocol consisted of a pre-test grip strength measurement, the exercise protocol to fatigue the muscles of the hand, the intervention, a 5-minute rest period, and the post-test strength measurement. To fatigue the muscles of the hand and the forearm, participants isometrically squeezed a hand exerciser until performance had declined to 60% of their baseline measurement. After the exercise period, the subjects were randomized to one of the following treatment groups: a 5-minute standardized massage to the dominant hand, a 5-minute standardized massage to the non-dominant hand, 5-minutes of passive shoulder and elbow range of motion, or 5-minutes of rest. The 5-minute massage protocol, consisting of effleurage and circular friction strokes, was performed by two senior therapeutic massage students. The authors found the massage intervention to be significantly superior to the non-massage interventions for post exercise grip performance. It was also observed that grip performance after massage was significantly greater in the non-dominant versus the dominant arm.

The most clinically relevant outcome was that the massage intervention demonstrated better results than the natural recovery of the control group. The authors surmise that applying massage (in this case for 5-minutes) shortly after fatiguing exercise is beneficial.

Mancinelli et al. investigated the effects of massage on female collegiate athletes when performed at the beginning of the basketball and volleyball seasons. Twenty-two NCAA division I women's basketball or volleyball players were recruited (11 allocated to the treatment group and 11 serving as controls). A 17-minute massage consisting of effleurage, petrissage, and vibration techniques was performed on the day of predicted peak soreness (as predicted by the strength coach). The authors found that the massage intervention helped to significantly decrease athletic performance during competition. The ramifications for sports performance during competition may be staggering. Theoretically, it would be beneficial to prescribe modalities that could either prevent the onset or decrease the impact of DOMS.

Six theories have been proposed to explain the mechanisms of DOMS. The six theories are: lactic acid, muscle spasm, connective tissue damage, muscle damage, inflammation, and enzyme efflux. Researchers have specifically investigated the effects of massage upon blood lactate levels and changes in blood flow (Table 5).

**Effect of Massage on Blood Flow**

Massage has been proposed as a treatment modality to increase blood flow. Proponents of massage argue that local circulatory changes occur as evidenced by changes in skin temperature and superficial hyperemia. Initial studies measuring Xe-133 isotope clearance and venous occlusion plethysmography indicated that massage had an effect on blood flow, whereas more recent studies using Doppler ultrasound techniques have found that massage had no effect on arterial or venous blood flow.

**Blood Lactate Clearance**

The rationale behind the lactic acid theory is that lactic acid produced after exercise contributes to the pain and soreness experienced by the athlete. Massaging a muscle or muscle group experiencing DOMS could, theoretically, help to facilitate the removal of lactic acid from those areas.
Many amateur sports (such as track and field, boxing, and swimming) may require athletes to participate in several events or matches during a short period of time. Hemmings et al.\(^\text{20}\) studied the effects of massage on both physiologic and perceived recovery in eight amateur boxers. The investigators designed a testing protocol to examine if massage performed between bouts of simulated boxing matches would help to improve physiologic variables (blood glucose and lactate concentrations), performance, and the athlete's perception of recovery. The experimental design consisted of a 10-minute active warm up period, five 2-minute rounds of simulated boxing matches with 1-minute rest periods between each round, an intervention period (20-minute massage or no massage), a 35-minute rest period (a time period representative of the period of time between events or matches), a second 10-minute active warm up period, and a repeat of the aforementioned boxing simulation. Four of the eight boxers served as controls during the first round of testing. During the second round of testing, the boxers switched groups.\(^\text{20}\)

During the intervention period, the athlete either received a massage or rested lying on a mat. The 20-minute massage (effleurage and petrissage) protocol consisted of 8 minutes of treatment performed on the legs, 2 minutes on the back, and 10 minutes for the shoulders and arms. Blood lactate testing was performed...
Robertson et al. examined the effects of massage on lactate clearance, muscular power output, and fatigue after bouts of high intensity training. Nine male athletes (rugby, football, or field hockey) were recruited for the study. A testing protocol began with a standardized warm up period consisting of 5-minutes of cycling and 3-minutes of static stretching for the hamstrings, calf, and quadriceps muscles. Six 30-second bouts of high intensity training were performed on a cycle ergometer (with 30 seconds of active recovery between sets). Upon completion of the high intensity repetitions, the athletes performed 5-minutes of active recovery followed by a 20-minute intervention. Subjects were randomized into one of two interventions: a 20-minute massage or 20-minutes of “passive supine rest.” The massage intervention was performed each time by the same physiotherapist. The massage sequence consisted of effleurage and petrissage techniques performed in a standardized protocol sequence of 5 minutes to the back of the left leg, 5 minutes to the back of the right leg, 5 minutes to the front of the right leg, and 5 minutes to the front of the left leg. After the intervention period, the athlete performed the same 8-minute warm up (5-minutes of cycling and 3-minutes of static stretching) followed by one 30-sec-

| Lightfoot et al. | Randomized controlled trial | 2 | 31 college-age subjects (12 men and 19 female) | Massage therapist | Petrissage | 10-minute to the left calf | Massage intervention to the left calf demonstrated no difference for soreness levels or leg volumes as compared to the control group. |
| Hart et al. | Within subjects experimental design with counter-balanced design | 3 | 19 college aged volunteers (10 men, 9 women), mean age 20.6±1.2 years | Certified athletic trainer | Petrissage (kneading) and effleurage (broad stroking) | 5-minute standardized “sports” massage | The sports massage protocol did not significantly reduce either leg girth or pain as compared to the control leg within 72 hours of exercise. |
| Monedero et al. | Within subjects experimental design with counterbalanced design | 3 | 18 healthy trained male cyclists, mean age 25±0.9 years | Certified masseur | Effleurage, stroking, and tapotement | Massage group: 15-minute massage Combined recovery group: 7.5 minutes of massage and 7.5 minutes of active recovery | 1. Combined recovery significantly better at removing blood lactate at 12-minutes (as compared to all interventions). 2. Combined recovery was a superior approach to maintaining performance over passive recovery and active or massage interventions. |
| Dawson et al. | Quasi-experimental pre-test/post-test | 3 | 12 runners (8 males, 4 females), mean age 35.2±8.3 years | Massage therapists | Effleurage, petrissage | 30-minute standardized protocol | The use of massage, when compared to the control leg, did not facilitate a faster return to baseline measures for strength, soreness, or leg circumference. |
| Hilbert et al. | Repeated measures pre-test/post-test RCT | 2 | 18 volunteers (male and female), mean age 20.4±1.0 years | A senior physical therapy student | Classic Swedish techniques (effleurage, percussion, petrissage) | 20 minute standardized protocol | 1. The massage protocol did not impact any of the following variables: range of motion, peak torque, neutrophil count, mood, or unpleasantness of soreness. 2. The massage protocol led to a significant decrease in intensity of soreness (Descriptive Descriptor Scale) in the massage group as compared to the control group. |
| Smith et al. | Randomized controlled trial: pre-test/post-test design | 2 | 14 untrained males; massage group (n=7, mean age 20.1±1.1) and control group (n=7, mean age 18.8±0.3) | Physical therapist | Effleurage (stroking), shaking, petrissage (kneading), wringing, cross-fiber massage | 30-minute standardized “sports” massage performed 2 hours after exercise | A significant trend analysis for treatment by time interaction effect with 1) the massage group reporting lower levels of muscle soreness; 2) reduced CK levels in the massage group; 3) massage group demonstrating elevated neutrophil levels. |
ond high intensity bout (Wingate test). Blood samples were collected prior to testing, after the first high intensity training, after 10- and 20-minutes of the intervention time period, and 3 minutes after the final high intensity test. 32

The authors found no statistical difference between the massage and passive rest interventions for blood lactate concentrations and power. A significant difference did occur between the massage intervention and the rest group for the fatigue index. The fatigue index is the percentage change in power output between the first 5-seconds and the last 5-seconds in a 30-second period. The authors suggested that additional investigations were necessary to identify the role of massage on an athlete’s fatigue profile. 32

Jonhagen et al 41 recruited 16 people (8 men and 8 women, mean age 28 years) in order to assess if sports massage can improve recovery after an eccentric exercise protocol. Subjects performed 300 maximal eccentric quadriceps contractions with each leg on a Kin-Com dynamometer (Harrison, TN). 41 A massage program was initiated 10 minutes after exercise, with one leg from each subject randomized to receive the massage treatment. The massage program consisted of 4-minutes of effleurage and 8-minutes of petrissage. The massage protocol was also performed daily each of the next two days. Testing was performed before the exercise protocol, after exercise, and on the third day. Strength testing was performed on the Kin-Com dynamometer, a vertical long jump was performed to measure functional changes, and a visual analog scale (VAS) was used to measure a subject’s pain. The VAS was performed before and after exercise and before and after the massage treatment. Microdialysis was also performed in the vastus lateralis muscle to analyze levels of the neuropeptide Y (NPY) and calcitonin gene-related peptide (CGRP). 41 Both NPY and CGRP are neuropeptides involved in the vasodilation of skin tissue and the modulation of pain. 41 The authors found that sports massage failed to influence any of the dependent variables. Resistant strength loss was significant in both treatment groups, even on the third day. Sports massage also failed to impact functional recovery. Both groups’ demonstrated significantly lower long jump scores, with a normalization of scores occurring by day three. No statistical difference was observed either in pain scores between legs or for changes in CGRP and NPY levels. 41

Additional studies evaluating the effects of massage on athletes experiencing DOMS have also failed to demonstrate positive effects. 42,43 Active recovery techniques have been shown to be consistently superior to massage for lactate clearance. 31,44-46 In addition, massage interventions have failed to effect post-exercise limb girth. 42,44-46 Subjects who received massage generally experienced no improvement in pain or soreness perception as compared with controls. 42,44-46 Hilbert et al 47 suggested massage can positively affect subjects’ perceived intensity of DOMS related soreness, but not until 48 hours post exercise.

Although it is commonly thought that lactic acid accumulation after exercise leads to the pain associated with DOMS, this theory has been recently rejected. 29 Any increased lactic acid levels after exercise return to baseline in approximately one hour after exercise. 29 Lactic acid likely only contributes to acute pain versus the pain experienced 24 to 48 hours after exercise. 29

**Massage Effects on Creatine Kinase and Neutrophil Levels**

Smith et al 48 designed a study to investigate the effects of massage on variables other than lactic acid. The authors theorized a massage intervention performed two hours after exercise interferes with neutrophil emigration which may reduce the intensity of pain due to inflammation. Initial results indicated that the 30-minute massage protocol applied two hours after the exercise program helped to reduce DOMS and creatine kinase levels. 48 This particular protocol appeared to demonstrate promising results, but the results are challenged by a small sample size (n=14). 48 Although the authors called for continued studies, to date, no further clinical studies have been published on this aspect. 48

**ROLE OF SPORTS MASSAGE IN THE TREATMENT OF SPORTS INJURIES**

Both classic massage techniques and deep transverse friction massage (DTFM) are performed in clinical rehabilitation settings (Table 6). Despite the popularity of these forms of massage by both therapists and patients, very few studies have been conducted on this intervention, making it a challenge to draw conclusions regarding the efficacy of their use.

**Paucity of Sports Massage Reports**

Despite the prevalence of low back pain, a review of the literature was unable to identify any randomized controlled trials or quasi-experimental studies investigating the role of massage in the treatment of sports-related back injuries. Two “non-sports” massage papers are presented.
here to demonstrate the challenges in interpreting the literature.

Preyde et al. researched the application of massage in the treatment of patients with subacute low back pain. In this study, subjects were randomized to one of four groups: a comprehensive massage therapy group (CMT), a soft tissue mobilization only group, a remedial exercise and postural education only group, and a placebo group who received a sham ultrasound. Subjects in the CMT group experienced a statistically significant improvement in function, reported less intense pain, and experienced a decrease in the quality of pain as compared to the other three groups.

Even though the author concluded that patients with subacute low back pain benefited from massage therapy, the CMT group received massage (utilizing a non-standardized treatment protocol), exercise prescription consisting of a lower extremity stretching program, were encouraged to walk, swim, do aerobics, and strengthening exercises, and received education on posture and body mechanics. While at the 1-month follow up period, a significant number of patients in the CMT group had no pain; it would be a leap to attribute all of this to the massage (only 27% of subjects in the massage only group were pain free at one month). Rather this research may demonstrate that those who receive posture/body mechanics education, perform exercises, and receive massage have better outcomes versus those who only receive one treatment modality.

A recent Cochrane Collaboration Back Review has concluded that the use of massage might benefit patients with subacute and chronic nonspecific low back pain, especially when the massage is combined with patient education and exercise prescription. Despite this conclusion, the panel highlights the need for additional studies to confirm the efficacy of massage for subacute and chronic LBP and to assess the effect of massage on returning-to-work.

Pettitt et al. reported the use of massage in the management of a 19-year old female middle distance runner suffering from sport-related chronic knee pain. The patient underwent an iliotibial band release after initial failure of conservative treatment. Despite a course of postoperative therapy, the patient continued to experience symptoms. The authors implemented a treatment program consisting of joint and soft tissue (massage) mobilization, therapeutic exercise, and neuromuscular electric stimulation. The massage protocol consisted of effleurage strokes. The authors reported that the subject was able to return to running and complete an entire season of indoor track and field after receiving this 10-week course of rehabilitation. While massage was one component of the
rehabilitation program, the authors acknowledge the fact that the unique role of any one treatment can not be known.51

Blackman et al52 investigated the effects of massage on chronic exertional compartment syndrome (CECS). This study again highlighted the design challenges that researchers investigating massage effects have experienced. Athletes suffering from CECS complain of cramping or aching pain that develops with exercise and resolves with cessation of activity.53,54 The authors recruited seven athletes (age range 21 to 29 years) with a confirmed diagnosis of anterior CECS.52 Each athlete participated in a 5-week rehabilitation program. A standard massage intervention consisted of various techniques for 15-minutes each session. Massage was performed two times a week during the first two weeks and one time a week for the remaining three weeks.52 Patients were also instructed to perform a standard stretching program for both anterior and posterior musculature twice a day. After the 5 week course of therapy, no significant changes were found in compartment pressures after exercise. The authors did find a significant change in the amount of exercise that could be performed prior to pain onset. Study limitations included the small sample size and the prescription of multiple treatments.52

Efficacy of Deep Transverse Friction Massage

Deep transverse friction massage (DTFM) has been suggested as a treatment option for tendon injuries such as tennis elbow.9 Paucity in the literature exists regarding the use of DTFM in the treatment of sports-related injuries. Despite the popularity of its use,9 a review of the available research literature fails to support the use of DTFM,55,56 whereas, eccentric exercise has demonstrated efficacy in the conservative management of tendinopathies.57,61

DISCUSSION

Despite the fact that massage has been used as a treatment modality for centuries, a poor appreciation for its clinical effectiveness exists. Although several unique studies have been designed to investigate the effects of sports massage, further investigations are warranted.

Indirect evidence exists suggesting that massage may be beneficial on factors related to an individual's psychological state. While these investigations demonstrated improvements in blood pressure,13 mood states,18,19 and perception of recovery,20,21 study design flaws limit the strengths of the conclusions. Future research should investigate the application of massage immediately prior to stressful sports performance situations, the effects of massage on an athlete's perception of recovery between bouts or events, and the effects of massage on an athlete's mood state throughout an entire season.

Massage has generally failed to demonstrate positive effects upon sports performance.20,32,41 One study utilizing massage at the beginning of the season demonstrated an increase in the experimental groups' vertical jump, but the study's conclusions are threatened by several design flaws.30 Researchers have demonstrated an association between massage and temporary changes in hamstring flexibility23,25 and grip performance.27 While the results from these studies do not predict future sports performance, these studies should provide guidance in the development of future investigations. Additional research should be directed at performing a massage prior to immediate athletic performance (e.g. massage to the upper extremity prior to a discus throw).

Massage has also generally failed to effect physiological parameters related to DOMS.20,32,34,40-45 The few studies that have reported positive effects from massage on a subject's pain or soreness perception have had study design flaws and no follow-up investigations to date.47,48 To account for the individuals who report decreased pain or a perceived improvement after a massage, future research should investigate local concentrations of chemo-inflammatory factors.

Minimal studies have been performed investigating the role of massage in sports rehabilitation.51,52 Paucity in the literature exist related to sports massage and the management of sports-related injuries. Evidence appears to suggest that massage is efficacious for use with patients with subacute and chronic low back pain.49,50 Clinical research and case reports are greatly needed to help guide physical therapy decision making when rehabilitating sports injuries.

CONCLUSION

Research evidence has generally failed to demonstrate massage significantly contributing to the reduction of pain associated with delayed onset muscle soreness, or significantly enhancing sports performance and recovery, or playing a significant role in the rehabilitation of sports injuries. Design flaws in research have challenged some of the positive outcomes. Additional studies examining the physiological and psychological effects of sports massage are necessary in order to enhance the sports physical ther-
apists' ability to develop and implement clinically significant evidence based programs or treatments.

REFERENCES


CLINICAL SUGGESTION

IMMOBILIZATION IN NEUTRAL ROTATION FOR A GLENOHUMERAL DISLOCATION USING A SLING AND SPLINT

Carrie W. Hoppes, DPT, ATC*

ABSTRACT

The purpose of this manuscript is to provide an expedient means of immobilizing a glenohumeral dislocation in neutral rotation. This technique for post-reduction immobilization of a glenohumeral dislocation is inexpensive and easy to fabricate. Anterior glenohumeral dislocations often involve an avulsion of the labrum from the glenoid rim. In contrast to immobilization in internal rotation, positioning the shoulder in 0-45° of external rotation approximates the labrum and glenoid rim. It is hypothesized that placing the shoulder in a more externally rotated position could allow for better healing and increased joint stability. This technique places the shoulder in neutral rotation, because 45° of external rotation is awkward and may interfere with certain activities of daily living. Structural aluminum malleable (SAM) splints are used as an alternative to a bolster sling. The SAM splints are lightweight, simply shaped, and easily stored.

Key Words: glenohumeral dislocation, immobilization, neutral rotation

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PROBLEM
Anterior glenohumeral dislocations are a common athletic injury. Initial treatment can include immobilization followed by physical therapy for range of motion and strengthening exercises, immediate surgery, or delayed surgery. Following a traumatic dislocation, many patients report glenohumeral joint instability. Anterior glenohumeral dislocations often involve an avulsion of the labrum from the glenoid rim. Immobilization in a standard arm sling places the glenohumeral joint in internal rotation and adduction. This position does not allow the avulsed labrum to contact the glenoid rim which could result in the labrum not healing, possibly leading to chronic glenohumeral instability. Positioning the shoulder in 0-45° of external rotation approximates the labrum and glenoid rim. It is hypothesized that placing the shoulder in a more externally rotated position could allow for better healing and increased joint stability. Physical therapists may encounter a traumatic glenohumeral dislocation on the playing field or on the battlefield and not have a bolster sling readily available to immobilize the joint in an optimal position post-reduction.

SOLUTION
The shoulder can be immobilized in neutral rotation using two structural aluminum malleable (SAM) splints (SAM Medical Products, Portland, OR), one standard arm sling, and one ace bandage. The two SAM splints are shaped into a triangle, and one is placed inside the other. Additionally, the edges should be slightly C-curved for increased strength and molded to the patient's flank and forearm. The patient's affected arm is placed in the standard sling and secured to one side of the SAM splint using the ace bandage. The other side of the SAM splint rests against the patient's flank. The arm is effectively immobilized in neutral rotation. This technique places the shoulder in neutral rotation, because 45° of external rotation is awkward and may interfere with certain activities of daily living.
DISCUSSION

The materials used in this technique are inexpensive, easy to use, and can be easily stored in a sports medicine bag. The splinting materials are lightweight, so as not to impart a significant traction force to the healing joint. This technique allows for efficient and effective immobilization of the glenohumeral joint in neutral rotation, which may contribute to improved healing and decreased instability following a dislocation.\textsuperscript{11}

REFERENCES


ABSTRACT

**Background.** Taping is a ubiquitous strategy to help prevent ankle sprains. The restrictive qualities of various taping methods may impair athletic performance.

**Objective.** The objective of the study was to compare the Gibney closed basket weave taping method with heel-locks to heel-locks and figure-eights in order to determine their effect on vertical jump performance and active range of motion (ROM) before and after exercise.

**Methods.** Eleven female varsity basketball athletes were subjected to three conditions of no ankle support (control), heel-locks, and figure-eights. The dependent variables of ankle active ROM, plantarflexor maximum voluntary contraction and jump height for the countermovement jump (CMJ), drop jump (DJ), and concentric only squat jump (COSJ) were randomly ordered. Following taping or control conditions, participants were pre-tested, completed a ten-minute treadmill run at 9.6 km/hr with a 3 minute cool down and then repeated the testing procedures.

**Results.** There were no significant differences in jump performance between taping methods or the effect of exercise. However significant differences for pre-/post-exercise for plantarflexor (p < 0.0001) and dorsiflexor (p = 0.007) active ROM and between no support and taping for plantarflexor ROM (p = 0.004) was found.

**Conclusions:** Despite plantarflexor active ROM being restricted by both taping procedures compared to the control, no effect on jump performance occurred.

**Key words:** flexibility, drop jump, countermovement jump, squat jump, ankle sprain

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METHODS
Experimental Design
Participants were tested before and after the application of a Gibney closed basketweave with heel locks (HL), Gibney closed basketweave with heel locks and figure-eights, and a control condition. Following the application of the tape, participants ran on a treadmill for 10 min at 9.6 km.h⁻¹ with a level grade and then were re-tested with the same cadre of tests used in the pre-test. These measures consisted of ankle active range of motion (ROM); drop, countermovement, and concentric only squat jumps; and plantarflexor maximal voluntary contraction.

Subjects
Eleven female college basketball athletes (height = 172.1 ± 6.7cm, weight = 69.2 ± 12.9kg, age = 20.6 ± 1.4, range, 19 to 25 years) with no ankle injury in the past three months volunteered to participate in this study. The attending athletic therapist assessed all subjects for healthy ankle function. Approval from the Interdisciplinary Committee in Ethics in Human Research (ICEHR) at Memorial University of Newfoundland was obtained and written informed consent was obtained from all subjects.

Instruments
All vertical jumps were performed using a contact mat (Innervations, Muncie, IN) and analyzed using the Kinematics Measurement Systems (Innervations, Muncie, IN) software program. The software program recorded jump height based on flight time. In order to ensure validity of the test, participants were asked to have their knees as fully extended as possible and ankles completely plantarflexed at both take off and landing. Subjects performed plantarflexor maximal voluntary control while seated in a straight-backed chair with hips and knees at 90°. Isometric contractions were performed with their leg secured in a modified boot apparatus with their ankles flexed at 10° of dorsiflexion. All torques were detected by strain gauges, amplified (Biopac Systems Inc., DA 100: analog-digital converter; Holliston, MA) and monitored on a computer (Sona Phoenix, St. John’s, Newfoundland). Data were stored on a computer at a sampling rate of 2000 Hz. Data were recorded and analyzed with a commercially designed software program (AcqKnowledge III, Biopac Systems Inc., Holliston, MA).
Taping Method
The same certified athletic therapist applied the tape bilaterally to each subject. Cramer® Tuf-Skin tape adherent (Gardner, Kansas) was initially sprayed on the feet of each participant. Next, Cramer® heel and lace pads (Gardner, Kansas) were applied to both feet at the posterior calcaneus and dorsum of the foot at the ankle (talocrural joint) to help prevent blistering from friction associated with the tape application. Cramer® Skin Lube lubricating ointment (Gardner, Kansas) had been placed on the heel and lace pads prior to application. The tape, 1 1/2 inch zinc oxide Johnson and Johnson Coach® athletic tape (Princeton, New Jersey), was then applied bilaterally to the participants in either the heel-lock or figure-eight methods, as according to Perrin.18

The Gibney closed basketweave with HL taping procedure had the ankle positioned at 90º of dorsiflexion. Two anchor strips were placed on the distal leg (foot anchors were left out as they frequently cause constriction and discomfort).18 A stirrup was applied from the medial aspect of the leg and pulled under the heel to the lateral aspect of the leg using the malleoli as landmarks. A horizontal horseshoe strip was placed from the medial to lateral aspect of foot, while another stirrup was placed in a weaving fashion. The horseshoe and then the stirrup process were continued until three stirrups were applied. The leg was enclosed with horizontal strips ensuring no skin was visible. Heel-locks were applied in a single manner (pulling in upward direction).

The other taping condition included the Gibney closed basketweave with heel-lock as well as a figure-eight. The additional figure-eight taping started on the lateral malleolus and continued down and under the medial aspect of the foot pulling up over the dorsum of the foot to the medial malleolus and around the back of the Achilles tendon and returning to the lateral malleolus. This process was repeated twice for the Figure 8 option.

Testing
Testing was conducted before and after exercise under three conditions: control, heel-locks and figure-eights. The treatment order was randomly assigned. Each testing condition occurred on separate days. Separate testing conditions were conducted within a range of 24–72 hours. Measurements included ankle joint active ROM, plantarflexor maximal voluntary control, and vertical jump tests involving concentric only squat jump (COSJ), countermovement jump (CMJ), and drop jumps (DJ). Ankle active ROM was always tested initially since dynamic jumping movements could loosen the tape adhesion. All jump measures were completed in a randomized order to prevent any effects from fatigue or learning.

Measurements of active ROM at the ankle joint were taken between full dorsiflexion and full plantarflexion for both feet (Figures 1 and 2). The focus of the paper was on the effects of these two adhesive ankle-taping methods on performance (strength, power, and ROM). Thus, changes in the plantarflexor and dorsiflexor ROM could possibly affect jump performance by hindering impulse (force x time) and work (force x distance) performed. Dorsiflexion (Figure 1) and plantarflexion (Figure 2) active ROM were measured as the participant sat with their leg hanging from a bench. Participants then contracted either their dorsiflexors or plantarflexors maximally in order to achieve the greatest active ROM possible. A goniometer was used with one lever of the goniometer placed on the proximal fibular head, while the other was placed on the fifth metatarsal. The pivot was positioned on the lateral malleolus. The ROM was recorded based on the position of the lever on the fifth metatarsal. The same certified athletic therapist completed all active ROM measurements.
first two trials) another three-minute rest was allocated.

The CMJ is similar to sport specific situations, therefore, emphasizing game-like maneuvers. Participants stood with their feet shoulder width apart and flat on the contact mat. With hands on hips, they were instructed to jump as high as possible by using their own choice of depth and pace. Allowing the subject a choice ensured that participants were using a comfortable jumping technique that they would normally utilize in an athletic setting. An athletic population was utilized due to their familiarity with the jumping technique, thereby, reducing variability.

The DJ, which emphasized the stretch-shortening cycle of the ankle, was performed with the participants standing with both feet flat on a 30cm high platform. This height has been used in previously published studies\textsuperscript{16,19,20} to ensure an optimal combination of jump height and minimum contact time. With hands on hips, participants were instructed to drop off the platform by stepping forward with whichever foot felt most comfortable. This foot was then used to initiate the DJ for all further testing. Upon contacting the mat with both feet, they were told to jump as high and as fast as possible. Subjects attempted to limit excessive knee flexion such that the ankle was emphasized to a greater extent in the generation of the jump forces.

The COSJ was tested due to its emphasis on impulse generation.\textsuperscript{16} With hands on hips, participants stood with feet shoulder width apart and flat on the contact mat with their knees flexed at 90°. This position was held for two seconds. After the two-second period they were told to jump as high as possible.

A thirty-second recovery was provided between all jump trials. Jump height was used as the indicator of best performance for all jumps. The three jumps were chosen to ascertain the effect of taping on three physiological parameters. This particular form of DJ was performed with specific instructions to mainly involve a rapid stretch-shortening cycle action of the ankles.\textsuperscript{14,19,20} In contrast, the CMJ used a moderate speed stretch-shortening cycle (angular speed dependent on participant’s preference) which emphasized both knees and ankles which contrasted with the COSJ that lacked a significant stretch-shortening cycle.

Previous research from our laboratory\textsuperscript{22} has reported the following intraclass correlation coefficients (ICC) for plantarflexor range of motion (0.94), squat jump (0.96), countermovement jump (0.93) and drop jump (0.89) respectively. Other research from our laboratory utilizing the plantarflexor maximal voluntary control has shown ICC values ranging from 0.91 – 0.99.\textsuperscript{17}

Participants then completed a ten-minute exercise protocol on a treadmill (9.6 km.h\textsuperscript{-1}) at a level grade followed by a three minute cool down (4.5 km/hr) to initiate the loss of the tape’s restrictive properties. The treadmill speed was chosen to provide a typical pace used in a pre-competition warm-up by these athletes. This speed was based on pilot studies utilizing the same athletes. At completion of the exercise protocol the testing procedures were repeated in a randomized order with active ROM again being completed first. Only two trials of each testing procedure were necessary unless there was more than a five percent difference between the two measurements and then a third measurement was conducted. All measurements were recorded with the best performance (maximal voluntary control force and jump heights) used for the data analysis.

Data Analysis
The data was analyzed using a two way ANOVA (two times: pre- and post-exercise x 3 tape conditions: control, heel-locks, figure-eights) with repeated measures. An alpha level of $p < 0.05$ was considered statistically significant. If significant differences were found, a Bonferroni-Dunn’s procedure was conducted to identify where the significant change occurred. Effect sizes (ES = mean change / standard deviation of the sample scores) were
also calculated and reported.\(^2\) Cohen\(^2\) applied qualitative descriptors for the effect sizes with ratios of <0.40, 0.41-0.70 and >0.7 indicating small, moderate and large changes, respectively. Means and standard deviations (SD) are reported in the text and figures.

**RESULTS**

Overall, for all dependent variables tested (maximal voluntary contraction force, CMJ, DJ, COSJ), except the active ROM, no significant differences existed for the taping method or the effect of exercise when comparing any of the independent variables (control, heel-locks, figure-eight). The control condition exhibited 24.9% and 27.5% significantly (p < 0.05) greater plantarflexion active ROM as compared to HL (ES = 0.99) and F8 (ES = 1.11) tape methods respectively (Figure 3). In addition, 25.7% and 9.6% significantly greater plantarflexion (p < 0.05; ES = 0.85) and dorsiflexion (p < 0.05; ES = 0.5) active ROM for both ankles were detected following exercise independent of the taping method (Figure 4).

**DISCUSSION**

The results of our study indicate that a significant reduction in plantarflexion active ROM occurred as a result of the two different tape application methods (heel-lock and figure-eight) as compared to the control. This is in agreement with other studies that reported similar conclusions as a result of the utilization of external ankle supports.\(^2\)\(^,\)\(^9\)

It had been theorized that tape restriction would impede the force generated by the plantarflexors. However, the present study indicated that maximum force production was not reduced as a result of tape application as no significant maximal voluntary control differences existed between the type of taping method (heel-locks or figure-eights) and the control, pre-, or post-exercise groups.

**Table:** Pre- and post-exercise means and standard deviations for all variables. The following definitions are defined as df = degrees of freedom, F = F ratio and p = probability value, MVC = maximal voluntary control.

<table>
<thead>
<tr>
<th>Countermovement jump (cm)</th>
<th>Heel lock</th>
<th>Heel lock</th>
<th>Figure 8</th>
<th>Figure 8</th>
<th>Statistics</th>
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</thead>
<tbody>
<tr>
<td>Pre-exercise</td>
<td>24.9 ± 3.6</td>
<td>24.7 ± 5.6</td>
<td>23.6 ± 3.2</td>
<td>25.3 ± 2.8</td>
<td>df = 32</td>
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<td>Post-exercise</td>
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<td>p = 0.43</td>
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<tr>
<td>Drop jump (cm)</td>
<td>20.7 ± 4.3</td>
<td>21.4 ± 4.7</td>
<td>21.2 ± 4.4</td>
<td>22.1 ± 4.6</td>
<td>df = 32</td>
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<td>F = 0.05</td>
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<td>p = 0.94</td>
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<tr>
<td>Drop jump contact time (ms)</td>
<td>232.9 ± 38.7</td>
<td>230.1 ± 31.1</td>
<td>216.6 ± 46.1</td>
<td>241.2 ± 30.1</td>
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<td>p = 0.48</td>
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<td>Concentric only squat jump (cm)</td>
<td>24.2 ± 3.4</td>
<td>23.5 ± 2.2</td>
<td>23.7 ± 3.4</td>
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<td>df = 32</td>
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<td>F = 1.44</td>
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<td>p = 0.25</td>
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<tr>
<td>Plantarflexors MVC (Newtons)</td>
<td>251.7 ± 55.6</td>
<td>253.6 ± 51.8</td>
<td>232.9 ± 51.1</td>
<td>217.3 ± 69.5</td>
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<td>F = 0.35</td>
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<td>p = 0.71</td>
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<tr>
<td>Dorsiflexion ROM (degrees)</td>
<td>10.4 ± 1.0</td>
<td>11.1 ± 1.8</td>
<td>10.1 ± 0.6</td>
<td>11.5 ± 0.7</td>
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<tr>
<td>Plantarflexion ROM (degrees)</td>
<td>27.9 ± 10.8</td>
<td>35.5 ± 11.8</td>
<td>26.0 ± 8.5</td>
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<td>df = 32</td>
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<td>F = 37.8</td>
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<td>p &lt; 0.001</td>
</tr>
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</table>
contributed to a stiffer or less compliant ankle joint which permitted a more rapid stretch-shortening cycle during the DJ contact time. Hence, although the tape restricted ankle ROM, the tape did not decrease the maximal voluntary contraction force generated by the ankle-foot complex during the DJ.

Plantarflexion is required for propulsion\(^5,6\) and during the push off phase\(^11\) of a vertical jump. The results of the present study indicate that no significant reductions in vertical jump height occurred with any condition tested. Similar research also reports a lack of change in vertical jump height with the application of external ankle supports\(^7,10,11,15\). Verbrugge\(^7\) utilized the heel-lock method while Paris\(^10\) utilized the figure-eight method. Neither study recorded a significant reduction in vertical jump height.

Cordova et al\(^4\) reviewed the literature indicating that taping did not decrease the magnitude of the forces produced, but the rate at which they were produced was slower. Alternatively, the present research did not find a significant difference in DJ contact time with taping. Muscle force and power have been reported to be compromised with increased muscle compliance\(^2,23\). The elongation of tendinous tissues can also have a deleterious effect on force output\(^24\). Belli and Bosco\(^25\) suggested that a stiffer musculotendinous unit would enhance the work performed during stretch-shortening cycle movements. Perhaps the restricted ROM of the taping methods contributed to a stiffer or less compliant ankle joint which permitted a more rapid stretch-negative cycle during the DJ contact time. Hence, although the tape restricted ankle ROM, the tape did not decrease the maximal voluntary contraction force generated by the ankle-foot complex during the DJ.

Plantarflexion is required for propulsion\(^26,27\) and during the push off phase\(^\text{ii}\) of a vertical jump. The results of the present study indicate that no significant reductions in vertical jump height occurred with any condition tested. Similar research also reports a lack of change in vertical jump height with the application of external ankle supports\(^7,10,11,15\). Verbrugge\(^7\) utilized the heel-lock method while Paris\(^10\) utilized the figure-eight method. Neither study recorded a significant reduction in vertical jump height.

These results concur with previous research that has tested maximum force production when ankles have been taped\(^5,7\).

Figure 3. The asterisk (*) indicates a significant ($p<0.05$) difference in plantarflexors (PF) ROM between the control (NS: no support) and type of taping (HL: heel lock, F8: heel lock, and figure 8) method. The acronyms PF, DF, HL and F8 refer to plantarflexors, dorsiflexors, Gibney closed basket weave with heel lock, and Gibney closed basket weave with heel lock and figure 8, respectively.

Figure 4. The asterisk (*) indicates a significant difference ($p<0.05$) between plantarflexors (PF) ROM pre- and post-exercise. The number sign (#) indicates a significant difference ($p=0.05$) between dorsiflexors (DF) ROM pre- and post-exercise. The acronyms PF and DF refer to plantarflexors and dorsiflexors, respectively.
height under these conditions. Other studies however have recorded significant reductions in vertical jump heights as a result of external ankle supports.1,8 Possible reasons for the lack of vertical jump impairment would include the aforementioned insignificant effects of ankle taping on maximal voluntary contraction force and the possible positive effect of increased ankle joint stiffness on the stretch-shortening cycle. Furthermore, ankle taping has also been found to increase proprioception and sensorimotor function through the stimulation of cutaneous mechanoreceptors.3,4,13 It has been theorized that the activity of these mechanoreceptors are enhanced as a result of the pressure an external ankle support places on the lower leg.13 If prime movers such as the plantarflexors are stimulated, these muscles could counteract the effect of the restricted plantarflexor ROM.

A study by Kean et al26 implementing six weeks of wobble board training, found an increase in vertical jump height. This study demonstrated that an improvement in stability could positively affect vertical jump height, as enhanced stability helps to direct jump forces in a vertical direction as opposed to slight deviations from vertical. In addition, improved stability can allow for a greater amount of force to be produced.17,27 The muscles involved in the movement can be dedicated more to producing motion rather than joint stabilization.26,27 As ankle taping improves stability, both of these factors have the potential of counteracting some of the negative effects from a reduction in ankle ROM.

The results of this study also indicated that significant increases occurred in plantarflexion active ROM across all conditions pre- and post-exercise. This finding is in agreement with other studies that attributed the increased ROM to the loosening of the tape as a result of exercise.7,15,28 Researchers have reported 40-50% of the tape's initial restrictive support is lost following just 10 minutes of activity.7 Despite the loosening of the tape and the increase in ROM, the tape still provides adequate restriction of ROM to aid in injury prevention.28 The proprioceptive stimulation provided by the adhesive tape to the lower leg would also be an aid for injury prevention.

Limitations of the present study include the small sample size (n = 11) and the convenience sample. As the sample included only female varsity athletes, the application of the present findings to other populations may be somewhat limited. Further research should examine the effect of other taping methods on performance, inversion/eversion range of motion and more varied samples (males, recreationally active individuals, younger and older individuals, individuals with present or former ankle sprains). More sophisticated analysis could be accomplished if similar research was conducted on a reaction force platform which could monitor changes in three planes, as well as proprioceptive testing.

CONCLUSION

Despite ankle active ROM being restricted by both taping procedures (heel-locks and figure-eights), no effect on vertical jump performance, contact time, or maximal voluntary contraction force occurred. As a result, the personal preference of the clinician, athlete, or coach can be used to determine the taping method without the possibility of decreasing vertical jump height.

REFERENCES


ABSTRACT

**Background.** Health care practitioners, including sports physical therapists, commonly prescribe and recommend aerobic exercise for those patients seeking to improve their cardiovascular fitness across all ages. Current literature demonstrates that weight bearing activities such as walking or running may lead to foot and ankle edema.

**Objectives.** The purpose of this study is to determine if a significant difference exists between foot volumes (edema) in pre versus post-exercise measurements during a loaded activity (treadmill walking) or an unloaded activity (upright exercise bike) in 31 healthy subjects 50 years of age and older.

**Methods.** After a rest period, a pre-exercise volumetric measurement of the right leg was obtained by the use of a foot volumeter. The first condition (walking or cycling) was randomly chosen. Each subject completed two 10-minute exercise sessions. Immediately following both exercise sessions, a post-exercise volumetric measurement was completed.

**Results.** A statistically significant difference in foot volume was found between pre (mean = 742.39ml, 95% CI: 685.23 – 799.55) and post (mean = 753.03ml, 95% CI: 697.51ml – 808.55ml) measurements for the treadmill (weight bearing) protocol. When considering each sex separately, males produced significant increases in foot volume following treadmill walking (pre mean = 871.00ml, 95% CI: 793.95ml – 948.05ml; post mean = 886.20ml, 95% CI: 811.28ml – 961.13ml), while females displayed no significant changes.

**Discussion and Conclusion.** This study demonstrated a 1.4% increase in foot volume after 10 minutes of treadmill walking. Based on these results, it may be advisable to prescribe non-weight bearing exercise to active older individuals with pre-existing conditions for edema.

**Key words:** edema, volumetrics, unloaded and loaded activities

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INTRODUCTION

Health care practitioners (including sports physical therapists) commonly prescribe and recommend aerobic exercise for those individuals of all ages seeking to improve their cardiovascular fitness. These aerobic activities often include walking, running, and cycling programs. Current literature demonstrates, however, that weight-bearing activities, such as walking or running, may lead to foot and ankle swelling. This acute swelling, which is a common complication resulting from weight bearing activities, can lead to more serious conditions such as fibrosis, joint stiffness, pain, and dysfunction.

One of the problems that results from aerobic exercise is edema formation in the lower extremities which can lead to peripheral vascular disease or other circulatory insufficiencies. Other research has shown an opposite effect, with aerobic activity resulting in a decrease in lower extremity volume. This decrease in lower extremity volume may be the result of the muscle-pumping effect of the gastroc-soleus complex. In addition to aerobic activities resulting in an increase in swelling, static activities have also been shown to produce edema in the lower leg.

Other research has examined the discrepancies involving the effects of loaded dynamic activity on lower extremity volume. Cloughley and Mawdsley found a greater increase in foot volume during running as compared to walking. These findings are supported by McWhorter et al who found significant increases in foot swelling during walking and running. Other researchers found increases in foot volume during running, but a decrease during walking. Evidence also exists demonstrating increases in interstitial and intracellular volume during and after exercise which are directly related to exercise workload.

During quiet static standing, subjects have been shown to increase lower extremity edema formation as a result of pooling of fluid in the lower extremity. Specifically, foot volume during standing has been shown to increase compared to a supine position, possibly the result of a decrease in perfusion of the veins that return to normal when the supine position is resumed.

Stationary bicycle ergometry is an example of an unloaded dynamic activity. Research by Stick et al found that stationary bicycling demonstrated a gradual decrease in foot volume. They also discovered a more significant decrease in foot volume occurred when subjects pedaled against a stronger resistance.

Other studies have examined the effects of differing postures on changes in foot volumes. Seated positioning has been shown to cause an increase in foot volume. Another posture, supine lying with or without leg elevation, has demonstrated a significant decrease in foot volume. All of these studies demonstrate that foot volume can be affected by its gravitational position.

In the young or recreational athlete, the small changes that occur as a result of running or walking may not be a problem. However, in older or geriatric adults, these small increases in foot volume when coupled with chronic resting edema could prove to be harmful. Peripheral edema is a common finding in the elderly, however, actual figures for prevalence are not known. A survey conducted on peripheral edema in elderly patients admitted to a geriatric ward found that 48% of patients had an overall presence of edema during their admission. Compounding the effects of existing edema with co-morbidities will make exercise prescription increasingly more difficult.

The increasing incidence of morbidities involving resting edema, such as coronary heart disease (CHD) and diabetes, showcases the need for further research in this area. Arnold et al reported the incidence of CHD to be 39.6 per 1,000 persons in men and 22.3 per 1,000 persons in women. Moreover, the incidence of CHD increases 9% with each year of age past 65. Bertoni et al reported a high incidence of mortality among older adults with diabetes and heart failure; 32.7 per 100 persons-years compared with 3.7 per 100 person-years among those with diabetes who did not suffer from congestive heart failure (CHF).

The purpose of this study is to determine if a significant difference exists between foot volumes (edema) in pre versus post-exercise measurements during a loaded activity (treadmill walking) or an unloaded activity (upright exercise bike) in the active healthy older population. Based on the findings of McWhorter et al, the hypothesis tested was that loaded activities will result in greater edema in the foot and ankle than unloaded activities. Additionally, it is hypothesized that the unloaded position of the bike coupled with the active and passive movement of the ankle may result in a reduction in foot volume secondary to a muscle pumping action moving fluid out of
the area. Results of this study may help health care practitioners prescribe a more appropriate exercise mode when addressing the cardiovascular health of the active geriatric individuals.

METHODS

Subjects
The subjects consisted of 21 female and 10 male volunteers between the ages of 50 to 67 years without a history of musculoskeletal injuries, health problems, or surgery to the lower extremities, and who had no difficulty or discomfort during walking on a treadmill or riding a bicycle ergometer. The mean age of all 31 participants was 56.26 (SD = 4.89) years. For the 21 females, the mean age was 56.1 (SD = 3.97) years and for the males was 56.6 (SD = 6.33) years. All subjects were recruited by using emails sent throughout the university. All participants completed the Physical Activity Readiness Questionnaire (PAR-Q) and signed an informed consent to participate. This research study was approved by the Institutional Review Board at the University of Nevada, Las Vegas. Participants were excluded if they met any of the following conditions: injury to the right lower extremity within the past year, abnormal swelling in the ankles or feet, history of bone or joint disorders that is aggravated by exercise, or any other physical reason provided by a physician that they should not exercise.

Instrumentation
All lower extremity measurements were obtained using a Lucite (Foot Volumeter; P.O. Box 146, Idyllwild, CA, 92349) foot volumeter set (Figure 1) which included the volumeter container, an obturator which was used to calibrate the water levels prior to each measurement, a receiver to catch the water overflow, and a 1000-ml graduated cylinder with 10-ml gradations. All measurements were taken following the manufacturer’s guidelines. Several studies have been performed establishing the reliability and validity of obtaining foot/ankle volume measurements using this equipment. The displaced water was captured in a plastic container and subsequently measured in a graduated cylinder. All data was immediately recorded on a personalized data sheet. As water has a tendency to creep up the sides of the plastic cylinder, measurements were taken from the lowest level at the water line. Each volume measurement was taken by the same observer to ensure proper consistency.

A pilot test was performed previously in order to allow the testers to practice taking foot volumetric measurements. At this time, the researchers performed the volumetric measurements on 10 volunteers. The three researchers involved in data collection were asked to take the measurements from the participants. The data were recorded by an independent observer. Two days later, the researchers, who were blinded to the previous results, took the measurements from the same participants. All measurements were compared for reliability and demonstrated a reliability intra-class correlation coefficient of 0.99 (95% limits of agreement +/- 7.54 ml).

Procedure
The subjects were given an individual instructional session at which time all aspects of the research study were explained and possible complications as a result of participation were discussed. All subjects were tested at the same time of day. They were informed to not exercise or consume alcoholic beverages on the days prior to being tested and to maintain their present eating habits. Each subject was required to sit in a straight back chair and slowly lower their right leg into the foot volumeter until the foot rested flat against the bottom. They remained in this position until all of the displaced water was collected. All subjects were tested during walking and cycling, thus serving as their own controls.

Prior to each exercise session, all subjects were instructed to bring their athletic footwear. All subjects were required to rest in a supine position for at least 10 minutes prior to testing. The subjects were seated in a chair immediately following their 10-minute rest period. At this time, a pre-exercise volumetric measurement of the right leg was obtained by having the subject slowly lower the right foot into the volumeter.

The activity for the first condition (walking or cycling) was randomly chosen by a flip of a coin. The treadmill (Star Trac Unisen, Inc., 4500 Treadmill, Star Trac, 14410 Myford Rd., Irvine, CA. 92606) speed and cycling (Fitron Cycle, First Fitness
Equipment International, 4750 Bryant Irvine Rd., Ste 808, PMB 229, Ft. Worth, TX 76132-3631) cadence were set at a self-selected comfortable pace for each individual participant. The speed of the treadmill and cadence of the cycle ergometer were recorded on the data sheet. These values were then used for the post-test measure. Due to the fact that walking and cycling speeds vary greatly among individuals, each individual was allowed to determine their own comfortable speed to more closely mimic a real life scenario.30,31

As the exercise session began, each subject performed a 2-minute warm-up session on the treadmill or cycle ergometer at which time they gradually increased their speed until they felt comfortable for the remaining 8 minutes. Subjects were not allowed to grip the handrails on the treadmill during the exercise sessions. The treadmill was kept at a level (zero degrees) elevation for all exercise sessions. During cycling, the seat was adjusted for each participant individually and used for all subsequent sessions. In addition, all cycling sessions used toe straps to minimize foot extraneous movements. The cycle tension was chosen by the participant and used for all subsequent sessions. At least 48 hours of rest was allowed between the two exercise sessions. All procedures were performed in a consistent manner for both sessions.

Data Analysis
Means and standard errors for the fluid volume data were calculated. Given the repeated measures in each exercise protocol, a 2 (exercise) x 2 (time) within factorial ANOVA was utilized to determine if statistical interaction existed in the data. The alpha level was set at 0.05. If statistical interaction was found, simple main effects were calculated using paired t-tests to determine if statistical significance was present.

RESULTS
Factorial results of the 2 x 2 ANOVA revealed a statistical interaction (Figure 2). Because statistical interaction was observed \( F(1,30)=5.705, p=.023 \), simple main effects were analyzed. Two paired samples t-tests using a Bonferroni correction \( p = .025 \) were used to determine the effect of weight-bearing vs. non-weight bearing exercise on foot volume (Table 1). A statistically significant dif-

![Figure 2: 2 x 2 within factorial ANOVA](image)

<table>
<thead>
<tr>
<th>Mode of Exercise</th>
<th>Mean Volume (ml)</th>
<th>Standard Error</th>
<th>t-values</th>
<th>p-values</th>
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<td>Pre-walk</td>
<td>742.39</td>
<td>27.99</td>
<td>-2.952</td>
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<td>Post-walk</td>
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<tr>
<td>Pre-bike</td>
<td>743.03</td>
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<td>0.376</td>
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<td>Post-bike</td>
<td>741.23</td>
<td>28.30</td>
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* Significance at \( \alpha = .025 \)

Table 1: Comparison of Fluid Volume Changes During Treadmill Walking (Weight Bearing) and Cycle Ergometry (Non-weight Bearing)
ference in foot volume was found between pre (mean = 742.39, 95% Confidence Interval: 685.229 – 799.546) and post (mean = 753.03, 95% Confidence Interval: 697.511 – 808.553) measurements for the treadmill protocol (weight-bearing), t = -2.952, p = .006 (Figure 3). There was no statistically significant difference between the pre (mean = 743.03, SD = 162.68) and post (mean = 741.23, SD = 155.83), cycle ergometry measurements (non-weight bearing), t = .376, p = .710.

A 2 (exercise) by 2 (time) within factorial ANOVA was also utilized to determine if statistical interaction was present in data sorted by sex. Because statistical interaction was observed for males (F(1,9) = 10.545, p = .010), simple main effects were analyzed. Paired samples t-testing using a Bonferroni correction (p = .0125) found a statistically significant difference in male foot volumes (Figure 4) between pre (mean = 871.00, SD = 107.706) and post (mean = 886.20, SD = 104.739) measurements for the treadmill protocol, t = -5.429, p < .0005. Statistical interaction was not observed for females (F(1,20) = .990, p = .332) and no further statistical analysis was performed.

**DISCUSSION**

Numerous methods have been used to measure extremity volume. Previous research has demonstrated the water displacement method of volumetry to be valid and reliable, and thus is known to be the gold standard.\(^{32-34}\) Many variables need to be considered when taking volumetric measurements. These include time of day, water temperature, positioning of subject, the temperature of the room, and recent musculoskeletal injuries. However, Moholkar and Fenelon\(^{28}\) showed that time of day does not significantly effect volume measurements of the extremities. Tepid water temperatures between 20 and 35º C did

![Figure 3: Pre and Post Foot Volume Measurements](image1)

![Figure 4: Pre and Post Foot Volume Measurements for Males](image2)
not significantly increase or decrease volume measurements, however, extreme hot or cold temperatures have been shown to affect volume.\textsuperscript{21,35,36} The temperature of the room was not shown to have an effect on the measurements of foot volumes following quiet standing.\textsuperscript{16} It also has been shown that individuals with a recent history of musculoskeletal injuries in the lower extremity will have an increase in edema formation.\textsuperscript{37} Therefore, it can be safely assumed that the performance of an activity rather than the previously mentioned variables affects foot volumes, except for the conditions of extreme water or room temperatures and recent injuries.

The data from this study showed that, in healthy older subjects, treadmill walking resulted in significant increases in foot and ankle fluid volumes compared to resting measurements. This finding was in agreement with the original hypothesis that weight-bearing exercise will increase foot volume. Additionally, when considering each sex separately, males produced significant increases in foot volume following treadmill walking, while females displayed no significant changes. However, when comparing pre and post-test measurements for biking, no significant changes were observed in the present sample. This lack of change also held true when considering each sex separately. The results did not support the hypothesis that the biking protocol would cause a significant decrease in foot volume.

The edema in the foot and ankle during walking can be attributed to the increase in blood flow to the exercising muscles. The increase in edema following weight-bearing activity has been shown to increase foot volume by as much as 8\%.\textsuperscript{26}

Stegal\textsuperscript{38} has demonstrated an 80 mmHg drop in venous pressure at the saphenous vein in the ankle during running as compared to quiet standing. As a result, the author suggests that there is an inability of the lower extremities to maintain a steady rate of venous return following vigorous weight-bearing activities.

Prior to this study, the hypothesis was made that the bike protocol would cause a significant decrease in foot volume secondary to a muscle pumping action. However, as previously mentioned, no significant difference was found. After analyzing the data, one possible explanation for these results was that riding an upright exercise bike does not require enough active foot and ankle muscular activity to cause a muscle pumping effect away from the distal lower extremities. Although movement does occur in the foot and ankle during this activity, much of the movement may be passive, thus not adequately activating the muscle pumping mechanism.

Sochart et al\textsuperscript{39} examined the relationship between passive and active movement of the foot and ankle related to venous return in the lower extremity. They found that an active “combined” movement (plantarflexion/dorsiflexion and inversion/eversion) produced a significantly larger increase in mean blood velocity than any of the three passive movement patterns. The results found by Sochart et al\textsuperscript{39} could help explain why a significant decrease in foot volume for the bike protocol was not observed in this present study.

A difference in fluid volumes after treadmill walking was also found to be significant between sex. In the present study, the participants demonstrated a mean increase in foot volume after a 10 minute walk on the treadmill, but significance between genders was only found in males. The females’ 1.2% increase in foot volume failed to produce significance. A review of the literature failed to identify any studies of post-exercise foot and ankle volume changes based on sex. Chalk et al\textsuperscript{26} demonstrated a slight non-significant decrease in foot volume in female inter-collegiate volleyball players after a 2-hour rigorous exercise session. In addition, the benefits of reducing foot volume in females during weight-bearing activities may be offset by the greater benefit of osteoporosis prevention.\textsuperscript{40-42} It should be noted that the sample size for this study is not large enough to draw firm conclusions with regard to sex and foot swelling.

The results of this study provide important clinical implications for physical therapists. This study demonstrated a 1.4% increase in foot volume after 10 minutes of treadmill walking. It is important to note that this statistically significant increase in foot volume occurred only after 10 minutes. Ambulating patients in the acute or rehab settings often takes longer than 10 minutes secondary to their age, medical condition, and other physical limitations. This information is also important for the older recreational athlete who may walk for an extended period of time. Keeping these patients on their feet for longer periods of time could cause further increases in foot volume, resulting in potential further constriction of venous return with possible negative consequences in those with already compromised circulation.\textsuperscript{3,43} Even in cases with mild edema, instability may result due to poorly fitting foot wear as well as the increased weight of the
edematous limb. Patients may experience a decline in walking confidence and become immobile, further aggravating the problem. It may be safer and more effective to prescribe non-weight bearing exercise as a warm-up or treatment alternative to patients with pre-existing peripheral edema or conditions that place them at risk for impaired venous return. Based on the small sample size, no concrete clinical suggestions can be made with regard to sex at this time.

This study had several limitations. For example, the statistical results would be more convincing if the sample had more subjects, particularly when considering statistics sorted by sex. The total sample of 31 provides a fairly strong field to draw conclusions, but when considering each sex separately, the sample size was reduced significantly. Another limitation in this study is the inability to control each subject's activity level prior to testing. A subject that was active versus sedentary could have a different circulation status upon arrival for exercise testing which could affect foot volume pre and post exercise testing. The non-weight bearing exercise protocol in this study utilized an upright exercise bike. The upright exercise bike caused a considerable flexion angle in the hip that could potentially impair venous return to the heart. A better alternative would be to use a recumbent bike, thus reducing the hip flexion angle.

Future studies should focus on patients with real pre-existing co-morbidities that cause foot edema to determine if these results hold true in such populations. Studies utilizing more subjects with these conditions could help draw firm conclusions regarding sex and foot edema. Although an upright stationary bike was utilized in this study, other forms of non-weight bearing exercise equipment are available. Future studies involving these different exercise modes could help determine the optimal piece of exercise equipment to help minimize foot swelling.

CONCLUSION
The results from this study suggest that treadmill walking (loaded exercise) results in an increase in foot edema when compared to riding an upright stationary exercise bike (unloaded exercise). Although it is difficult to conclude that riding an exercise bike is an effective way to decrease foot edema, these results suggest that stationary biking is a safer mode of exercise than treadmill walking in controlling foot edema, especially in older men. Therefore, unloaded activities may be the most appropriate exercise to prescribe when an increase in foot volume is unwanted. Further investigations into the injured (ankle sprains) and chronically ill (congestive heart failure, peripheral vascular disease, diabetes) patients are necessary to ascertain whether similar findings would result. This knowledge would be very applicable for clinical use of the cycle ergometer as a modality to positively influence venous stasis and decrease the problems associated with ankle and foot edema.

REFERENCES
ABSTRACT

Background. Stretching has long been an integral component of pre-performance activities for a multitude of athletic endeavors. Previous research has demonstrated that stretching may have detrimental effects on performance. Specific knowledge of the precise effects of stretching may influence the decision to appropriately apply stretching techniques in the sport and therapeutic settings.

Objective. The purpose of this pilot study was to examine the effects of static stretching, proprioceptive neuromuscular facilitation (contract-relax) stretching, and no stretching of the quadriceps muscle group on agility performance.

Methods. Twelve healthy, female, collegiate soccer players aged 18 – 25 performed one of the three stretching protocols (static, contract-relax, no stretch) and the agility test (T-test) on three non-consecutive days. Agility times were recorded and compared based on stretching technique and day that each test was performed.

Results. No significant difference was found among the means of the different stretching techniques. The t-test agility performance times were as follows: control, =9.7 seconds; static stretch, =9.73 seconds; and contract-relax, =9.62 seconds.

Conclusion. The results of this study suggest that agility performance may be independent of stretching technique of the quadriceps performed in female collegiate soccer athletes. It is recommended that female soccer athletes about to engage in agility activity may perform either no stretch, static stretch, or contract-relax stretching according to individual preference.

Key words: agility performance, contract-relax stretching, static-stretching, female athletes.

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INTRODUCTION

Stretching is a common component of pre-performance activities for many athletic events. As such, the literature is rich with evidence supporting the effects of stretching on flexibility, with mounting evidence as to the effects of stretching on performance. However, limited research exists concerning the acute affects of different stretching techniques on athletic performance variables, specifically, agility.

Several types of stretching techniques are currently incorporated by athletes for pre-event activities. Static stretching and proprioceptive neuromuscular facilitation (PNF) are common techniques used by therapists, athletic trainers, strength and conditioning professionals, and athletes to enhance flexibility. In most cases, these stretching activities are integrated as part of a warm-up session.

Some researchers studying the effects of stretching on performance have reported significant deficits in performance-related variables, while others found little or no difference. Church et al examined the effects of warm-up and flexibility treatments on vertical jump performance in females. Results demonstrated a decrease in vertical jump height for the PNF treatment group, leading researchers to speculate that performing PNF stretching techniques before a vertical jump test may be detrimental to performance. Wallmann et al investigated the effects of static stretching of the gastrocnemius on vertical jump performance in healthy adults. Researchers concluded that, since vertical jump height decreased by 5.6%, static stretching of the gastrocnemius had an immediate adverse effect on maximal jumping performance.

In contrast to the aforementioned findings, Unick et al examined the acute effects of stretching on vertical jump performance in female collegiate basketball players and concluded that vertical jump performance was not affected by stretching. They measured the effects of static and ballistic stretching, as well as power output at 15 and 30 minutes post-stretch. They reported no significant difference between power output and vertical jump values pre and post-stretch. Likewise, Behm et al reported that static stretching showed a 6.9% decrease in maximal voluntary contraction of the quadriceps while a control group experienced a 5.6% decrease in maximal voluntary control of the quadriceps from pre-test to post-test.

A major component of sport performance that has been poorly researched in the stretching literature is agility. The American College of Sports Medicine describes agility as the “…ability to rapidly change the position of the entire body in space with speed and accuracy.” Agility can be thought of as a systemic integration of neuromuscular coordination, reaction time, speed, strength, balance. This complex nature of agility performance has lead many researchers to conduct studies that involve a breakdown of its component parts.

Cochrane et al additionally noted the complexity of factors that interact to produce agility performance and the difficulty in actually identifying and measuring those components. McMillian et al examined the effects of static versus dynamic warm-up protocols on agility performance, utilizing a common standardized agility test called the T-test. Results revealed a difference between the dynamic warm-up and both the static warm-up and no warm-up groups. Researchers concluded that a dynamic warm-up protocol may provide performance benefits that are superior to static or no warm-up protocols.

Given the paucity of literature regarding the effects of stretching on agility, the purpose of this pilot study was to examine the effects of three different stretching techniques (static, contract-relax stretching, and no stretch) on the quadriceps muscle group with regards to agility performance. The quadriceps muscle group was chosen primarily because females have been shown to be quadriceps dominant and it was thought that this dominance may be affected by stretching. The hypothesis to be tested is that agility performance would decrease in association with bouts of static stretching and PNF.

METHODS

Subjects

Twelve female Division I collegiate soccer players ages 18 - 25 (mean = 19.17; SD = 0.94) participated in this study. The following criteria were used to select the subjects: a member of the women’s soccer team, age 18-25, not currently pregnant, and no lower extremity orthopaedic injuries sustained within the last six months that would hinder the ability to give maximal effort during the T-test. Before initiating the study, the Biomedical Institutional
Review Board of the University of Nevada, Las Vegas approved the study. Each subject gave both written and oral consent before engaging in the research protocol.

**Equipment**

The T-test (Figure 1) is a common test used to measure 4-directional agility, and evaluates the ability of the subject to rapidly change direction while maintaining balance without loss of speed.19 The subject starts with both feet behind a line and sprints 10 yards forward, then shuffles 5 yards to the left, followed by 10 yards to the right, then 5 yards to the left, and finally, 10 yards backward to the original starting point. Pauole et al19 demonstrated that the T-test is a reliable and valid measure of leg speed, leg power, and agility.

Four cones were placed on the floor using the standard parameters for the T-test as described by Pauole et al.19 Additionally, two timing photocells (Lafayette Instrument Co., Lafayette, IN) were placed 6 ft apart at the start/finish position to record the time it took each subject to complete the T-test. One plinth was used for the PNF stretching station and one stool was used for the stretching subject to hold on to for balance during the static stretching station. One stopwatch was utilized to measure the duration of stretch at each station, and one stop-watch was used to time the 5-minute self-selected jog warm-up.

**Procedure**

A repeated-measures design was used to determine the effectiveness of different stretching techniques on agility performance in female college soccer players over a one week period. The dependent variable was the time it took each athlete to complete the T-test. The independent variable consisted of three stretching techniques: contract-relax, static stretching, and a control group.

A pre-study information session was conducted in which subjects were instructed on the testing protocol as well as the proper method for each technique. A demonstration of the T-test was given and all subjects were asked to perform the T-test one time to allow for familiarity with the test. Subjects were also instructed not to participate in excessive physical activity prior to the testing sessions, but to continue with their normal workout routines.

Data was collected on three non-consecutive days over the course of one week. Using a balanced Latin square22 to reduce test order bias, subjects were randomly assigned into one of three different test orders as follows:

a) Group A performed no stretching on Monday, static stretching on Wednesday, and contract-relax stretching on Friday.

b) Group B performed contract-relax stretching on Monday, no stretching on Wednesday, and static stretching on Friday.

c) Group C performed static stretching on Monday, contract-relax stretching on Wednesday, and no stretching on Friday.

Prior to engaging in the stretching protocols, each subject completed a 5-minute warm-up jog at a self-selected speed. The purpose of this jog was to provide a general warm-up to minimize the risk of straining the quadriceps muscles during a maximal agility effort. Subjects then completed the assigned stretch protocol for that day. Immediately after completing the protocol, subjects performed the T-test one time. The three stretching protocols were as follows:

a. Static stretching. This activity consisted of actively stretching the quadriceps muscles of each leg alternately three times each for 30 seconds each (3 minutes total) for both legs. The knee of the leg being stretched was flexed and held by the same upper extremity as the lower extremity being stretched. In order to maintain consistency with this technique and enhance the feeling of inducing a stretch, the subjects were instructed to push their hips forward during the stretch to facilitate a posterior pelvic tilt. An investigator stood with each subject and called out the 30-second increments with the use of a stopwatch so that the
subject could maintain the appropriate time frame for each stretch (Figure 2).

b. Contract-relax. This activity consisted of interactive stretching between the subject and the tester. The tester provided resistance to active contraction of the quadriceps for 6 seconds with a 4 second relaxation phase for a total of 30 seconds alternately three times each (3 minutes total) for both legs. The subject was placed supine on a plinth with the leg to be stretched hanging off of the table. The other leg was held in a knee to chest position in which the knee and hip were both flexed. The tester asked the subject to push the stretching leg into the tester’s hand giving approximately 30% of maximal effort. The subjects were then asked to relax the stretching leg and the tester then pushed the leg into its new available range of motion (Figure 3).

c. No stretching. No stretching was performed; the subject sat on the ground for 3 minutes. This group served as the control group.

Statistical Analyses
A one-way repeated measures analysis of variance (ANOVA) was used to analyze the differences among the three different stretching protocols. Statistical significance was set at $p = 0.05$ and all analyses were carried out using the Statistical Package for the Social Sciences version 13.0 (SPSS, Inc, Chicago, IL).

RESULTS
A repeated measures ANOVA revealed no statistically significant difference among the means, $F(2,22) = 0.759$, $p=0.480$, power = 0.162 for the control (no stretch), static stretching, and contract-relax stretching techniques in T-test agility performance times. The mean T-test performance times and standard deviations for control, static stretching, and contract-relax stretching as well as 95% confidence intervals are displayed in Table 1.

DISCUSSION
The purpose of this pilot study was to examine the differences among three different stretching techniques on agility performance in female collegiate soccer athletes. The results of this study revealed no differences among the three treatment groups on agility performance times.

An accurate comparison of this study to other studies is difficult secondary to a lack of published literature about the topic. However, results of this study are consistent with a similar study conducted by Faigenbaum et al, in which researchers examined the acute effects of pre-event static stretching, dynamic exercise, and static stretching and

Table 1. Means (± standard deviation) and confidence intervals for T-test agility performance times (seconds)

<table>
<thead>
<tr>
<th>Technique (n=12)</th>
<th>Mean Times T-test (seconds)</th>
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dynamic exercise combined on vertical jump, medicine ball toss, 10-yard sprint, and pro-agility shuttle run in teenage athletes. Prior to testing, participants performed 5 minutes of walking/jogging followed by one of the warm-up protocols. Results revealed that performance on the vertical jump, medicine ball toss, and 10-yard sprint were significantly improved after dynamic exercise, and dynamic exercise and static stretching combined, as compared to static stretching alone. No significant difference was noted in the agility performance after the three different warm-up protocols. These results led researchers to believe that pre-event dynamic exercise or static stretching followed by dynamic exercise may be more beneficial than pre-event static stretching alone in teenage athletes participating in power activities.

Little and Williams\textsuperscript{18} examined the effects of different stretching protocols during warm-ups on high-speed motor capacities in 18 professional soccer players. Their design was similar, in that they examined the effects of no stretching and static stretching on agility performance. However, their design differed as they incorporated a dynamic stretch, rather than a PNF stretching technique. In addition, the agility task was performed on a zigzag course, versus the T-test used in the current study. These authors concluded that there was no difference between the control and static stretching groups. This result is consistent with the results revealed in the present study; however, the authors did report that the dynamic stretch protocol produced significantly faster agility performance than did both the control and static stretch groups.

Although a paucity of literature exists regarding the effects of stretching on agility performance, other components of agility have been researched, namely, speed and strength. The evidence on the effect of stretching on sprint performance provides conflicting results with questionable research quality making definitive conclusions difficult.\textsuperscript{24} However, work by other researchers\textsuperscript{4,17} supports the hypothesis that static stretching has a detrimental effect on sprint performance.

The evidence regarding the effects of stretching on force, torque, and jump performance also appears to provide inconclusive results.\textsuperscript{4,11,12,25} Whereas Wallmann et al\textsuperscript{10} and Church et al\textsuperscript{9} reported significant decreases in vertical jump height after bouts of static stretching and PNF stretching, respectively, Unick et al\textsuperscript{11} reported no difference in vertical jump scores as a result of static or ballistic stretching. The Unick et al\textsuperscript{11} study included 16 actively trained women who performed a series of vertical jumps at 4 minutes, 15 minutes, and 30 minutes after stretching the hamstrings, quadriceps, and gastrocnemius/soleus muscle complex. The protocol required the stretch to be held for a period of 15 seconds. This short time period may not have been long enough to induce a tissue extensibility change within the muscle. Research has shown that at least 30 seconds is needed to be effective in bringing about a change in flexibility.\textsuperscript{2,26} In addition, the vertical jumps were performed after 4 minutes of walking, which may have allowed the muscle to return to its pre-stretched length, thereby, affecting the results.

Power et al\textsuperscript{25} found that no difference existed in vertical jump scores after a static stretching routine. However, decreases in isometric maximal voluntary contraction and an increase of inactivation of the quadriceps were found to be statistically significant. Maximal voluntary contraction force of the quadriceps muscle showed a 9.5% decrease over the course of the 120 minute measurement period, while a 5.4% increase of inactivation of the quadriceps muscle was revealed, suggesting that static stretching may adversely affect these variables. Behm et al\textsuperscript{13} reported similar results in regard to maximal voluntary contraction of the quadriceps muscle. In their study, the static stretching group showed a 6.9% decrease in maximal voluntary contraction of the quadriceps muscles while the control group experienced a 5.6% decrease in maximal voluntary contraction of the quadriceps muscle from pre-test to post-test. Although these previous studies revealed decreases in both speed and strength, which are components of agility, the studies do not appear to be consistent with the present results, which showed no differences in agility T-test performance scores. This may be because much of the current literature involves examining the effects of stretching on performance utilizing the hamstrings and triceps surae musculature.

In the present study, the authors chose to isolate the quadriceps muscle group, primarily because females have been shown to be quadriceps dominant and it was thought that this dominance\textsuperscript{27-29} may be affected by stretching. Additionally, there is very little, if any, literature investi-
gating the effects of stretching on performance of only the quadriceps muscles. However, the results of this study reveal that the quadriceps muscle group may only play a small role in the variance of agility performance. Consequently, agility performance does not appear to be immediately affected by stretching only the quadriceps muscle group.

Strengthening other muscle groups may have varied the results. But it would be difficult to determine effects of stretching several muscle groups at once as this stretching may allow the muscles to return to their pre-stretched length prior to athletic performance due to the length of time between stretches.

**Limitations**

Other limitations in this study include varying of testing times, activity level of the subjects prior to our testing time, and a small testing sample. There were some variations regarding data collection times due to time constraints on the part of the soccer team. For example, on Monday and Wednesday, data were collected at 2:00 p.m., while on Friday, data collection occurred at 9:00 a.m. Concerning activity level, the subjects were in a pre-season conditioning program, so we could not control the activity level of each subject prior to data collection, although we did ask the participants to maintain their current level of physical activity during the testing week. This variance in activity level may have affected the effort given by each subject while performing the T-test. The number of subjects participating in this study was small; a larger sample size would be more desirable and may have increased the power of the study. As such, the power was very low for the study. Consequently, the chance of making a type 2 error was high. However, as this was a feasibility study, we believe that the results from this study offer evidence for investigating the effects of stretching using the quadriceps and other muscle groups on agility performance using a more rigorous design.

**Research Importance**

This study holds relevance to the field of sport research in that current literature has demonstrated both the positive and adverse effects of stretching on flexibility, running, jumping, muscle strength, and power output; however, despite the availability of such literature, little research exists that investigates the acute effects of stretching on agility performance. Agility is a major component of many popular sports. Scientific knowledge regarding the effects of stretching on agility may be beneficial in the development of a training regimen designed to enhance athletic performance.

**CONCLUSION**

In conclusion, the results of the present study suggest that static stretching, contract-relax stretching, and no stretching of the quadriceps muscle group have no immediate adverse effect on agility performance in female collegiate soccer players. Further controlled-randomized trials are needed to fully examine and understand the complex nature of this topic. Also, a follow-up study with a larger sample size is needed. In addition, future research should also examine other muscle groups, motivational factors involved in stretching and performance, and athlete preferences and beliefs towards the effects of stretching and performance. It is recommended that female soccer athletes about to engage in agility activity may perform either no stretch, static stretch, or contract-relax stretching according to individual preference with no adverse effects on performance.

**REFERENCES**


A SYSTEMATIC REVIEW OF THE EFFECTIVENESS OF ECCENTRIC STRENGTH TRAINING IN THE PREVENTION OF HAMSTRING MUSCLE STRAINS IN OTHERWISE HEALTHY INDIVIDUALS

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Andrew Grant, BSc (Kin), MPT
Amanda Beers, BHK, MPT
Trevor Moizumi, BSc (Kin), MPT

ABSTRACT

Background. Hamstring strains are the most common soft-tissue injury observed in recreational and athletic activities, yet no consensus exists regarding appropriate primary and secondary strategies to prevent these strains. Eccentric exercise has been reported to reduce the incidence of hamstring strains but its role has not been clearly defined.

Objective. The objective of this systematic review was to determine the effectiveness of eccentric exercise in preventing hamstring strains.

Data Sources. Online databases, including MEDLINE, PubMed, CINAHL, PEDro, SPORTDiscus, EMBASE, Cochrane Database of Systematic Reviews, Cochrane Central Register of Controlled Trials, and Web of Science were searched for relevant articles. Each database was searched from the earliest date to July 2007.

Study Selection. Selection criteria included diagnosis of hamstring strain, otherwise healthy individuals, and at least one group receiving an eccentric exercise intervention. Seven articles {three randomized controlled trials (RCTs) and four cohort studies} met the inclusion criteria.

Data Extraction. Data were extracted using a customized form. Methodological rigor of included studies was assessed using the PEDro scale and Oxford Centre for Evidence-based Medicine Levels of Evidence.

Data Synthesis. Studies were grouped by eccentric exercise intervention protocol: hamstring lowers, isokinetic strengthening, and other strengthening. A best-evidence synthesis of pooled data was qualitatively summarized.

Conclusions. Findings suggest that eccentric training is effective in primary and secondary prevention of hamstring strains. Study heterogeneity and poor methodological rigor limit the ability to provide clinical recommendations. Further RCTs are needed to support the use of eccentric training protocols in the prevention of hamstring strains.

Key Words: eccentric; hamstring strain; prevention

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INTRODUCTION

Hamstring strains are the most prevalent soft-tissue injury in recreational and sports activities that involve sprinting, jumping, and kicking. Strains to this muscle group remain a primary concern for rehabilitation professionals as they result in a debilitating injury characterized by acute loss of functional performance, prolonged periods of recovery, and subsequent increased incidence of recurrence. A recent review indicated hamstring injuries have the highest recurrence rates in sports, ranging from 12-31%.

A muscle strain is defined as an excessive stretch, which leads to muscle fiber damage and disrupts the integrity of related vascular and connective tissue structures. A muscle is commonly strained or torn during rapid acceleration or deceleration movements. A strain can be classified into grades from mild to severe to reflect injury severity. A mild (first degree) strain involves damage to a small number of muscle fibers and localized pain without loss of strength. A clear loss of strength coupled with pain reproduced on resistance is indicative of a moderate (second degree) strain. A severe (third degree) strain corresponds with complete rupture of the muscle and loss of strength and function.

The hamstring muscle group is at increased risk for strains due to its anatomical configuration. The hamstrings are composed of three muscles - semitendinosus, semimembranosus, and biceps femoris - forming a triad in the posterior compartment of the thigh. The musculotendinous junction of the biceps femoris is the most common site of strain. A rapid phase change of muscle contraction from eccentric to concentric has been suggested as the underlying mechanism for hamstring strains. Eccentric contractions are characterized by active lengthening of muscle fibers, in which the force of contraction increases as the speed of contraction increases. Conversely, concentric contractions involve the shortening of muscle fibers and an inverse relationship between the force and speed of contraction. For example, during gait, the bi-articular arrangement of the hamstring muscles across the hip and knee allow the hamstrings to work eccentrically during late swing to decelerate the lower leg and control knee extension. A concentric contraction follows to initiate hip extension prior to heel strike. Hamstrings are maximally loaded and lengthened during this rapid phase change.

In addition to clinical investigations into the biomechanical predisposition of hamstring strains, retrospective studies have focused on the identification of other etiological factors which may predict the occurrence of hamstring strains. Intrinsic risk factors for hamstring muscle strains include older age, ethnicity, previous injury, decreased hamstring flexibility, and reduced strength. Other potential intrinsic risk factors include sex, decreased angle of peak torque, and agonist-antagonist muscle imbalance. Extrinsic factors such as fatigue, lack of warm-up, and inadequate preseason training have also been associated with increased risk of hamstring strains. However, research suggests the most significant predictor of hamstring injury is a history of previous strain to the muscle. The direct influence of risk factors remains inconclusive as investigations do not provide strong evidence to support their individual or collective effect on development of hamstring strains.

Despite the high prevalence and subsequent high incidence of recurrent hamstring strains, there is a lack of consensus with respect to appropriate primary and secondary prevention strategies. Primary prevention is defined as an intervention that prevents the occurrence of an initial injury, while secondary prevention is an intervention that prevents the recurrence of subsequent or further injury. Identification of valid and reliable prevention strategies is essential to reduce the incidence of injury and direct current rehabilitation efforts.

The protective effect of muscle strengthening on the occurrence of hamstring strains has been reported in the literature; however, the preventative role of eccentric exercise has not been clearly defined. Muscle adaptation is mode specific, with eccentric training increasing eccentric strength. Hamstring strains commonly occur during the eccentric phase of a muscle contraction, therefore, overloading these muscles with eccentric training could potentially serve to prevent hamstring strains.

Subsequent bouts of eccentric muscle overloading have demonstrated a cumulative protective effect against further exercise-induced damage. This “repeated bout effect” causes a shift in the length-tension curve, such that peak tension is generated at longer muscle lengths. Research suggests that sarcomeres are added in series following eccentric loading. Given the length-dependent nature of muscle damage in hamstring strains near end range, this structural adaptation optimizes the angle of peak torque to reduce the risk for potential injury.
Eccentric exercise has the potential to result in delayed onset muscle soreness (DOMS), which needs to be differentiated from muscle strain. Delayed onset muscle soreness is clinically characterized by muscle soreness, stiffness, inflammation, and loss of function peaking one to three days after unaccustomed exercise. With DOMS, repeated bouts of exercise result in progressively less tissue damage and soreness. In comparison, muscle strain is characterized by immediate acute pain, and exercise too soon after strain can lead to a more disabling injury.

A preliminary search of the literature found that no systematic reviews currently exist investigating the benefit of eccentric training on the primary and secondary prevention of hamstring strains. Thus, the objective of this systematic review is to evaluate the existing evidence to determine effectiveness of eccentric exercise on primary and secondary prevention of hamstring muscle strains.

Movement of the ankle may result in a reduction in foot volume secondary to a muscle pumping action moving fluid out of the area. Results of this study may help health care practitioners prescribe a more appropriate exercise mode when addressing the cardiovascular health of the active geriatric individuals.

METHODS

The Question

This systematic review was undertaken to determine if eccentric strength training was effective in the prevention of hamstring strains in otherwise healthy individuals. Studies included were those in which the subjects underwent an eccentric strength training intervention for the primary or secondary prevention of hamstring strains. When appropriate, comparisons were made between groups receiving eccentric strength training and groups receiving alternative interventions. The primary outcome measure of interest was incidence of hamstring strains, which included first-time muscle strains and strain recurrences. The secondary outcome measure was the severity of hamstring strain.

Search Strategy

Electronic databases searched for the purpose of this systematic review included: MEDLINE, PubMed, EMBASE, CINAHL, the Cochrane Central Register of Controlled Trials, the Cochrane Database of Systematic Reviews, SPORTDiscus, PEDro, and Web of Science. In addition, reference lists of all studies included in the review, additional articles published by leading authors in this area of research, and other relevant academic journals were hand searched. Grey literature resources were also hand searched, including: CIRRIE Database of International Rehabilitation Research, NARIC’s REHABDATA Literature Databases, and Critically Appraised Topics. Grey literature materials are not formally published in regularly accessible, peer-reviewed journals or indexed in major electronic databases. Common formats of grey literature include: works in progress, unpublished theses, statistical reports, and conference proceedings. All databases were searched from the earliest date to March 2007 to ensure the comprehensive identification of all relevant publications. The search was limited to articles in English or French.

The search began with the identification of MeSH terms referring to hamstring strains. These MeSH terms were “exploded” in all databases in order to tailor the search terms to each specific database. Databases were searched using MeSH terms and keywords such as: “athletic injuries,” “sprains and strains,” “leg injuries,” AND “hamstring,” “semitendinosus,” “semitendinosus,” “biceps femoris,” AND “eccentric.”

Study Selection

A list of citations was accrued from the database searches and assessed for eligibility by two independent reviewers. Citations must have included: 1) “strain” or “injury” AND 2) one of “hamstring,” “eccentric,” “prevention,” “exercise,” or “training,” or some variation thereof. Reviewers selected citations they deemed eligible, and abstracts were obtained for any citations selected by at least one reviewer. Abstracts were evaluated for eligibility by two independent reviewers based on predetermined selection criteria. Study selection criteria included: diagnosis of hamstring strain (any grade), otherwise healthy individuals, and at least one group receiving eccentric exercise intervention. Full text articles were retrieved for all abstracts deemed eligible by at least one reviewer. When an abstract was not available, the full text article was retrieved. Finally, full text articles were evaluated by two independent reviewers using a customized article screening form. Reviewers discussed their decisions and reached a consensus regarding whether or not to include each full text article. If two reviewers were unable to reach a consensus, a third reviewer evaluated the full text article and made a final tie-break decision.

Search Results

Results of the overall search strategy are summarized in Figure 1. An initial 354 primary articles were identified
for potential inclusion. Of these articles, 259 were excluded after citation screening, leaving 95 citations. For the remaining 95 citations, abstracts were obtained and screened for eligibility. Seventy-four abstracts were excluded in the second phase of screening, leaving 21 eligible full text articles. Some reasons for abstract exclusion included: lack of eccentric training intervention, no report of hamstring strains, and limitation in study design (i.e., a review article). Of the 21 full text articles included in the final phase of screening, a further 16 were excluded. Reasons for exclusion included: lack of specified eccentric exercise intervention (n=12) and lack of reported hamstring strain incidence or severity (n=4). Studies were not excluded on the basis of study design. In total, five full text articles were included after the systematic review of the literature. Following hand searching of relevant journals and recent grey literature searches, two additional articles were subjected to the same process and deemed eligible for inclusion, for a total of seven included full text articles. Of the seven included full text articles, three were randomized controlled trials (RCTs). The RCTs are prospective trials in which eligible participants are randomly assigned to one or more treatment groups or a control group. The remaining four articles were cohort studies which followed groups of individuals and examined the relationship between an intervention (eccentric strengthening) and the incidence of the outcome of interest (hamstring strain) in study participants.

**Data Extraction and Synthesis**

Using a customized data extraction form, two independent reviewers extracted data regarding subject characteristics, type of eccentric intervention and controls, study design, and results. Discrepancies were resolved by discussion between the two reviewers. If additional study information was required prior to determining eligibility, the primary author was contacted via e-mail. Pertinent data were qualitatively summarized in both text and tabular forms.

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<th>Article</th>
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<td>y</td>
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* = consensus reached by changing this score

**Table 1. PEDro scores and inter-rater reliability**
Quality Assessment
The Physiotherapy Evidence Database (PEDro) Scale was used by two independent reviewers to assess the methodological quality of each included full text article. A third reviewer acted as a tie-breaker when necessary. The PEDro Scale is scored out of ten with a single point awarded when a specified criterion is met. Criteria evaluated include: random allocation, concealed allocation, baseline similarity, blinding, reported outcome measures, intention to treat analysis, statistical comparisons, and measures of variability. Table 1 summarizes the quality assessment scores of included full text articles. Of the seven included full text articles, three were randomized controlled trials (RCTs) with PEDro scores ranging from 6 to 7. Scores greater than 6 are considered strong evidence. The remaining four articles were cohort studies and achieved PEDro scores ranging from 2 to 5. The average kappa value for inter-rater reliability of PEDro scores was 0.89 (range 0.62 to 1.00), indicating strong agreement between reviewers.

Methodological rigor of included articles was also evaluated using Oxford Centre for Evidence-based Medicine Levels of Evidence. Levels of evidence categorizations ranged from 2b to 4, where 2b represented individual cohort studies or low quality RCTs and 4 represented case-series, poor quality cohort, and case-control studies. Results of this analysis are summarized in Table 2.

RESULTS
A summary of included studies is displayed in Table 3. A concise summary of results is available in Table 4. A lack of similar methodologies negated a quantitative meta-analysis of results. The seven included studies were grouped by eccentric intervention type: “hamstring lowers” protocol (n=3), isokinetic strengthening protocol (n=2), and other strengthening protocols (n=2). A best-evidence synthesis of pooled data is qualitatively described below.

Effect of Eccentric Exercise - “Hamstring Lowers” Protocol
Three studies (two cohorts, one RCT) examined the effects of eccentric exercise, using a “hamstring lowers” protocol, on the prevention of hamstring muscle strain injuries and their severity. The “hamstring lowers” protocol involved participants kneeling on the floor with upright trunk perpendicular to floor (Figure 2). Feet were supported under a low bench or held by a partner. Arms were kept folded across chest and body was lowered forward. Participants lowered their body until they were no longer able to hold the position, at which point the participant was allowed to relax and use their arms to catch themselves as they reached the floor. This protocol was employed in conjunction with other conservative treatments including stretching, combined eccentric and concentric strengthening exercises, and range of motion of the lumbar spine.

Arnason et al examined the effect of eccentric “hamstring lowers” and contract-relax proprioceptive neuro-muscular facilitation (PNF) stretching on incidence (i.e., number of hamstring strains) and severity (i.e., duration of absence from play) of hamstring strains in male soccer players from top Icelandic and Norwegian soccer leagues during the 1999 to 2002 soccer seasons. Participants completed one of three interventions, which included combinations of warm-up PNF stretching, PNF flexibility exercises, and eccentric strength training. Results from the intervention teams were compared to results from baseline seasons (1999 and 2000) and to control teams. Control teams did not partake in the intervention programs during the 2001 and 2002 soccer seasons. Incidence of hamstring strains in the “hamstring lowers” group was less compared to baseline seasons among intervention teams. Differences in injury severity and re-injury rates, however, were not statistically significant between baseline seasons amongst intervention teams. When compared to control teams (0.62 ± 0.05 hamstring strains per 1000 player hours), the overall incidence of hamstring strains was 65% lower in the “hamstring lowers” group (0.22 ± 0.6 hamstring strains per 1000 player hours). However, the severity of injury and re-injury rates were not significantly different between “hamstring lowers” and control groups.

Brooks et al examined the effectiveness of “hamstring lowers” and hamstring stretching on...
Table 3. Summary of included studies

<table>
<thead>
<tr>
<th>Author &amp; Study Design</th>
<th>Prevention</th>
<th>Participants</th>
<th>Groups</th>
<th>Intervention</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arnason et al. 38</td>
<td>Combined 1’ &amp; 2’ Prevention</td>
<td>Icelandic and Norwegian elite league male soccer teams (elite)</td>
<td>Warm-up stretching, flexibility, strength training n=8 teams (age: not reported)</td>
<td>Warm-up stretching of hamstrings using contract-relax</td>
<td>Incidence of hamstring muscle strain&lt;br&gt;Eccentric training: Overall incidence of hamstring strains was 65% lower compared to control* (0.22 ± 0.06 vs. 0.62 ± 0.05; RR 0.35; 95% CI 0.19-0.62, p&lt;0.001). Incidence of hamstring strains was lower compared to baseline (RR 0.42 [0.21-0.84], p=0.009).&lt;br&gt;Flexibility training: No significant difference was found in the incidence of hamstring strains between intervention and control (0.54 ± 0.12 vs. 0.35 ± 0.10; relative risk 1.53; 95% CI 0.76-3.08, p=0.22) No difference in re-injury rates between “hamstring lowers” group compared to control and baseline. Severity of hamstring muscle strain No difference in injury severity between “hamstring lowers” group compared to control. Injuries in the “hamstring lowers” group were less severe compared to baseline.</td>
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<tr>
<td>Cohort (prospective)</td>
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<td>Askling et al. 30</td>
<td>Combined 1’ &amp; 2’ Prevention</td>
<td>Premier league male soccer players from Sweden (elite)</td>
<td>Training group n=15 (age: 24±2.6 yrs)</td>
<td>General training &amp; eccentric hamstring strength training using YoYo Flywheel ergometer&lt;br&gt;General training not described&lt;br&gt;Eccentric: 4 sets x 8 reps; 16 sessions over 10 weeks</td>
<td>Incidence of hamstring muscle strain&lt;br&gt;Incidence of hamstring strains decreased in trained group (3/15) when compared to control group (10/15).</td>
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<td>RCT</td>
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<tr>
<td>Brooks et al. 2</td>
<td>Combined 1’ &amp; 2’ Prevention</td>
<td>Professional male rugby players in the English Premiership rugby union club (elite)</td>
<td>Strengthening (S) n=148 (age: 25.5±4.1 yrs)</td>
<td>Regular concentric &amp; eccentric hamstring strengthening&lt;br&gt;Strength: 1.2 sessions/wk; 3.6 sets x 8.2 reps (Exercises not described)</td>
<td>Incidence of hamstring muscle strain&lt;br&gt;S: 1.1 (95% CI 0.74-1.4) injuries/1000 player hours; 26% proportion of recurrences&lt;br&gt;SS: 0.59 (95% CI 0.34-0.84) injuries/1000 player hours; 28%</td>
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<tr>
<td>Study</td>
<td>Intervention</td>
<td>Outcome Measures</td>
<td>Key Findings</td>
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<tr>
<td>Croisier et al.</td>
<td>Strengthening &amp; stretching (SS) n=144 (age: 25.8±4.0 yrs)</td>
<td>Regular concentric &amp; eccentric hamstring strengthening and static stretching</td>
<td>Strength: 1.8 sessions/wk; 3.3 sets x 7.5 reps Flexibility: 2.6 sessions/wk; 2.8 sets held 25 seconds (Exercises not described)</td>
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<tr>
<td>Cohort (prospective)</td>
<td>Strength, stretching and Nordic† strengthening n=200 (age: 25.4±4.1 yrs)</td>
<td>Regular concentric &amp; eccentric hamstring strengthening, static stretching and eccentric strength training using “hamstringowers”</td>
<td>Strength: 1.3 sessions/wk; 3.0 sets x 7.5 reps Flexibility: 1.8 sessions/wk; 2.6 sets x 28 reps Eccentric: 1.3 sessions/wk; 2.8 sets x 6.7 reps (Exercises not described)</td>
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<td>Gabbe et al.</td>
<td>2’ Prevention</td>
<td>National or international male soccer, track &amp; field, martial arts athletes (elite) n=18 (age: 25±8 yrs)</td>
<td>Initial individualized isokinetic concentric, eccentric, or combined eccentric and concentric programs 10-30 sessions; 3x/week, 4-8 reps at 30° or 120°/s Followed by 12-month standardized maintenance program, including manual muscle strengthening and static stretching</td>
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<td>RCT</td>
<td>Incidence of hamstring muscle strain</td>
<td>No participants sustained a hamstring strain after return to their respective sports for 12 months.</td>
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<td>Pain of initial hamstring muscle strain</td>
<td>Before rehabilitation, pain VAS was 5.9 ± 1.1. On return to activity pain VAS was 0.9 ± 0.6. Intervention significantly reduced pain at P &lt; 0.001.</td>
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<tr>
<td>Gabbe et al.</td>
<td>Combined 1’ &amp; 2’ Prevention</td>
<td>Senior or reserve grade male team from VAPA 2004 (competitive)</td>
<td>Eccentric strengthening n=114 (age: 23.4; range 18.0-35.0 yrs)</td>
<td>Controlled hamstring lowers 5 sessions/12 weeks; 12 sets x 6 reps</td>
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<tr>
<td></td>
<td>Incidence of hamstring muscle strain</td>
<td>Intervention group not at decreased risk for hamstring injury when intention to treat was analyzed (RR 1.2, 95% CI 0.5-2.8) Of participants who completed at least two training sessions, 4% of the eccentric strengthening group and 13.2% of stretching and ROM exercise group sustained a hamstring strain (RR 0.3, 95% CI 0.1-1.4; p=0.098)</td>
<td>Static stretching</td>
<td>Gastrocnemius, hip flexors, hamstrings stretches held for 30 seconds; lumbar spine stretch held for 15 seconds.</td>
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<td></td>
<td>Stretching and ROM exercises n=106 (age: 23.9; range 17.4-36.0 yrs)</td>
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reducing incidence (i.e., number of injuries per player hours) and severity (i.e., number of days lost per injury) of hamstring muscle strains in 546 professional rugby players. One hundred and forty-eight players were in the strengthening group, 144 players in the conventional strengthening and stretching group, and 200 players in the intervention group, which combined conventional strengthening and stretching with “hamstring lowers.” The incidence of hamstring strains in the intervention group (0.39 injuries per 1000 player hours) was reported as significantly lower than in the strengthening group (1.1 injuries per 1000 player hours) and the conventional strengthening and stretching group (0.59 injuries per 1000 players). Although a difference in hamstring strain severity existed across the three training groups, this difference was not significant.

Effect of Eccentric Exercise - Isokinetic Strengthening Protocol

Two prospective cohort studies investigated the incidence of hamstring strains following eccentric exercise using isokinetic strengthening protocols. Croisier et al observed the recurrence of hamstring muscle strains in 26 male athletes with pre-existing unilateral strains. Participants’ baseline isokinetic profiles of hamstring and quadriceps muscle function were assessed on a Kintrex 500® dynamometer (Puidoux, Switzerland) before individualized rehabilitation programs were prescribed. Rehabilitation programs involved isokinetic eccentric exercise using the same dynamometer. During the 12-month follow-up period, no participants sustained a clinically diagnosed recurrent hamstring strain. Initial injury severity (i.e., rating of muscle pain and discomfort on a 10-point
visual analogue scale) decreased from 5.9±1.1 points pre-intervention to 0.9±0.6 post-intervention (p< 0.001) and remained constant for 12 months.

A more recent study by Queiros Da Silva et al.40 explored the use of eccentric exercise using an isokinetic strengthening protocol with a Cybex® Medway, MA isokinetic dynamometer coupled with “classical kinesiotherapy” (i.e., cryotherapy, “physiotherapy,” non-steroidal anti-inflammatories, deep transverse massage, progressive passive musculotendinous stretching, manual eccentric exercise, and proprioception exercises) for the secondary prevention of thigh muscle injuries. Of the eight participants with hamstring strains, none sustained a recurrent strain during the 8-month follow-up period post-intervention.

**Effect of Eccentric Exercise - Other Strengthening Protocols**

Two RCTs investigated the use of other eccentric exercise strengthening protocols on the incidence of hamstring strains. Askling et al.30 examined the effects of pre-season overloading using a YoYo™ flywheel ergometer (Stockholm Germany) on incidence of hamstring muscle strains in 30 Swedish elite male soccer players. As described in Askling et al., rotation of the flywheel was initiated with a concentric contraction of the hamstrings. An eccentric contraction of the hamstring muscle group was subsequently required to decelerate the movement of the flywheel. Eccentric overloading of the hamstrings required the performance of an eccentric contraction over a smaller angular displacement. The training group completed general training combined with concentric and eccentric hamstring strength training using a YoYo™ flywheel ergometer, while the control group completed general training only. Results showed a decreased incidence of hamstring strains in trained (n=3) compared to control (n=10) groups. Six of the 13 participants who sustained a hamstring strain reported a previous hamstring injury. Of these participants, two were in the training group and four in the control group.
In 2004, Sherry Best examined the effectiveness of two rehabilitation protocols. Stretching and strengthening (STST, n=11) were compared to progressive agility and trunk stability (PATS, n=13) in 24 male and female subjects with acute hamstring strains. Eccentric strengthening (STST group) for the hamstring muscles was performed using “standing foot catches.” “Standing foot catches” were performed by having participants stand on one leg parallel to a wall and simulate the swing phase of walking or running (Figure 3). Participants contracted their quadriceps muscle to perform a rapid knee kick. Eccentric loading of the hamstring occurred when participants “caught” or stopped the lower leg from reaching full extension by eccentrically contracting their hamstrings. Hamstring strain recurrence was significantly lower for athletes in the PATS group when compared to the STST group at 16 days after return to sport. At one year following return to sport, one additional participant in each group sustained a hamstring strain.

**Adverse Effects and Dropouts**

Intervention-related muscle soreness was reported during the initial phases of training in three of the seven included studies. The majority of subjects in Askling et al (n=11/15) reported muscle soreness lasting 1-3 days after training sessions. A large dropout rate was observed across all training groups in the Gabbe et al study. With the primary reason for non-compliance, reported by players, being DOMS. Less than half of participants (46.8%) completed at least two of the five training sessions, and less than 10% completed all required sessions over the 12-week period. Adherence in the eccentric strengthening group was lower than in the stretching and range of motion group. Arnason et al reported that DOMS was also the principle factor underlying the dropout of one team. This team opted not to follow the prescribed “hamstring lowers” protocol and adopted a program that was much more intensive.

Other reasons for non-adherence reported in the included studies were unrelated to study design. One participant in the Croisier et al study was excluded following lack of improvement in his isokinetic strength profile following nerve compression related to ectopic calcification. In Sherry Best, four participants did not complete the prescribed training for reasons unrelated to the intervention (e.g., death in a motor vehicle accident).

**Diagnosis of Hamstring Strain**

The methodology employed to diagnose hamstring strains varied amongst included studies (Table 5). In all seven included studies, sport clinicians (i.e. physiotherapists and other medical personnel) completed the assessment and diagnosis of hamstring strains. Criteria for clinical diagnoses included tenderness on palpation of the musculotendinous junction, pain with isometric contraction, mechanism of injury that resulted in sudden onset of posterior thigh pain, limitation of activities, and pain with stretching.

**DISCUSSION**

After a thorough review of the literature, seven studies were included and qualitatively analyzed in the systematic review, including cohort studies and RCTs with Oxford Centre for Evidence-based Medicine Levels of Evidence ranging from 2b to 4. Due to this low level of evidence, limited support exists for the use of “hamstring lowers,” isokinetic exercises, and other eccentric strengthening exercises as effective training protocols to reduce the incidence and subsequent recurrence of hamstring strains.
Effect of Eccentric Exercise - “Hamstring Lowers” Protocol

Three included studies \(^2,28,29\) examined effects of eccentric exercise using “hamstring lowers” protocols, in conjunction with other conservative treatments (e.g., stretching, combined eccentric and concentric strengthening exercises, and range of motion of the lumbar spine), on the prevention of hamstring strains and reduction of their severity. The prospective cohort studies showed a lower incidence of hamstring strains with eccentric training, but no significant difference in severity of injury.\(^2,28\) Conversely, the RCT by Gabbe et al\(^29\) found that the “hamstring lowers” group was not at decreased risk for hamstring strains following intention to treat analysis. However, participants in this intervention group who completed at least two training sessions sustained fewer hamstring injuries.

These three studies included competitive to elite level athletes.\(^2,28,29\) In the study of male Premier League soccer players, Askling et al\(^30\) contended that care should be taken when extrapolating findings from elite athletes as they train at a higher intensity and frequency than recreational athletes, and may therefore be at greater risk for hamstring injury.\(^30,41\) Moreover, they argued that significant findings of a protective effect in elite athletes are more remarkable and robust since these athletes are typically closer to a theoretical ceiling effect for eccentric strength gains. Furthermore, Heidt et al\(^4\) suggest the risk of injury may actually increase with progressively higher levels of play.

Poor adherence and high dropout rates plagued two of the three “hamstring lowers” studies.\(^28,29\) Gabbe et al\(^29\) attributed their high dropout rate to participants’ subjective responses to DOMS. Arnason et al\(^28\) noted none of the teams that performed the progression of “hamstring lowers” as prescribed, complained of DOMS. However, one team employed a more intensive training protocol than prescribed and consequently incurred considerable DOMS and dropped out of the study.\(^29\) Gabbe et al\(^29\) followed a “hamstring lowers” protocol as described in Brockett et al:\(^27\) 12 sets of 6 repetitions, with 10 seconds of rest between repetitions and 2-3 minutes of rest between sets, in five sessions over a 12-week period. Conversely, Arnason et al\(^28\) followed a protocol proposed by Mjolsnes et al.\(^26\) This protocol involved a 5-week introductory period, increasing from two sets of five repetitions one time in the first week, to three sets of 8-10 repetitions three times per week by the end of the fourth week.\(^26\) Thereafter, participants performed three sets of 8-12 repetitions three times per week for weeks 5-10.\(^26\) It stands to reason that the progressive nature of the program suggested by Mjolsnes et al,\(^26\) which incorporated a lower intensity introductory period, may explain why fewer participants reported DOMS in the Arnason et al\(^28\) study compared to Gabbe et al.\(^29\)

Based on the low level of evidence and paucity of published “hamstring lowers” studies, these results should be interpreted cautiously. While the included studies suggest that “hamstring lowers” appear to provide a clinically useful and inexpensive means of loading the hamstring muscles eccentrically to help protect against strain, none

Figure 3. Simulated swing phase of walking.
of the three studies adequately controlled for concurrent training methods (e.g., combined stretching and strength training). Consequently, it is impossible to isolate the effects of the “hamstring lower” protocols. Thus, additional research isolating “hamstring lowers” from other interventions needs to be conducted in order to draw any definitive conclusions with respect to their effectiveness in the primary and secondary prevention of hamstring strains.

**Effect of Eccentric Exercise - Isokinetic Strengthening**

Two studies investigated the use of isokinetic eccentric strengthening for preventing recurrent hamstring strains - both showed protective effects. No participants in the Croisier et al. study examining male athletes sustained a hamstring strain during the first 12 months after returning to sport, and rehabilitation seemed to be successful in reducing self-reports of muscle pain and discomfort. Likewise, during a six-to-nine month follow-up period in the Queiros Da Silva et al. study of athletes, no recurrent hamstring strains were reported.

Both of the foregoing studies were prospective cohort studies with no control groups. In addition, they incorporated isokinetic eccentric strengthening in conjunction with other interventions. As a result, data need to be interpreted with caution. Due to weak study design, it is unclear exactly how much protection against recurrent hamstring strains was due to isokinetic eccentric strengthening and how much was due to other factors. Possibly, other physiotherapy interventions used in these studies (i.e., concentric strengthening and stretching of the quadriceps and hamstring muscles, trans-cutaneous electrical nerve stimulation, “kinesiotherapy,” and sport specific activities) contributed to the observed protection against recurrent hamstring strains. Another limitation of both studies was small sample size, leading to a lack of precision to provide reliable answers to the questions investigated by reducing the likelihood of observing any significant effect. As well, neither study conducted follow-up beyond one year, so longer term outcomes are not known.

Despite the inherent limitations and lack of supporting evidence in these studies, both Croisier et al. and Queiros Da Silva et al. recommended that eccentric exercise should be included in the rehabilitation of hamstring strains to help prevent recurrent strains. More specifically, Croisier et al. concluded that persistence of muscle strength abnormalities may give rise to recurrent hamstring strains and pain, and that “classic rehabilitation” may be improved by including individualized isokinetic eccentric strengthening exercises.

Results of these two studies suggest that adequate warm-up followed by isokinetic eccentric strengthening at low velocities (5-30°/second) is necessary to avoid DOMS. However, without an established means of differentiating muscle strain from DOMS, it is not possible to distinguish hamstring strain and DOMS from these results. Treatment should be progressed by increasing eccentric

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**Table 5. Criteria for hamstring strain diagnosis**

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<td>Tenderness on palpation</td>
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<td>4</td>
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<td>Pain with isometric contraction</td>
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<td>X</td>
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<tr>
<td>Pain with stretching</td>
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<td>Known mechanism of injury</td>
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<td>Limitation of activities</td>
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<td></td>
<td>X</td>
<td>X</td>
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<td>4</td>
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velocity, and should ideally be performed three times per week, which is in agreement with Cotte,\textsuperscript{41} in order to minimize time to return to sport.\textsuperscript{1,40} Isokinetic eccentric strength values can also be used to determine when return to sport is appropriate. Both studies agreed that bilateral strength differences should be no less than 5% before returning to competition. This 5% value has been repeatedly cited in the literature\textsuperscript{1,2,4,44} since it is believed that hamstring strength deficits are a risk factor for strain.\textsuperscript{1,13,16,44,45}

Due to study limitations (i.e., no control groups, isokinetic strengthening not examined in isolation, and small sample sizes), these protocols and recommendations must be interpreted carefully. Additional high-level research examining primary prevention and involving larger sample sizes is needed. Also, incorporating better controls, such as isokinetic eccentric strengthening in isolation compared with no exercise, concentric exercise or stretching, is necessary to accurately assess the degree to which hamstring strain incidence may be decreased using isokinetic eccentric training.

**Effect of Eccentric Exercise - Other Strengthening Protocols**

Two RCTs included in the systematic review utilized other eccentric strengthening protocols.\textsuperscript{14,30} Using a YoYo\textsuperscript{TM} flywheel ergometer, Askling et al\textsuperscript{30} examined the effects of pre-season hamstring strengthening, incorporating concentric and eccentric overload, on the occurrence and severity of hamstring strains in elite Swedish male soccer players. The eccentric training group had a significantly lower number of injuries compared to the control group. The results of this study suggest a pre-season eccentric strengthening program may reduce the incidence of hamstring strains. One major limitation of the Askling et al\textsuperscript{30} study was the inability to differentiate between the concentric and eccentric phases of the YoYo\textsuperscript{TM} flywheel ergometer exercise. Therefore, the effects of eccentric training in isolation are unknown. Also, the small sample size may have decreased the reliability of the reported results by reducing its power to detect small size effects. It should also be noted that participants involved in the study were all elite male athletes. As previously discussed, research has suggested that elite level athletes may be at greater risk for hamstring injury,\textsuperscript{41} thus limiting the extrapolation of these results to other populations.

Sherry Best\textsuperscript{14} investigated the effectiveness of two different rehabilitation programs for the secondary prevention of hamstring strains. This study demonstrated that a rehabilitation program consisting of progressive agility and trunk stabilization (PATS) exercises was significantly more effective than a program of hamstring stretching and concentric-eccentric strengthening (STST). Of note, the interventions in both the PATS and STST groups incorporated multiple training modes. The use of agility training, which involved considerable eccentric loading through stopping and starting, was not identified as a specific eccentric intervention, which may be a confounding factor explaining why the PATS group sustained fewer hamstring strains. Furthermore, no attempt was made to measure trunk stability, making it difficult to determine the extent that trunk stabilization had on preventing hamstring strains. A small sample size and lack of therapist blinding also reduced the methodological rigor of this study. Because of the limitations in these two studies, it is not possible to affirmatively support the use of other eccentric strengthening protocols in hamstring strain prevention.

Additionally, Sherry Best\textsuperscript{41} were the only investigators to include both male and female participants. Numerous studies have shown sex differences in muscle response to eccentric exercise.\textsuperscript{17,30,44,47} For example, MacIntyre et al\textsuperscript{47} found sex differences in severity of DOMS, muscle torque, and inflammatory markers following eccentric exercise. Therefore, eccentric training protocols designed to prevent hamstring strains may have to be modified to address these sex differences. It is imperative that the results of studies utilizing only male participants not be generalized to females. Furthermore, the effect of sex differences on the incidence of hamstring strains following eccentric training should be investigated in more rigorous controlled trials.

**Adverse Effects and Dropouts**

As previously discussed, YoYo\textsuperscript{TM} flywheel ergometry and "hamstring lowers" both resulted in increased participant dropout due to occurrence of muscles soreness and DOMS.\textsuperscript{25-30} The lack of adherence to eccentric training protocols and subsequent adverse effects reported in Arnason et al,\textsuperscript{21} Gabbe et al,\textsuperscript{29} and Askling et al,\textsuperscript{30} may restrict the implementation of these protocols in clinical settings. However, it is interesting to note the eccentric isokinetic intervention used in the Croisier et al\textsuperscript{1} study seemed to decrease the severity of initial injury.

**Diagnosis of Hamstring Strains**

Hamstring strains are typically diagnosed through clinical examination by a team physician or physical therapist.\textsuperscript{5,48} Verrall et al\textsuperscript{1} confirmed that the common clinical features of hamstring strains are sudden onset associated with running or acceleration, pain, posterior thigh tenderness, and pain on
resisted muscle contraction. Other clinical features include loss of function and pain provocation with range of motion.\textsuperscript{5,48} Therefore, it can be assumed that clinical assessment was an appropriate method to diagnose hamstring strains in the seven included studies.

**CONCLUSION**

Previous investigations show improvements in the structural integrity and performance of the hamstring muscles with eccentric training.\textsuperscript{3,6,27} Although authors of these studies advocated the use of eccentric exercise to prevent hamstring strains, limited evidence exists to support its use. A lack of high-level trials impedes the ability to effectively generalize these findings to the clinical settings.

The studies included in this review varied in methodological rigor, population, sample size, and most notably, type of eccentric intervention. While the interventions varied in their prescription, no studies examined the effect of eccentric training in isolation. The coupling of eccentric training with other interventions may have limited, or conversely enhanced, the observed effects of eccentric training on the incidence and severity of hamstring strains. Thus, results of the included studies must be interpreted with caution.

In summary, seven studies were included in this review following a comprehensive appraisal of the available literature. This limited number of relevant articles highlights the need for future well-designed randomized controlled trials to conclusively evaluate the effectiveness of eccentric training in the prevention of hamstring muscle strains. Until more evidence becomes available, concrete recommendations to support or counter the use of eccentric training protocols for the primary and secondary prevention of hamstring strains cannot be made.

**REFERENCES**


ABSTRACT

Background. Shoulder injuries account for up to 17% of all golf related musculoskeletal injuries. One cause may be the repetitive stresses applied to the lead shoulder during the backswing and follow-through phases, which may contribute to the frequency of these injuries. The “elite” golfer may be predisposed to developing a shoulder injury based upon the reported adaptations to the glenohumeral joint.

Objective. To examine and compare bilateral glenohumeral joint rotational range of motion in elite golfers using standard goniometric procedures.

Methods. Twenty-four “elite” male golfers were recruited for this study. Glenohumeral internal (IR) and external rotation (ER) passive range of motion was measured bilaterally at 90º of abduction using a standard universal goniometer. Paired t-tests were utilized to statistically compare the rotational range of motion patterns between the lead and the trailing shoulder.

Results. No statistical differences existed between each shoulder for mean IR or mean ER measures. This finding was consistent throughout different age groups. External rotation measurements were greater than IR measurements in both extremities.

Discussion and Conclusion. Unlike other sports requiring repetitive shoulder function, the “elite” golfers sampled in this pilot investigation did not demonstrate a unique passive range of motion pattern between the lead and trailing shoulders. Factors, including subjects' age, may have confounded the findings. Further studies are warranted utilizing cohorts of golfers with matching age and skill levels. Additional shoulder range of motion measures should be evaluated.

Key Words: golf, passive shoulder range of motion, glenohumeral joint, shoulder injuries

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INTRODUCTION

People of all ages and skill levels play golf worldwide.1-3 For a golfer to improve to the level of an elite player, a combination of natural athletic ability and dedicated practice is required.4 To stay at the top of one’s game, an elite golfer will routinely practice daily for hours on end.4 Competitive golfers may perform up to 2000 swings each week.5 Due to the high volume of swings performed during practice and in competition, golfers are at risk of developing overuse injuries.5-18

Shoulder injuries have been shown to account for 8% to 17.6% of all golf injuries.6,12-15 Injuries to the shoulder rank 3rd behind injuries to the low back and the left wrist in professional male golfers.6,13 For male amateur golfers shoulder injuries rank 4th following injuries to the low back, the elbow, and the hand and wrist.4,16

The modern golf swing consists of five phases: the takeaway, the backswing, the downswing, acceleration, and follow-through.8 It has been proposed that the repetitive stresses applied during the backswing and follow-through phases contribute to the development of golf-related overuse injuries.17 The lead shoulder (the left shoulder for the right hand dominant golfer) tends to experience more injuries than the trailing shoulder.7-9,11 Impingement, rotator cuff disease, acromioclavicular joint pain, acromioclavicular osteoarthritis, and distal clavicular osteolysis have been reported in the golfer’s lead shoulder.4,8,18 Golfers may also be at risk for developing posterior glenohumeral instability.7,9

Posterior Glenohumeral Instability in Golfers

Posterior shoulder instability occurs less frequently than anterior shoulder instability accounting for only 2% to 12% of all glenohumeral instability cases.19-21 Traumatic and repetitive overuse mechanisms for the development of posterior shoulder instability have been reported in the literature.19,20,22,23 In contact sports, the mechanism for traumatic posterior shoulder instability is the result of a force directed toward the flexed, adducted, and internally rotated arm.20,24 Posterior shoulder instability may also be the result of attenuation of the posterior shoulder structures through repetitive mechanisms.19,25

Two investigations have reported the presence of posterior shoulder instability in "elite" golfers.7,9 Hovis et al7 retrospectively reviewed eight cases of golfers who were experiencing pain in the lead shoulder. Each "elite" golfer (handicap of 5 or less) reported experiencing pain and "a sense of instability at the top of the backswing (Figure 1) when their lead arm was fully adducted across the body."7 A diagnosis of posterior glenohumeral instability was established in each golfer’s lead shoulder with six of the eight also receiving a secondary diagnosis of subacromial impingement.7 Mallon and Colosimo7 published a retrospective review of 35 cases of shoulder injury in "elite" golfers. Each golfer was defined as either being a professional or a competitive golfer with a handicap of 3 or less.9 The lead shoulder was involved in 34 of the 35 cases with 12% of the patients experiencing posterior glenohumeral subluxation.9

Glenohumeral Joint Range of Motion Patterns in Overhead Athletes

Overhead athletes present with unique rotational range of motion (ROM) patterns.26-32 For example, javelin throwers and collegiate water-polo players tend to have significantly greater external rotation (ER) motion in their dominant (throwing) arm than their nondominant arm.20,29 Ellenbecker et al26 found elite junior tennis players demonstrate significantly less internal rotation (IR) motion with the dominant extremity. Range of motion patterns of the glenohumeral joint have been extensively researched in baseball pitchers.27,30,32-41 Baseball pitchers typically demonstrate increased passive ER range of motion that is significantly greater in the dominant throwing arm and significantly less passive IR range of motion in the throwing shoulder as compared with the contralateral side.27,30,32,38,39 It has been proposed that the repetitive stresses to the shoulder experienced by the overhead athlete may lead to attenuation of the anterior shoulder capsule and ligaments.39,40 While this may be the case in many of the aforementioned sports, recent published reports suggest that osseous adaptations may play a significant role in the ROM presentations in the baseball pitcher.32,33,34,37,41

For some overhead athletes the extremes of gleno-
humeral joint motion that occur during overhead sports activities increase their risk of injury to the shoulder.40,42 Appreciating the unique ROM patterns in competitive athletes may assist sports medicine professionals when developing injury prevention strength training programs and rehabilitation strategies for the injured athlete.43 While golf specific rehabilitation programs have been published in the literature, a paucity of injury prevention programs exist.42,44 Unfortunately, published reports of conservative treatment programs for golfer’s with a diagnosis of posterior shoulder instability has only helped to return a minority of athletes successfully back to sport.7,9 In response to failed conservative treatments physicians have prescribed nonsteroidal medication, injected the shoulder with steroids, and performed surgery to help return golfers back to sport.7,9

Pathomechanics of the Golf Swing
Previous reports have suggested that the biomechanics of the golf swing may contribute to the development of posterior shoulder instability.7,9 During the backswing phase, the golfer’s lead shoulder elevates and horizontally adducts (Figure 1). Mitchell et al45 found that the lead shoulder horizontally adducts during the golf swing upwards of 126º ± 7º.45 It is plausible that attenuation of the posterior structures of the lead shoulder may occur in response to performing a high volume of golf swings.

Hovis et al7 proposed that the development of posterior instability in elite golfers is a result of two factors: serratus anterior muscle fatigue and repetitive internal shoulder rotational forces created by subscapularis muscle activity.7 Kao et al46 utilizing dynamic electromyography and cinematography found that the serratus anterior muscle on the lead arm side is active during the entire swing4,46. Due to this fact, the serratus anterior muscle on the lead arm side is believed to be at risk of muscular fatigue during practice or competition.7,8,46 Muscular fatigue of the serratus anterior (or other scapular muscles) will affect the normal biomechanical relationship between the scapula and the humerus.7,46-48 Alterations to scapular position may impair the ability of the external rotators of the shoulder to provide stability at the glenohumeral joint.48 Hovis et al7 propose that continuing to play golf, in the presence of scapular muscular fatigue, will allow the subscapularis muscle to impart an internal rotation stress to the shoulder contributing to the attenuation of the posterior shoulder.

The purpose of this pilot study was to compare the passive rotational ROM patterns of the glenohumeral joint in the trailing (dominant) and lead (nondominant) shoulders in a group of elite golfers. To the date, the rotational range of motion patterns of the glenohumeral joint have not been studied in the elite golfer.

METHODS
Subjects
Twenty-four right hand dominant male golfers with a handicap of 5 or less (mean = 2.13; SD = 1.43) volunteered to participate in the study. The golfers, ranging in age from 24 to 57 years (mean = 39.67; SD = 9.78), were recruited at the Oregon Golf Association course in Woodburn, Oregon on June 3rd, 2006. A golfer was excluded from participation in the study if he had a handicap greater than 5, if he was experiencing a current episode of shoulder pain, or had a previous history of a traumatic shoulder injury or a surgical procedure to either shoulder. None of the subjects who volunteered were excluded. The Institutional Review Board of Pacific University approved this study prior to data collection; informed consent was obtained from each subject.

Procedure
The lead examiner, blinded to the lead shoulder of each golfer, performed all measurements. Range of motion testing was performed in a manner similar to other studies investigating range of motion patterns in athletic populations.27,30 Subjects were asked to lie in a supine position on a portable physical therapy treatment table. The shoulder was positioned in 90º of shoulder abduction with the elbow flexed to 90º and the forearm in a neutral position. Range of motion measurements were recorded using a standard universal goniometer. The axis of the goniometer was placed at the olecranon process with the stationary arm directed vertically and the moving arm aligned with the ulna.
Starting from a position of neutral shoulder rotation, the subject’s extremity was passively externally rotated with slight overpressure added at the end range to appreciate the end feel. The end feel, as defined by Cyriax, is the sensation experienced by the examiner at the terminal ROM during passive motion testing. Scapula stabilization was maintained through manual contacts on the anterior shoulder and from the weight of the subject’s body against the table. Once the limit of ER motion was achieved, the angle was measured. Passive internal rotation was performed in a similar manner with the tester internally rotating the extremity with a stabilizing force manually applied to the coracoid and anterior shoulder in order to prevent scapular movement. Three measurements were recorded for both IR and ER with means calculated for each.

Intrarater reliability was established prior to data collection. Passive shoulder external and internal rotation ROM was measured bilaterally in five elite-level golfers with 48 hours between the two tests. A paired t-test was used to analyze the passive range of motion for lead and trailing shoulders and total rotation range of motion. The alpha level was set at 0.05.

### RESULTS

Tables 1-3 present the passive range of motion measures for the entire group of elite golfers and by each age category. No significant differences existed between the lead and the trailing shoulders for either IR or ER passive ROM for the entire cohort or within each individual group. In addition, no significant difference for total rotation ROM existed between extremities for the entire group or within each individual group.

In general, ER passive ROM measurements were greater than internal rotation measurements in both extremities (Table 1). This relationship (ER > IR) was consistent throughout each age group (Table 2-3).

### DISCUSSION

If “elite” level golfers had an increased risk of posterior glenohumeral instability, it was thought that a statistically significant difference in either ER or IR motion between the lead and the trailing shoulder would be found. The results of this study demonstrate that within this sample of “elite” golfers, no significant difference existed between the lead and the trailing shoulder for either glenohumeral ER or IR passive ROM.

Several challenges were faced in attempting to research the “elite” golfer including subject recruit-

| Table 1. | Shoulder Passive Range of Motion Measurements for the 24 Male Elite Golfers. The right arm was the dominant (trailing) arm in all of the golfers. All PROM measurements recorded in degrees. NS = not significant. |
|---|---|---|---|---|
| | Mean (SD) | p Value | t value | Significance |
| **External Rotation** |  |  |  |  |
| Trailing Arm | 91.04° (7.85°) | p = .466 | t = .74 | NS |
| Lead Arm | 90.32° (6.54°) |  |  |  |
| **Internal Rotation** |  |  |  |  |
| Trailing Arm | 50.11° (9.34°) | p = .334 | t = -0.99 | NS |
| Lead Arm | 51.76° (10.40°) |  |  |  |
| **Total Rotation Range of Motion** |  |  |  |  |
| Trailing Arm | 141.15° (10.87°) | p = .61 | t = -0.53 | NS |
| Lead Arm | 142.08° (13.67°) |  |  |  |
ment and selecting which shoulder motions to measure. The first challenge encountered was recruiting a high number of “elite” golfers with a 5 or lower handicap. Team sports provide researchers a large subject population in a central location to test at one time. Unlike team sports, golf is an individual sport (except at the high school or collegiate level), allowing the golfer to practice and play whenever or wherever one chooses. This obviously increases the challenge of locating the target population.

Several options were discussed for obtaining our target population including recruiting golfers from local colleges, recruiting local golf professionals, and recruiting members from a local course. The greater Portland, Oregon region is devoid of NCAA division I universities, but has numerous smaller division III colleges. While golfers at these schools were readily accessible, their skill level consistently fell short of the “elite” definition (as defined in literature by Hovis et al7 as 5 or below). In addition, many of the division III collegiate golfers were unaware of their handicap level. Measuring the ROM of local golf professionals appeared to be a means to recruit subjects, but this endeavor would have been a too time intensive. Recruitment of golfers during one session at the Oregon Golf Association course was decided. Based upon professional contacts, it was determined that golfers at the Oregon Golf Association course would meet the inclusion criteria. Twenty four golfers participated in this study. Despite the limited time commitment to testing, some golfers declined participation. The subject population, based upon handicap level, is similar to those reported by Mallon et al9 and Hovis et al.7

The second challenge encountered was in deciding how many passive shoulder motions to measure. The initial goal for this study was to collect passive

<table>
<thead>
<tr>
<th>External Rotation</th>
<th>Mean</th>
<th>SD</th>
<th>p Value</th>
<th>t ratio</th>
<th>Significance</th>
</tr>
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<tbody>
<tr>
<td>Trailing Arm</td>
<td>90.36°</td>
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<td>p = .575</td>
<td>0.58</td>
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<td>Lead Arm</td>
<td>89.69°</td>
<td>5.43°</td>
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<td></td>
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<tr>
<td>Internal Rotation</td>
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</tr>
<tr>
<td>Trailing Arm</td>
<td>53.29°</td>
<td>8.73°</td>
<td>p = .362</td>
<td>-0.95</td>
<td>NS</td>
</tr>
<tr>
<td>Lead Arm</td>
<td>55.21°</td>
<td>10.97°</td>
<td></td>
<td></td>
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<tr>
<td>Total Rotational</td>
<td></td>
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<tr>
<td>Range of Motion</td>
<td></td>
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<tr>
<td>Trailing Arm</td>
<td>143.63°</td>
<td>12.00°</td>
<td>p = .60</td>
<td>-0.54</td>
<td>NS</td>
</tr>
<tr>
<td>Lead Arm</td>
<td>144.90°</td>
<td>14.53°</td>
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</tbody>
</table>

| Table 2. Shoulder Passive Range of Motion Measurements for Male Golfers Age Range 24 to 39 Years (n = 13). The right arm was the dominant (trailing) arm in all of the golfers. All PROM measurements recorded in degrees. NS = not significant. |

<table>
<thead>
<tr>
<th>External Rotation</th>
<th>Mean</th>
<th>SD</th>
<th>p Value</th>
<th>t ratio</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trailing Arm</td>
<td>91.85°</td>
<td>8.17°</td>
<td>p = .653</td>
<td>0.46</td>
<td>NS</td>
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<td>Lead Arm</td>
<td>91.00°</td>
<td>7.86°</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Internal Rotation</td>
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<td></td>
</tr>
<tr>
<td>Trailing Arm</td>
<td>46.37°</td>
<td>9.00°</td>
<td>p = .654</td>
<td>-0.46</td>
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<tr>
<td>Lead Arm</td>
<td>47.69°</td>
<td>8.42°</td>
<td></td>
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<tr>
<td>Total Rotational</td>
<td></td>
<td></td>
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<tr>
<td>Range of Motion</td>
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</tr>
<tr>
<td>Trailing Arm</td>
<td>138.22°</td>
<td>9.01°</td>
<td>p = .853</td>
<td>-0.19</td>
<td>NS</td>
</tr>
<tr>
<td>Lead Arm</td>
<td>138.76°</td>
<td>12.40°</td>
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</table>

| Table 3. Shoulder Passive Range of Motion Measurements for Male Golfers Age Range 40 Years or Older (n = 11) The right arm was the dominant (trailing) arm in all of the golfers. All PROM measurements recorded in degrees. NS = not significant. |
ROM measurements bilaterally for shoulder ER, IR, and horizontal adduction. Based upon where and how to conduct the study, it was decided to only measure glenohumeral ER and IR for this pilot investigation. These measurements can be performed quickly with minimal positional changes and minimal equipment requirements. It was believed that conducting the horizontal adduction measures might affect the recruitment potential of volunteers due to the time requirements associated with the positional changes and additional measurements. Adequate testing environment (space, equipment, and staff) to appropriately perform the horizontal adduction measurements would also have been a challenge.

Future research is suggested to build upon this investigation by testing bilateral glenohumeral rotation ROM patterns as well as horizontal adduction. Recruiting subjects from the professional ranks, NCAA division I schools, and from the American Junior Golf Association is also suggested. Reported ROM patterns observed in golfers may be the result of age specific changes versus sport related adaptations. Compared to other team and individual sports, golf can be “picked up” with participants achieving success (low handicap) at any age. Range of motion patterns observed in the 30-, 40- or 50-year old “elite” golfer may be due to sport or occupational pursuits from an earlier age. Range of motion patterns should also be investigated in junior and collegiate aged golfers, excluding those who had previous participation in overhead sports. If unique ROM patterns were identified in these populations then subsequent longitudinal testing should be conducted.

CONCLUSION
This study was an initial investigation of the anthropometric characteristics of the shoulders in “elite” golfers. The results demonstrated no statistical difference between extremities for each rotation pattern. Further testing is warranted to measure additional shoulder measures in specific “elite” golfer samples. A comprehensive appreciation of the golfers’ shoulder may lead to advances in injury prevention training strategies and rehabilitation programs.

REFERENCES


ABSTRACT

Background. Shoulder muscle imbalance is a potential shoulder injury risk factor in athletes performing overhead sports. While normative functional peak strength of concentric external to concentric internal shoulder muscle fatigue data is available, comparisons of functional eccentric external to concentric internal shoulder rotator muscle fatigue resistance, which impacts muscle imbalance throughout the duration of play, have not been studied in this population.

Objectives. To assess fatigue resistance of the internal and external shoulder rotator muscles in female tennis players.

Methods. Fifteen female collegiate tennis players were tested bilaterally for shoulder concentric internal and eccentric external peak torque production throughout 20 maximal repetitions on a Kin-Com isokinetic dynamometer. Twelve t-tests were conducted to evaluate for differences in peak torque, relative fatigue ratios, and functional peak torque ratios between extremities and mode of activation during the first, as well as, last five repetitions that were conducted.

Results. Non-dominant concentric internal and eccentric external peak torque production significantly decreased throughout the twenty repetitions. Neither dominant concentric internal peak torque decrements and eccentric peak torque decrements were not significantly different across the twenty contractions.

These changes in peak torque upon subsequent repetitions resulted in relative fatigue ratios of dominant eccentric external rotation that were significantly greater than non-dominant eccentric external rotation. Relative fatigue ratios of dominant concentric internal rotation did not differ from non-dominant concentric internal rotation.

Conclusions. The data suggest that eccentrically activated external shoulder rotator muscles could possibly adapt to overhead activities by becoming more fatigue resistant.

Key Words: muscular fatigue, muscle imbalance, injury risk factor

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INTRODUCTION
Shoulder muscle imbalance, indicated by a low external to internal shoulder rotator muscle strength ratio, has been observed in patients with glenohumeral joint instability and impingement and is considered to be a shoulder injury risk factor for athletes performing overhead activities. Early studies on amateur, elite junior, as well as professional tennis players have isokinetically assessed the shoulder rotator musculature concentrically, showing that shoulder muscle imbalance often occurs as the result of an adaptation to frequent overhead motions, which causes greater increases in concentric internal rotator strength than in concentric external rotator strength.

While assessment of concentric internal and concentric external shoulder rotator strength provided early isokinetic normative values, researchers increasingly acknowledged the need to test the strength of the external shoulder rotator musculature eccentrically, which is the dominant mode of activation of the external shoulder rotator muscles during overhead motions. McCarrick and Kemp showed that while mean peak torque of the internal rotator muscles was similar when tested eccentrically as compared to concentrically, eccentric external rotation mean peak torque was significantly greater as compared to concentric external rotation mean peak torque. Consequently, functional muscle eccentric external to concentric internal rotation strength ratios were found to be significantly greater than concentric external to concentric internal strength ratios in athletes performing overhead activities. Data by Noffal further supported these findings leading to the suggestion that functional eccentric assessments of the external rotation muscles rather than concentric assessment might be a better identifier of possible muscular imbalance. Normative data of eccentric and concentric peak strength of internal and external rotation, as well as functional ratios have since been published for various groups of athletes. Results vary depending on sex, angular velocity, range of motion and testing position, as well as the type of athletic involvement of the subjects.

In contrast to the growing body of normative peak strength data, very few studies have attempted to assess isokinetic muscular fatigue of the shoulder internal and external rotator musculature. as well as Ellenbecker and Roetert assessed concentric internal and concentric external fatigue of the shoulder rotator muscles and found that concentrically activated external rotator muscles fatigue faster than concentrically activated internal rotator muscles. These authors suggested that shoulder muscle imbalances increase upon prolonged activity, thereby, potentially increasing the risk of injury to the athlete throughout the duration of play.

Furthermore, only one study is currently available that assessed relative fatigue of eccentrically activated external shoulder rotator muscles on athletes who did not perform overhead activities. Similar to the studies that assessed concentric external shoulder rotator muscle fatigue, the study by Mullaney and McHugh showed no significant difference in fatigue of the concentrically activated internal rotator muscles versus eccentrically activated external rotator muscles in athletes participating in recreational sports. Data on eccentric fatigue of the external rotator muscles in comparison to concentric internal rotator muscle fatigue in athletes performing overhead activities, however, was not reported. Since such a functional fatigue ratio potentially provides a better indicator of the change in shoulder muscle imbalance throughout the duration of play and, hence, is a potential predictor for sustaining shoulder injuries, normative data on functional relative fatigue ratios in athletes performing overhead activities are warranted. The purpose of this study was to assess the effects of fatigue on concentric internal and eccentric external shoulder rotation strength in a group of female collegiate tennis players.

METHODS
Subjects
Fifteen collegiate Division II and National Association of Intercollegiate Athletics tennis players without a history of previous shoulder injury were recruited for this study (Table 1). All subjects completed a brief personal history form including age, years played, and arm used to serve. Weight and height measurements were also recorded. The study was approved by the Institutional Review Board of Indiana at the University of Pennsylvania. Informed consent was obtained and the rights of all subjects were protected prior to and after the data collection process.

Assessing Isokinetic Shoulder Strength
Assessment of muscular strength was conducted using the Kin-Com AP Muscle Testing System (Chattecx Corp., Hixson, Tennessee). Testing employed maximum contractions during concentric internal and eccentric external shoulder rotation. An angular velocity of 120°/second was selected to minimize variance as well as to reduce the risk of injury to the subjects. The subjects completed 10 submaximal contractions to familiarize themselves with the procedure and to aid in a specific neuromuscular warm-up.
Throughout the assessment, the subjects were seated without the legs touching the ground and the trunk secured to the chair. To approximate shoulder and elbow positioning throughout an actual overhead motion and in accordance with previous studies, the shoulder was abducted to 90° and the elbow was flexed to 90°.6,7,11,20 The elbow was then secured in a custom-made support. The range of motion completed during the test was between 90° external rotation and 30° internal rotation. While the external range of motion stop was chosen based on prior studies,11,21 the internal range of motion stop was chosen based on established passive range of motion limits that were as low as 30° of internal rotation for some of the subjects. Hence, greater internal rotation range of motion stops during isokinetic testing as employed in prior studies 11,21 would have increased the risk of injury to the subjects and were, consequently, avoided. Imitating the sequence of muscle involvement in a serve, concentric internal rotation was decided upon to always be tested first, immediately followed by eccentric external rotation. Each subject performed 20 maximal contractions during the test. To calculate a relative fatigue ratio, the total peak torque produced in the last five repetitions was divided by the total peak torque produced throughout the first five repetitions.

**Data Analysis**

Means (± standard deviations) of isokinetic peak torque on the dominant and non-dominant extremity were calculated for each condition. Twelve t-tests were conducted to evaluate for differences in peak torque, relative fatigue ratios, and functional peak torque ratios between extremities and mode of activation during the first, as well as last five repetitions that were conducted. A Bonferroni adjustment was used to correct for the multiple comparisons. Originally, the data were considered significantly different at the 0.05 level if the p value was less than 0.05/12 = 0.00416 within any of the subsets.

**RESULTS**

**Peak Torque Protection**

The results of eccentric external and concentric internal isokinetic peak torque on the dominant and non-dominant extremity are summarized in Table 2. The data of the following t-test discussion are provided in Table 3.

Subjects showed a tendency to reach a lower peak torque during eccentric external rotation on the dominant extremity (15.42 ± 4.46) than on the non-dominant extremity (17.78 ± 2.94; t = 2.946; df = 14, p = 0.0053) but the difference was not significant. Concentric internal rotation peak torque was not significantly different between extremities (dominant internal rotation 13.98 ± 3.05; non-dominant internal rotation 15.58 ± 2.78; t = 1.464; df = 14, p = 0.0826).

Throughout the twenty repetitions, concentric internal and eccentric external peak torque production on the non-dominant extremity significantly decreased (p ≤ 0.008). Concentric internal peak torque decrements on the dominant extremity were not significant (Mean ± standard deviation: dominant internal rotation 1-5 = 13.98 ± 3.05, dominant internal rotation 15-20 = 12.08 ± 2.80; p = 0.0092), and dominant eccentric external peak torque did not significantly change upon subsequent

<table>
<thead>
<tr>
<th>Table 1. Subjects demographics (n=15)</th>
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<tbody>
<tr>
<td>Subject</td>
</tr>
<tr>
<td>Age</td>
</tr>
<tr>
<td>Years Played</td>
</tr>
<tr>
<td>Weight [kg]</td>
</tr>
<tr>
<td>Height [cm]</td>
</tr>
<tr>
<td>BMI* [kg/m²]</td>
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</table>

* body mass index

**Table 2. Mean concentric internal rotation and eccentric external rotation peak torques, of the dominant and non-dominant extremity during the first and last five repetitions.**

<table>
<thead>
<tr>
<th>Peak Torque [Nm]</th>
<th>Mean ± S.D.</th>
<th>Range</th>
<th>Mean ± S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1R 1-5</strong></td>
<td>13.98 ± 3.05</td>
<td>8.51 – 18.48</td>
<td>15.58 ± 2.78</td>
<td>10.12 – 20.46</td>
</tr>
<tr>
<td><strong>1R 15-20</strong></td>
<td>12.18 ± 2.80</td>
<td>7.36 – 17.25</td>
<td>12.75 ± 1.75</td>
<td>10.40 – 16.80</td>
</tr>
<tr>
<td><strong>ER 1-5</strong></td>
<td>15.42 ± 4.46</td>
<td>8.51 – 26.62</td>
<td>17.78 ± 2.94</td>
<td>13.20 – 25.52</td>
</tr>
<tr>
<td><strong>ER 15-20</strong></td>
<td>15.15 ± 4.41</td>
<td>8.80 – 27.50</td>
<td>14.57 ± 2.48</td>
<td>10.08 – 18.04</td>
</tr>
<tr>
<td><strong>ER / IR Ratio 1-5</strong></td>
<td>1.11 ± 0.24</td>
<td>0.70 – 1.73</td>
<td>1.19 ± 0.41</td>
<td>0.78 – 2.50</td>
</tr>
<tr>
<td><strong>ER / IR Ratio 15-20</strong></td>
<td>1.27 ± 0.37</td>
<td>0.75 – 0.37</td>
<td>1.17 ± 0.25</td>
<td>0.86 – 1.48</td>
</tr>
</tbody>
</table>

**D** = dominant extremity, **ND** = non-dominant extremity, **IR** = concentric internal rotation, **ER** = eccentric external rotation.
repetitions, as well (dominant external rotation 1-5 = 15.42 ± 4.46. dominant external rotation 15-20 = 15.15 ± 4.41; p = 0.3444).

Relative Fatigue Ratios and Functional Peak Torque Ratios
While the relative fatigue ratios for concentric internal rotation of the dominant extremity (88.78 ± 20.03) were not significantly different from the relative fatigue ratios for concentric internal rotation on the non-dominant extremity (84.08 ± 18.13; t = 0.590; df = 14; p = 0.2822), relative fatigue ratios for eccentric external rotation on the dominant extremity (100.48 ± 21.76) were significantly less than relative fatigue ratios for eccentric external rotation on the non-dominant extremity (82.71 ± 13.25; t = 3.151; df = 14; p = 0.0035). Additionally, dominant extremity eccentric external rotation peak torque (100.48 ± 21.76) showed a tendency to decrease less than concentric internal rotation peak torque (88.78 ± 20.03; t = 2.387; df = 14; p = 0.0158). Decrements in eccentric external rotation peak torque on the non-dominant extremity (82.71 ± 13.25) were not significantly different from decrements in concentric internal rotation peak torque (84.08 ± 18.13; t = 0.210; df = 14; p = 0.4184). As a result, eccentric external rotation to concentric internal rotation peak torque ratios on the dominant extremity during the last five repetitions tended to increase from 1.11 ± 0.24 to 1.27 ± 0.37 (t = 2.515; df = 14; p = 0.0124) whereas eccentric external to concentric internal rotation peak torque ratios on the non-dominant extremity did not change (non-dominant external rotation / internal rotation Ratio 15-20: 1.17 ± 0.25; non-dominant external rotation / internal rotation Ratio 1-5: 1.19 ±

<table>
<thead>
<tr>
<th>Measurement</th>
<th>t stat</th>
<th>p</th>
</tr>
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<tbody>
<tr>
<td>Peak Torque</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DER 1-5</td>
<td>2.946</td>
<td>0.0053</td>
</tr>
<tr>
<td>DIR 1-5</td>
<td>1.464</td>
<td>0.0826</td>
</tr>
<tr>
<td>DIR 1-5</td>
<td>2.670</td>
<td>0.0092</td>
</tr>
<tr>
<td>NDIR 1-5</td>
<td>3.900</td>
<td>0.0008*</td>
</tr>
<tr>
<td>DER 1-5</td>
<td>0.0409</td>
<td>0.3444</td>
</tr>
<tr>
<td>NDIR 1-5</td>
<td>4.954</td>
<td>0.0002*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relative Fatigue Ratios (15-20 / 1-5)</th>
<th></th>
</tr>
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<tbody>
<tr>
<td>DIR</td>
<td>0.590</td>
</tr>
<tr>
<td>DER</td>
<td>3.151</td>
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<tr>
<td>NDIR</td>
<td>2.387</td>
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<table>
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<tr>
<th>Functional Peak Torque Ratios (Eccentric External/Concentric Internal)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>D 1-5</td>
<td>2.515</td>
</tr>
<tr>
<td>D 15-20</td>
<td>0.257</td>
</tr>
</tbody>
</table>

Table 3. t-test evaluations of peak torque, relative fatigue ratios and functional peak torque ratios between extremities and mode of activation during the first and last five repetitions that were conducted

DISCUSSION
The subjects in this study exhibited weakness of eccentric external rotation on the dominant extremity compared to the non-dominant extremity. This weakness is in accordance with findings of previous studies on eccentric external peak torque differences between the dominant and non-dominant extremity in athletes performing overhead activities and is thought to be an adaptation to frequent overhead motions.10,22 Increased concentric internal peak torque in the dominant extremity, another common adaptation to frequent overhead motions,6,10 was not observed in this study. Conversely, athletes in this study tended to display increased fatigue resistance of the eccentrically activated external rotator muscles compared to the concentrically activated internal rotator muscles on the dominant extremity. Moreover, fatigue resistance of the eccentrically activated external rotator muscles on the dominant extremity was significantly increased as compared to the non-dominant extremity.

The present study is the first available study to observe greater fatigue resistance of the eccentrically activated external rotator muscles of the dominant extremity in athletes performing overhead activities and stands in contrast to previous findings on fatigue resistance of the shoulder rotator muscles.4,16,17 Previous studies by Ellenbecker et al16 and Chandler et al,4 however, differed from this study as their assessment employed concentric instead of eccentric contractions of the external rotator muscles as well as several other varying parameters of angular velocity and range of motion being assessed.
Employing concentric external contractions at an angular velocity of 300°/sec, the study by Ellenberger et al\textsuperscript{14} demonstrated decreased fatigue resistance of the concentrically activated external rotator muscles as compared to the concentrically activated internal rotator muscles. Furthermore, no difference in concentric external fatigue resistance of the contralateral extremity was observed.\textsuperscript{15} Similarly, the study by Chandler et al\textsuperscript{4} which assessed fatigue of the shoulder rotator muscles on the dominant extremity only, also employed concentric contractions of the external rotator muscles at an angular velocity of 300°/sec. That particular study observed no difference in fatigability between the concentrically activated external and internal rotator muscles.

The only available study on fatigue resistance of concentrically activated internal rotator muscles together with eccentrically activated external rotator muscles by Mullaney et al\textsuperscript{17} focuses on a group of 10 non-athletes. In that study, fatigue resistance was determined by the change in peak torque between the first and last five of a total of 32 repetitions at an angular velocity of 120°/sec. Like Ellenberger et al\textsuperscript{14} and Chandler et al,\textsuperscript{4} Mullaney et al\textsuperscript{17} did not observe a significant difference in fatigue of the eccentrically activated external rotator muscles versus the concentrically activated internal rotator muscles. Since Mullaney et al\textsuperscript{17} accessed the dominant extremity only, no statements could be made regarding fatigue resistance of the eccentrically activated external rotator muscles on the dominant as compared to the non-dominant extremity.

Considering that fatigue ratios for concentric internal rotation in the present study were similar to those observed in prior studies, the authors hypothesize that the greater relative fatigue ratios for eccentric external rotation observed in this study were primarily due to the eccentric instead of concentric mode of activation of the external rotator muscles, rather than varying ranges of motion, angular velocities, or positioning of the body. This hypothesis is supported by previous studies that showed that muscular adaptations are contraction specific. McCarrick et al\textsuperscript{18} for example, showed that mean peak torque of the external rotator muscles is increased after a 12 week resistance training program if tested eccentrically but not if tested concentrically. Based on this finding, as well as the present data, the authors suggest that eccentric fatigue measures instead of concentric fatigue measures of the external rotator muscles might provide rehabilitation professionals with further functional data of shoulder muscle fatigue relevant to athletes performing overhead activities.

Furthermore, the authors hypothesize that the difference in fatigue of the eccentrically activated external rotator muscles on the dominant extremity observed in this study compared to the study by Mullaney et al\textsuperscript{22} could be attributed to specific adaptations of the shoulder rotator musculature in response to frequent overhead motions among the present group of tennis players versus the group of non-athletes studied by Mullaney et al.\textsuperscript{22} Such an eccentric external rotation fatigue resistance in these athletes performing overhead activities would be in accordance with previously reported data on eccentric fatigue resistance of the knee extensors, plantarflexors and the dorsiflexors. Tesch et al\textsuperscript{23} showed a 34 - 47% decrement in strength during 96 concentric contractions of the knee extensors without any fatigue occurring during 96 eccentric contractions. Hortobagyi et al\textsuperscript{24} found fatigue of the plantarflexors during 50 maximal isometric and concentric contractions to be 41% and 32%, respectively, but found no change in force during 50 eccentric contractions. Eccentric fatigue resistance was also observed in dorsiflexors with a strength decrement of 31.6% during concentric contractions but only 23.8% during eccentric contractions.\textsuperscript{25} All of these cases of eccentric fatigue resistance have been found in the lower extremity and concern segments that are trained in daily activities such as walking, jogging, or biking. Eccentric fatigue resistance could be hypothesized to be an adaptation to regular eccentric activation of a given muscle, suggesting that it might also be a prevalent adaptation in athletes performing overhead activities which is absent in athletes who do not perform overhead activities.

Assuming that the present data provides an accurate reference of functional muscle fatigue during repetitive overhead motions, the authors make the following conclusions. First, since muscle fatigue of the eccentrically activated external rotator muscles have not been found to be greater than muscle fatigue of the concentrically activated internal rotator muscles, perhaps, muscle balance is not exacerbated throughout repetitive overhead motions, and appears that no need exists for further exercises to improve fatigue resistance of the external rotator muscles in healthy athletes. Second, peak torque muscle strength imbalance assessments during only a few repetitions can potentially be used to assess a healthy athlete’s possible risk of injury due to muscle imbalance without having to consider a potentially increased risk due to differential fatigue throughout prolonged overhead activities. Finally, increased fatigue resistance of the eccentrically activated external rotator muscles might be an adaptation to frequent overhead activities that protects the athlete performing overhead activities from overuse injuries to the shoulder. More research is warranted regarding the role of increased fatigue resistance of the eccentrically activated external rotator muscles in injury prevention. Potentially, athletes returning to overhead activities after shoulder
injury could benefit from specific strength training to increase fatigue resistance of the eccentrically activated external rotator muscles. Lastly, testing of relative fatigue ratios of concentric internal and eccentric external rotator strength could possibly be applied to evaluate a rehabilitating athlete’s readiness to return to the sport.

CONCLUSION
Contrary to previous studies, this study was the first to show increased fatigue resistance of the eccentrically activated external shoulder rotator muscles in adult and uninjured athletes performing overhead activities. The authors hypothesize that this adaptation might protect athletes performing overhead activities from sustaining overuse shoulder injuries. Athletes returning to play after injury might benefit from specific strength training exercises to increase fatigue resistance of the eccentrically activated external rotator musculature. Isokinetic testing of fatigue resistance of the shoulder rotator musculature might also be useful to determine an athlete’s readiness to return to competition.

REFERENCES
ABSTRACT

Objectives. To measure short-term post surgery glenohumeral internal and external rotation strength, shoulder range of motion (ROM), and subjective self-report ratings following arthroscopic superior labral (SLAP) repair.

Background. Physical therapists provide rehabilitation for patients following arthroscopic repair of the superior labrum. Little research has been published regarding the short-term results of this procedure while the patient is typically under the direct care of the physical therapist.

Methods. Charts from 39 patients (7 females and 32 males) with a mean age of 43.4±14.9 years following SLAP repair were reviewed. All patients underwent rehabilitation by the same therapist using a standardized protocol and were operated on and referred by the same orthopaedic surgeon. Retrospective chart review was performed to obtain descriptive profiles of shoulder ROM at 6 and 12 weeks post surgery and isokinetically documented internal and external rotation strength 12 weeks post surgery.

Results. At 12 weeks post-surgery, involved shoulder flexion, abduction, and external rotation active ROM values were 2-6 degrees greater than the contralateral, non-involved extremity. Isokinetic internal and external rotation strength deficits of 7-11% were found as compared to the uninjured extremity. Patients completed the self-report section of the Modified American Shoulder Elbow Surgeons Rating Scale and scored a mean of 37/45 points.

Conclusion. The results of this study provide objective data for both glenohumeral joint ROM and rotator cuff strength following superior labral repair at time points during which the patient is under the direct care of the physical therapist. These results show a nearly complete return of active ROM and muscular strength following repair of the superior labrum and post-operative physical therapy.

Key Words: glenohumeral joint, labrum, rehabilitation

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Tetsuro Sueyoshi, ATC
Matthew Winters, DPT
David Zeman, MD
INTRODUCTION

The glenoid labrum serves several important functions including deepening the glenoid fossa to enhance the concavity and serving as the attachment for the glenohumeral capsular ligaments. Injury to the labrum can compromise the concavity compression phenomena by as much as 50%. Individuals with increased capsular laxity and generalized joint hypermobility have increased humeral head translation which can subject the labrum to increased shear forces. In the athlete performing overhead throwing, large anteriorly directed translational forces are present at levels up to 50% of body weight during arm acceleration of the throwing motion with the arm in 90 degrees of abduction and external rotation. This repeated translation of the humeral head against and over the glenoid labrum can lead to labral injury. Labral injury can occur as either tearing or as actual detachment from the glenoid and can occur in virtually any location around the circumference of the glenoid fossa. Two of the most common areas for labral detachment encountered by physical therapists in orthopaedic and sports rehabilitation are the Bankart and SLAP lesion. In 1906, Perthes was the first to describe the presence of a detachment of the anterior inferior labrum in patients with recurrent anterior instability. Bankart initially described a method for surgically repairing this lesion that now bears his name.

In addition to labral detachment in the anterior inferior aspect of the glenohumeral joint, similar labral detachment can occur in the superior aspect of the labrum and have been defined as superior labrum anterior posterior (SLAP) lesions. Snyder et al classified superior labral injuries into four main types. Type I shows labral degenerative changes and fraying at the edges, but no distinct avulsion. Type II are the most commonly reported superior labral injuries and have been described as complete labral detachment from anterosuperior to posterosuperior glenoid rim with instability of the biceps long head tendon noted. Morgan et al have further sub-classified the type II superior labral lesion into type II anterior, type II posterior and type II anterior and posterior. Of significance is the increased (three times more) likelihood of type II posterior or SLAP lesions in athletes that throw, as well as the finding of the Jobe subluxation relocation test as the most accurate and valuable test to identify the type II posterior lesion. Type II anterior SLAP lesions are most commonly associated with trauma and are less likely to be found in athletes performing overhead activities. A type III labral injury involves the displacement of the free margin of the labrum into the joint in a bucket-handle type fashion with no instability of the biceps long head tendon noted. A type IV labral lesion is similar to a type III lesion with a bucket handle displacement of the glenoid labrum, however, a type IV lesion involves a partial rupture in the direction of its fibers of the the biceps long head tendon.

Consequences of a superior labral injury include significant losses in the static stability of the human shoulder. Cheng and Karzel demonstrated the important role the superior labrum and biceps anchor play in glenohumeral joint stability by experimentally creating a SLAP lesion between the 10 and 2 o’clock positions in cadaveric shoulders. They found 11 to 19% decreases in the glenohumeral joints ability to withstand rotational force, as well as 100 to 120% increases in strain on the anterior band of the inferior glenohumeral ligament after a SLAP lesion. These changes demonstrate a significant increase in the load on the capsular ligaments in the presence of superior labral injury.

Arthroscopic surgical repair of the detached superior labral lesion has evolved from the use of bioabsorbable tacs to the use of direct suture techniques using suture anchors. Cadaveric research has shown that increases in glenohumeral translation created with experimentally induced labral detachment are only partially restored during repair of the human labrum. Patients are referred to physical therapy following arthroscopic SLAP repair to restore both range of motion and important muscular strength to provide dynamic stabilization following the repair.

The purpose of this descriptive study was to objectively measure and report shoulder range of motion (ROM) and muscular strength following arthroscopic SLAP repair the results of the study will show the effectiveness of rehabilitation using a standardized rehabilitation protocol.

METHODS

Patients

A retrospective review was undertaken of patients who underwent arthroscopic SLAP repair and were referred to Physiotherapy Associates Scottsdale Sports Clinic over a three year period (2003-2006) for rehabilitation by the senior author (TE) using a standard rehabilitation protocol for
rehabilitation following superior labral repair (Appendix). Subjects were not included in the chart review if concomitant procedures were performed including rotator cuff repair, thermal capsulorrhapsy, or capsular plication. To be included in the study, subjects had to be free from injury or surgery in the contralateral extremity as that extremity served as the baseline for bilateral testing in this investigation. To be included in this study, subjects had to have a type II labral tear which required arthroscopic surgical repair using direct suture technique and suture anchors. Patients with labral debridement were not included in this investigation. The research procedure was reviewed and approved by the Institutional Review Board of Physiotherapy Associates (Memphis, TN).

Rehabilitation Program
Additional information regarding the post-operative rehabilitation protocol is described to provide insight into the specific treatment each patient received following the arthroscopic SLAP repair. Sling use was directed by the physician with the recommendation for use in precarious situations (such as when outside the home or work environment) and to provide comfort. No specific objective criterion were used to monitor and direct sling use. Due to the possible attenuation of the superior labral repair during forceful muscular contraction of the biceps brachii, patients were instructed to avoid lifting objects and to wear the sling to prevent and minimize biceps muscle contraction in the immediate post-operative period. The time interval between surgery and the initial visit of physical therapy post surgery was 2.6 ± 1.93 weeks for the 39 patients in this study. Patients were given instructions for gentle active assistive ROM including Codman’s pendulum exercises by the referring physician to perform until reporting for their initial post surgical rehabilitation visit.

Early passive, active assistive, and active ROM and gleno-humeral joint mobilization was initiated in all planes of motion. Basic science research has provided guidance to the provision of early range of motion for patients following superior labral repair. Morgan and Burkhart14 have identified the concept of the “peel back” mechanism. (Figure 1) The peel back mechanism occurs with the gleno-humeral joint in 90 degrees of abduction and external rotation; in a position simulating the throwing motion. In this position, the biceps tendon force vector has been found to assume a more vertical and posterior direction creating the peel back of the superior labrum.

In the first 6 weeks following surgery, all patients were not placed in the abduction - external rotation position with any external load applied to minimize the effects of the peel back mechanism. Kuhn et al15 tested cadaveric specimens in the abduction-external rotation “peel back position” as well as simulating the “follow-through phase” of the throwing motion (60 degrees abduction and 15 degrees horizontal adduction). They found significantly less load to failure of the biceps labral complex in the peel back position as compared to the follow-through position, thereby, supporting the vulnerability of the shoulder and, specifically, the biceps labral complex in the abducted externally rotated position. Glenohumeral external rotation range of motion and stretching was performed in 0-45 degrees of abduction during this time period. Terminal ranges of motion were targeted in all other planes of motion using primarily physiologic mobilization and end range stretching techniques. The use of
Accessory mobilization during this time period was limited to minimize glenoid shear over the repaired labral structure.

Patients also performed active assistive range of motion on a multiple daily basis (2-3 times a day) at home using an overhead pulley to address elevation range of motion in the scapular plane. In addition, a stick or cane was used in the supine position.

In the early post-surgical phase (weeks 1-3) submaximal resistive exercise was initiated for the rotator cuff. The primary movements initiated were internal and external rotation, and prone shoulder extension and horizontal abduction. These movements were targeted due to activation of the infraspinatus, teres minor, and subscapularis muscles and use of protective positions below 90 degrees of elevation, short lever arms, and positioning of the glenohumeral joint in or anterior to the scapular plane. Use of low level Thera-band tubing (Hygenic Corp, Akron, OH) and little or no added weight to the extremity was recommended initially to minimize substitution. Moncrief et al have shown how the use of these resistive exercise patterns can lead to increases in rotator cuff strength using a low resistance high repetition format utilized in this study.

In the early post-operative rehabilitation phase, patients performed isolated manual resistance of the scapula in the motions of protraction and retraction. Exercises emphasizing scapular retraction and depression were given to recruit the serratus anterior and lower trapezius force couple without the use of rowing and other traditional scapular exercises that utilize substantial elbow flexion muscle activity. Use of early active shoulder flexion in the balance point position refers to the use of a supine patient position with the extremity in 90 degrees of flexion. In this position the patient is able to balance their extremity with minimal muscular activation and perform short active motions of flexion and extension and horizontal abduction/adduction with the therapist guiding the patient’s ROM. At 6 weeks post surgery, progression of the balance point work to the integration of rhythmic stabilization to this balance point position is also followed using the command “hold, don’t let me move you” while the patient holds the 90 degree flexed extremity stabilizing against external challenges in multiple directions of movement by the therapist. A position of scapular protraction or “plus” position is employed with this exercise, as well, based on the concepts of Mosley et al and Decker et al to increase activation of the serratus anterior.

The use of shoulder flexion initially in an active assistive role and then active and eventually resisted role is warranted based on the work of Yamaguchi et al and Levy et al. These studies have shown minimal levels (1.7-3.6% of maximal voluntary contraction) of muscle activation of the biceps long head during multiple directions of shoulder movement such as scapular plane elevation and gleno-humeral rotational movements. This basic science research helps to differentiate early exercise and active range of motion patterns for clinicians to utilize while protecting the repaired superior labrum and biceps long head anchor. Resistive exercise for the elbow flexors is delayed until between 6-8 weeks post-surgery and is applied in the form of rowing variations, upper body ergometry, and isolated elastic and isotonic resistance exercise.

At 10-12 weeks post-surgery, patients were introduced to the isokinetic dynamometer at submaximal intensities. The accommodative resistance, ability to exercise via a sequence of progressively increasing contractile velocities, and objective feedback all provide the rationale for inclusion of this type of resistive exercise. Additionally, previous studies have reported significant increases in glenohumeral joint internal and external rotation following isokinetic training. Upper extremity plyometrics were also introduced during this time interval to provide both concentric and eccentric muscle activation.

Outcome Measures

Variables included in the retrospective review were, subject age, dominant arm, estimated time from injury to surgery, time from surgery to initiation of physical therapy, as well as objective measures of ROM and strength. Range of motion was measured passively in the supine position at 6 weeks post-surgery for forward flexion and abduction with a universal goniometer and standardized measurement techniques. Internal and external rotation was measured actively with 90 degrees of glenohumeral joint abduction and scapular stabilization. At 12 weeks post-surgery, active ROM measurements were taken with the subject in a seated position such that antigravity forward elevation and abduction were measured, in addition to supine active internal and external rotation with 90 degrees of abduction with scapular stabilization. The
identical active ROM procedure was used to document the ROM of the uninjured extremity during the initial post-operative evaluation. Measurements were recorded to the nearest degree. All measures were taken by the senior author as part of the rehabilitation process with prior test-retest reliability of the glenohumeral joint rotational measures published previously.30

Isokinetic strength testing was performed on all 39 patients 12 weeks post-surgery using a Cybex 6000 Isokinetic dynamometer (Stoughton, MA). Testing was performed with the patient in a standing position with the dynamometer placed in 30 degrees of tilt from the horizontal base position and placed the patient's shoulder in 30 degrees of elevation in the scapular plane.26 A ROM of 70 degrees of internal rotation and 30 degrees of external rotation was set using ROM stops. Four gradient (ie 50, 75, 90 and 100% of maximal effort) submaximal warm-up repetitions were used followed by five maximal effort repetitions for data collection at the testing speeds of 90, 210 and 300 degrees per second with 30 seconds rest between testing speeds followed. Testing was performed at three test speeds to provide information from the patient's ability to generate resistance at slow, intermediate, and a fast testing speed. Testing was performed on the uninjured extremity first without randomization of testing speed sequence to enhance reliability.32

Following testing on the uninjured extremity, identical set-up and testing procedures were used on the post-operative extremity. Isokinetic parameters chosen to represent muscular strength in this sample were the single repetition work value calculated by the Cybex 6000 software as the area under the torque curve versus joint angle curve for the best repetition of the five performed by the subject. Additionally, the external/internal rotation unilateral strength ratio was recorded as calculated by the Cybex 6000 software by dividing the external rotation work value obtained at each speed by the corresponding internal rotation value. The reliability of the Cybex 6000 concentric isokinetic dynamometer has been previously published,33 as has the reliability specific to the application of isokinetic testing to the glenohumeral joint.34

The self report section of the modified American Shoulder Elbow Surgeons (ASES) rating scale was administered at 12 weeks post-surgery.35,36 Patients answered the series of 15 questions following standardized instructions estimating their ability to perform the activities with their injured extremity at the instrument was completed. Each patient's responses were tallied to form a composite score against 45 possible points. The modified ASES rating scale has been studied and found to have excellent test-retest reliability and responsiveness in patients with shoulder pain.35,36 The modified ASES rating scale compared favorably to other shoulder rating scales and was found to be more sensitive to change than a generic questionnaire and was chosen for use in this investigation.35

RESULTS
The mean ± standard deviation (SD) age of the 39 patients (6 females and 41 males) studied was 43±14.9 years. The mean time from initial injury to surgical repair of the superior labrum was 23 ± 26.83 weeks with a range of 4 weeks to 92 weeks. Patients were seen for their first visit of physical therapy and evaluated 2.6 ± 1.93 weeks post-surgery. Surgery was performed on the dominant arm in 27 of 39 cases.

Passive ROM measures for forward flexion and abduction taken in the supine position and active internal and external rotation measures also taken in the supine position 6 weeks following arthroscopic rotator cuff repair are presented in Table 1. In addition the active ROM values of the contralateral limb taken during the initial evaluation are listed for reference. Passive ROM values measured in the supine position at 6 weeks post surgery showed greater forward flexion than active anti-gravity measures from the uninjured extremity and less than 10 degree differences in movement for abduction and external rotation. The largest difference in ROM at 6 weeks post surgery was in the motion of internal rotation measured with 90 degrees of glenohumeral joint abduction.

Table 2 contains the active ROM measures taken at 12 weeks following superior labral repair as well as the number of degrees of difference relative to the uninjured extremity. Values obtained for forward flexion, abduction, and external rotation actually exceeded those measured on the uninjured extremity by 2-6 degrees at the 12 week post surgery. Mean deficits of 12 degrees in internal rotation were measured at 90 degrees abduction and compared to the uninjured extremity.
Table 3 contains the isokinetic single-repetition work values. In addition, Table 3 presents isokinetic bilateral strength comparisons, expressed as the percent deficit of the injured extremity relative to the uninjured extremity for shoulder internal and external rotation at the three testing speeds. Results show deficits of 7-11% for external rotation compared to the uninjured extremity. Internal rotation strength deficits of 8-9% were measured at 90 and 210 degrees per second, with 4% greater strength identified on the injured extremity at 300 degrees per second.

Table 4 contains the external/internal rotation work ratios for the injured and uninjured extremity. Mean external/internal rotation ratios ranged between 48 and 61% similar to that measured on the contralateral extremity. The self report section of the modified ASES rating scale administered 12 weeks post surgery produced mean values of 37 out of 45 possible points.

DISCUSSION
This study provides descriptive information on the short-term outcome following a common surgical procedure seen in orthopaedic and sports physical therapy clinics. The ROM findings reported in this patient series suggest the value of limited immobilization postsurgery and early physical therapy and ROM exercise. The use of this rehabilitation protocol produced ROM values in nearly all planes of motion within 5-10 degrees of the contralateral uninjured extremity as early as 6 weeks post-surgery. By 12 weeks post-surgery, the ROM values actually exceeded baseline contralateral ROM values in all planes except for internal rotation. One possible explanation for the decrease in internal rotation ROM measured at 90 degrees of glenohumeral joint abduction with scapular stabilization was demographic that 19 of the 39 patients in this series were former or current competitive baseball, tennis, or softball players (athletes performing overhead activities). Since pre-operative measures were not performed on this series of patients, the assumption for the purpose of this study was that subjects had bilaterally symmetric glenohumeral joint ROM values. However, research has consistently shown in athletes performing overhead activities, reductions in dominant arm internal rotation ROM from osseous adaptations such as humeral retroversion and musculotendinous and...
as these studies do provide valuable information that can be disseminated to patients regarding their overall recovery following surgery, little can be gained regarding the objective parameters directly affected during post-operative rehabilitation while the physical therapist has direct contact with the patient.

Cadaveric research\textsuperscript{13} has highlighted the importance of dynamic musculo-tendonous stabilization in the gleno-humeral joint following simulated SLAP lesion and subsequent repair. A complete restoration of glenohumeral joint stability requires the addition of muscular stabilization, which is a key component of shoulder rehabilitation programs in physical therapy\textsuperscript{41,42,43,44}.

Long term outcome studies have shown a high rate of return to overhead sports\textsuperscript{11,12} following SLAP repair which indirectly infer the return of dynamic stabilization to the shoulder. However, studies using objective documentation of muscular strength during long-term follow-up are lacking.

The present study shows a return of internal and external rotation strength documented isokinetically within 10\% of the contralateral extremity during dynamic testing.

Comparison of this series to others with respect to specific objective measurement of gleno-humeral joint ROM is limited. Most studies following arthroscopic superior labral repair use composite functional outcome ratings and return to specific activity statistics with limited objective data on range of motion or muscular strength.\textsuperscript{10,11,12} Kim et al\textsuperscript{12} evaluated 34 patients at a mean 33 months following superior labral repair using a UCLA rating score. Repair of the superior labrum resulted in satisfactory UCLA scores in 94\% of the patients with 91\% reporting a full return to pre-injury shoulder function. Despite the long-term follow-up, no objective data on ROM or strength was reported. Ide et al\textsuperscript{11} reported on 40 patients 41 months following superior labral repair using suture anchors. A modified Rowe score was used showing improvement from 27.5/100 preoperatively to 92.1 points. Seventy five percent of the patients were rated as excellent on the modified Rowe score with 75\% reporting a return to pre-injury level athletic activity. While long term outcomes research such
fy muscle balance between opposing muscle groups, were also calculated and measured in this study. Normal values for the external/internal rotation ratio in healthy uninjured shoulders have been reported to be 66% in descriptive studies. Ratios measured in the patients 12 weeks following superior labral repair ranged between 48 to 61%, well below the normal range targeted in post-operative rehabilitation. Continued emphasis on posterior rotator cuff strengthening to improve external/internal rotation muscular balance is recommended for these patients both during continued rehabilitation and in home programming following discharge. Further research, including long term follow-up, with documentation of specific muscular strength relationships beyond the 12 week post-operative time interval is presently needed.

Another important component measured in this study was the patient’s perception of their function captured using the modified ASES rating scale. The self-report section totaled 37/45 possible points 12 weeks following surgery. The compares closely to patients following mini-open rotator cuff repair 12 weeks post-surgery who measured 38.7/45 points.

A limitation of this study is that the study was performed retrospectively, and followed patients for a limited time interval post-operatively while they were undergoing outpatient physical therapy. An additional limitation is that the study design included only a single surgeon and physical therapist. Therefore, the ability to generalize this information beyond this surgical technique and rehabilitation protocol used in this study is cautioned. One strength of the use of a single physical therapist in this study was that this therapist performed all goniometric measures increasing reliability of recording over other studies using multiple examiners. An additional strength was the use of an objective reliable measurement instrument for internal and external rotation strength.

CONCLUSION

The data collected 12 weeks following superior labral repair show deficits of 10 degrees in internal rotation Active ROM and a full return of flexion, abduction, and external rotation relative to the contralateral extremity. Deficits in muscular strength of 7-11 % were found in the internal and external rotators 12 weeks following surgery. Self reported data from the modified ASES Rating Scale showed patients to score 37/45 points. These results show a nearly complete return on active ROM and strength following repair of the superior labrum and post-operative rehabilitation.

REFERENCES


Appendix

ARTHROSCOPIC SUPERIOR LABRAL (SLAP) REPAIR POST-OPERATIVE PROTOCOL

- Note: Specific alterations in post-operative protocol if SLAP repair is combined with thermal capsulorrhaphy, capsular plication, rotator interval closure or repair of full thickness rotator cuff repair.

- Sling use as needed for precarious activities and to minimize bicep muscle activation during initial post-operative phase. Duration and degree of sling use determined by physician at post-op recheck.

- Early use of stomach rubs, sawing, and wax-on/wax-off exercise to stimulate home based motion between therapy visits recommended.

PHASE I - EARLY MOTION (Weeks 1 - 3):

1. Passive range of motion of the glenohumeral joint in movements of flexion, scapular and coronal plane abduction, cross arm adduction, internal rotation in multiple positions of elevation. External rotation performed primarily in the lower ranges of abduction (<60 degrees) to decrease the stress on the repair from peel-back mechanism. Cautious use of glenohumeral joint accessory mobilization unless specific joint hypomobility identified on initial post-operative examination. Use of pulleys and supine active assistive elevation using a cane applied based on patient tolerance to initial passive range of motion post-op.

2. Patient to wear sling for comfort as needed.

3. Range of motion of elbow, forearm, and wrist.


5. Initiation of submaximal internal and external rotation resistive exercise progressing from manual resistance to very light isotonic and elastic resistance based on patient tolerance using a position with 10-20 degrees of abduction in the scapular plane.

6. Manual resistance for elbow extension, forearm pronation/supination, and wrist flexion/extension as well as the use of theraband or ball squeezes for grip strengthening. ** NOTE: No elbow flexion resistance or bicep activity for the first 6 weeks post-op to protect the superior labral repair.

7. Modalities to control pain in shoulder as indicated.
PHASE II – PROGRESSION OF STRENGTH AND ROM (Weeks 4-6):

1. Continue with previous exercise guidelines.

2. Begin to progress gentle passive range of motion of the glenohumeral joint with 90 degrees of abduction to terminal ranges with full external rotation with 90 degrees of abduction expected between 6 and 8 weeks post-op. All other motions continue from in Phase I, with continued use of both physiological and accessory mobilization as indicated by the patient’s underlying mobility status.

3. Advance rotator cuff progression using movement patterns of sidelying external rotation, prone extension, prone horizontal abduction using a light weight or elastic resistance.

4. Initiate upper body ergometer for scapular and general upper body strengthening

5. Rhythmic stabilization performed in 90 degrees of shoulder elevation with limited flexion pressure application to protect SLAP repair.

PHASE III TOTAL ARM STRENGTH: (Weeks 6 - Week 10):

1. Initiation of elbow flexion (biceps) resistive exercise.

2. Initiate seated rowing variations for scapular strengthening.

3. Advance rotator cuff and scapular progressive resistive exercise using oscillation based exercise to increase local muscular endurance. Initiation of 90 degree abducted exercise in scapular plane for internal and external rotation if patient requires extensive overhead function at work or in sport.

4. Progression to closed chain exercises by week 8 including step-ups, quadruped rhythmic stabilization, and progressive weightbearing on unstable surface.

5.

6. Initiate upper extremity (two arms) plyometric program progressing from Swiss ball to weighted medicine balls as tolerated.
PHASE IV: ADVANCED STRENGTHENING (Weeks 10 – 12/16):

1. Begin isokinetic exercise in the modified neutral position at intermediate and fast contractile velocities.
   Criterion for progression to isokinetics:
   a. completion of isotonic exercise with a minimum of a 3# weight or medium resistance with elastic tubing.
   b. pain-free range of motion in the isokinetic training movement pattern

2. Isokinetic test performed after 2-3 successful sessions of isokinetic exercise. Modified neutral test position.

3. Progression to 90 degree abducted isokinetic and functional plyometric strengthening exercises for the rotator cuff (shoulder internal and external rotation) based on patient tolerance.

4. Continue with scapular strengthening and range of motion exercises listed in earlier stages.

PHASE V - RETURN TO FULL ACTIVITY:

1. Return to full activity is predicated on physician’s evaluation, isokinetic strength parameters, functional range of motion, and tolerance to interval sport return programs.
ABSTRACT

Knee pain is one of the most common problems encountered by recreational and competitive athletes. Pain over the lateral aspect of the knee can be the result of intra or extra articular conditions. The purpose of this clinical suggestion is to present the modification of a traditional clinical test to aide in the differential diagnosis of lateral knee pain. This method has not been described elsewhere and anecdotally has been helpful in the evaluation of patients with lateral knee pain.

Key Words: differential diagnosis, iliotibial band, Noble compression test, Ober test

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PROBLEM

Functional limitations due to knee pain are among the most common problems encountered by physically active individuals. For healthcare professionals, a thorough history and physical exam will often enable accurate medical diagnosis. In some cases, however, differentiation among multiple pathologies is difficult.

One area in which differential diagnosis can be difficult is in determining the source of lateral knee pain in the active individual. For individuals experiencing lateral knee pain as a result of high volume training (e.g., running, biking), patellofemoral syndrome (PFS) and iliotibial band syndrome (ITBS) are common. In addition to these common overuse conditions, a myriad of other possibilities should be considered (Table 1).

To narrow down the list of possibilities, special tests are commonly utilized. For the diagnoses listed in Table 1, numerous special tests exist to confirm these conditions. Many of these tests, although stated for a specific pathology, have not been proven to yield satisfactory sensitivity and

Table 1. Potential causes of lateral knee pain

- Patellofemoral syndrome
- Iliotibial band syndrome
- Popliteus syndrome
- Lateral meniscus tear
- Discoid lateral meniscus
- Lateral collateral ligament sprain
- Lateral compartment osteochondral injury/arthritis
- Proximal tibio-fibular joint sprain or instability
- Patellar instability
- Hamstring strain
- Common fibular (peroneal) nerve injury
- Popliteal artery entrapment
- Lumbar radiculopathy
- Distal femur bone stress injury

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specificity. Apley's compression and McMurray tests, advocated in the evaluation for a meniscus injury, will often yield a pain response in individuals with PFS or ITBS. To evaluate extra-articular lateral knee pain the Noble compression test and Ober test are commonly recommended for the differential diagnosis of ITBS. The Noble compression test is begun with the patient supine and the knee flexed to 90 degrees. The clinician applies and maintains pressure to the lateral femoral epicondyle while extending the knee. A positive test is indicated if the patient complains of pain over the lateral femoral epicondyle at approximately 30 degrees of flexion, the approximate point at which the iliotibial band moves over the lateral femoral epicondyle.

The Ober test is performed by positioning the patient on their side with the extremity being tested facing upward. The clinician flexes the knee to 90 degrees and abducts and extends the hip to place the thigh in line with the trunk. From this starting position the clinician allows the thigh to adduct as far as possible. The “modified Ober test” is performed in the same manner as the original Ober test but the knee is fully extended at the start of the test and knee extension is maintained as the lower extremity is allowed to drop into adduction. The Ober test, while assessing for flexibility, does not frequently reproduce the patient's symptoms.

While the iliotibial tract (ITT) insertion is often listed as localized to the lateral tubercle of the tibia (Gerdy's tubercle), a recent anatomical study of the anatomy of the ITT has demonstrated a complex network of distal insertions to various structures about the knee joint. In addition to the insertion at Gerdy's tubercle, the ITT also has insertions at the linea aspera, lateral epicondyle, lateral patella, as well as a broad capsular-osseous insertion.

In many patients with subacute or infrequent symptoms, these two tests may be of marginal benefit in reproducing patient symptoms. Since the onset of symptoms experienced during running may not present within the early stages of lower-level activity, a movement placing more stress on the implicated tissue has proven helpful.

**SOLUTION**

In order to better localize iliotibial band related pain from other conditions about the lateral knee, is suggested combining the Ober's and Noble compression test into a singular special test. Begin by taking the patient into the Ober's position with the knee flexed to 90 degrees. With the knee flexed to 90 the clinician should passively extend and flex the knee, while applying direct pressure over the lateral femoral epicondyle, monitoring the patient for a pain response. (Figure 1)

If this combination does not reproduce the patient's symptoms some modifications can be added to further strain the iliotibial band while moving the knee. Testing is progressed from passive extension and flexion of the knee to active flexion and extension of the knee. Evaluation through an arc of motion is supported by Orchard et al who reported that iliotibial band impingement, at the lateral femoral epicondyle, occurred at different angles of knee flexion. Furthermore, the addition of a medially or laterally directed patellar glide during passive or active flexion and extension of the knee may further impact symptom reproduction and localization. (Figure 2) Medial patellar glide commonly results in an increase of symptoms while application of lateral patellar glide more commonly reduces the patients symptoms. Application of internal rotation of the tibia while moving from flexion to extension may also aide in symptom reproduction. (Figure 3) When the side-lying technique does not adequately reproduce the patient's symptoms...
symptoms the same test movement can be performed in weight bearing, either partially unloaded (Figure 4) or with full weight acceptance. The movement pattern in standing is similar to a drop-step or “corkscrew” lunge with the uninvolved leg passing behind the involved leg. Caution is recommended if performing this movement in full weight bearing due to the increased load placed on the lateral compartment of the knee and the potential for adversely impacting intra-articular pathology.

DISCUSSION

As with many special tests, a key component is accurate reproduction of the patient's symptoms. Not only has this testing sequence been helpful for differentiating iliotibial band pain but also for reproduction and localization of lateral patellofemoral joint pain.

Critical review of clinical tests combined with advancing knowledge of anatomy and orthopedic pathology may lend itself to further modifications of currently accepted physical examination techniques. Clinical research would be helpful to further substantiate the aforementioned techniques along with other orthopedic special tests and their modifications.

REFERENCES

This summer brings great anticipation as the world’s best athletes prepare to compete in Beijing, China for the Olympic and Paralympic Summer Games. Athletes, coaches, technical staff, and sport medicine specialists are all hard at work, carefully planning the final phases of training and competition strategy.

Canada is paying special attention to these Games, as we eagerly await our turn in hosting the world! The 2010 Winter Olympic/Paralympic Games will take place in beautiful Vancouver, BC. Although the Winter Games are still in the future, we can definitely feel the spirit and momentum building!

Canada and the United States have shared a proud sport medicine history of supporting our national athletes during international competition. Each country provides an accomplished Integrated Support Team (IST) to manage the health and wellness needs of its athletes. Sport Physiotherapy Canada (SPC) is one of the Expert Provider Groups through which sport physiotherapists are selected to the Canadian Olympic and Paralympic Games’ medical teams. We know that our athletes will be in very competent hands! However, we also recognize the need for on-going professional development of our members and are committed to leaving a strong sport medicine legacy for the future.

One upcoming educational initiative will demonstrate the evidence-based approach to elite level physiotherapy for Paralympic Athletes. SPC and the Vancouver Olympic/Paralympic Organizing Committee (VANOC) are pleased to present *High Performance Preparation for Athletes of Diverse Abilities*. This course will be offered as a post-congress course to the Canadian Physiotherapy Association’s (CPA’s) Annual Congress (May 29-June 1, 2008) in Ottawa, Ontario on June 2, 2008.

**Course Objectives**

This course will introduce physiotherapists to the unique area of Paralympic and Olympic winter sport. The classification system used in para-sport will be outlined and the role of physiotherapists working with athletes with a physical difference will be identified. Physiotherapists will be provided with resources to use in their communities to promote sport participation for individuals of all abilities. The epidemiology of injury in Paralympics and Olympics past will be examined. Physiotherapists will also be updated on the sport medicine team preparations for the winter 2010 Paralympic and Olympic Games. An evidence-based review of high performance preparation and recovery techniques for these athletes will also be featured. Our keynote presenters are Nancy Quinn, Chief Canadian Therapist for the Beijing Paralympic Games and Rick Celebrini, Chief Therapist for the 2010 Olympic Winter Games.

**Learning Outcomes**

Upon completion of this workshop participants will:

1. Increase awareness and expertise specific to the unique physiotherapy management of Paralympic and Olympic athletes.
2. Maximize knowledge and expertise in preparation for the unique role as a Paralympic and Olympic team therapist.
3. Increase knowledge related to an evidence-based approach to high performance sport preparation and recovery techniques for athletes of diverse abilities.
4. Have resources to take back to their communities to promote sport participation for individuals of all abilities.

We warmly welcome our American Sports Physical Therapy Section (SPTS) colleagues and students to participate! Learn more about the program and register for the course at the CPA website www.physiotherapy.ca, or contact information@physiotherapy.ca for assistance.
SYSTEMATIC REVIEW OF LITERATURE

A SYSTEMATIC REVIEW OF THE EFFECTIVENESS OF ECCENTRIC STRENGTH TRAINING IN THE PREVENTION OF HAMSTRING MUSCLE STRAINS IN OTHERWISE HEALTHY INDIVIDUALS

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Andrew Grant, BSc (Kin), MPT a
Amanda Beers, BHK, MPT a
Trevor Moizumi, BSc (Kin), MPT a

ABSTRACT

Background. Hamstring strains are the most common soft-tissue injury observed in recreational and athletic activities, yet no consensus exists regarding appropriate primary and secondary strategies to prevent these strains. Eccentric exercise has been reported to reduce the incidence of hamstring strains but its role has not been clearly defined.

Objective. The objective of this systematic review was to determine the effectiveness of eccentric exercise in preventing hamstring strains.

Data Sources. Online databases, including MEDLINE, PubMed, CINAHL, PEDro, SPORTDiscus, EMBASE, Cochrane Database of Systematic Reviews, Cochrane Central Register of Controlled Trials, and Web of Science were searched for relevant articles. Each database was searched from the earliest date to July 2007.

Study Selection. Selection criteria included diagnosis of hamstring strain, otherwise healthy individuals, and at least one group receiving an eccentric exercise intervention. Seven articles {three randomized controlled trials (RCTs) and four cohort studies} met the inclusion criteria.

Data Extraction. Data were extracted using a customized form. Methodological rigor of included studies was assessed using the PEDro scale and Oxford Centre for Evidence-based Medicine Levels of Evidence.

Data Synthesis. Studies were grouped by eccentric exercise intervention protocol: hamstring lowers, isokinetic strengthening, and other strengthening. A best-evidence synthesis of pooled data was qualitatively summarized.

Conclusions. Findings suggest that eccentric training is effective in primary and secondary prevention of hamstring strains. Study heterogeneity and poor methodological rigor limit the ability to provide clinical recommendations. Further RCTs are needed to support the use of eccentric training protocols in the prevention of hamstring strains.

Key Words: eccentric; hamstring strain; prevention

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INTRODUCTION

Hamstring strains are the most prevalent soft-tissue injury in recreational and sports activities that involve sprinting, jumping, and kicking. Strains to this muscle group remain a primary concern for rehabilitation professionals as they result in a debilitating injury characterized by acute loss of functional performance, prolonged periods of recovery, and subsequent increased incidence of recurrence. A recent review indicated hamstring injuries have the highest recurrence rates in sports, ranging from 12-31%.

A muscle strain is defined as an excessive stretch, which leads to muscle fiber damage and disrupts the integrity of related vascular and connective tissue structures. A muscle is commonly strained or torn during rapid acceleration or deceleration movements. A strain can be classified into grades from mild to severe to reflect injury severity. Mild (first degree) strain involves damage to a small number of muscle fibers and localized pain without loss of strength. A clear loss of strength coupled with pain reproduced on resistance is indicative of a moderate (second degree) strain. A severe (third degree) strain corresponds with complete rupture of the muscle and loss of strength and function.

The hamstring muscle group is at increased risk for strains due to its anatomical configuration. The hamstrings are composed of three muscles - semitendinosus, semimembranosus, and biceps femoris - forming a triad in the posterior compartment of the thigh. The musculotendinous junction of the biceps femoris is the most common site of strain. A rapid phase change of muscle contraction from eccentric to concentric has been suggested as the underlying mechanism for hamstring strains. Eccentric contractions are characterized by active lengthening of muscle fibers, in which the force of contraction increases as the speed of contraction increases. Conversely, concentric contractions involve the shortening of muscle fibers and an inverse relationship between the force and speed of contraction. For example, during gait, the bi-articular arrangement of the hamstring muscles across the hip and knee allow the hamstrings to work eccentrically during late swing to decelerate the lower leg and control knee extension. A concentric contraction follows to initiate hip extension prior to heel strike. Hamstrings are maximally loaded and lengthened during this rapid phase change.

In addition to clinical investigations into the biomechanical predisposition of hamstring strains, retrospective studies have focused on the identification of other etiologic factors which may predict the occurrence of hamstring strains. Intrinsic risk factors for hamstring muscle strains include older age, ethnicity, previous injury, decreased hamstring flexibility, and reduced strength. Other potential intrinsic risk factors include sex, decreased angle of peak torque, and agonist-antagonist muscle imbalance. Extrinsic factors such as fatigue, lack of warm-up, and inadequate preseason training have also been associated with increased risk of hamstring strains. However, research suggests the most significant predictor of hamstring injury is a history of previous strain to the muscle. The direct influence of risk factors remains inconclusive as investigations do not provide strong evidence to support their individual or collective effect on development of hamstring strains.

Despite the high prevalence and subsequent high incidence of recurrent hamstring strains, there is a lack of consensus with respect to appropriate primary and secondary prevention strategies. Primary prevention is defined as an intervention that prevents the occurrence of an initial injury, while secondary prevention is an intervention that prevents the recurrence of subsequent or further injury. Identification of valid and reliable prevention strategies is essential to reduce the incidence of injury and direct current rehabilitation efforts.

The protective effect of muscle strengthening on the occurrence of hamstring strains has been reported in the literature; however, the preventative role of eccentric exercise has not been clearly defined. Muscle adaptation is mode specific, with eccentric training increasing eccentric strength. Hamstring strains commonly occur during the eccentric phase of a muscle contraction, therefore, overload ing these muscles with eccentric training could potentially serve to prevent hamstring strains.

Subsequent bouts of eccentric muscle overloading have demonstrated a cumulative protective effect against further exercise-induced damage. This “repeated bout effect” causes a shift in the length-tension curve, such that peak tension is generated at longer muscle lengths. Research suggests that sarcomeres are added in series following eccentric loading. Given the length-dependent nature of muscle damage in hamstring strains near end range, this structural adaptation optimizes the angle of peak torque to reduce the risk for potential injury.
Eccentric exercise has the potential to result in delayed onset muscle soreness (DOMS), which needs to be differentiated from muscle strain. Delayed onset muscle soreness is clinically characterized by muscle soreness, stiffness, inflammation, and loss of function peaking one to three days after unaccustomed exercise. With DOMS, repeated bouts of exercise result in progressively less tissue damage and soreness. In comparison, muscle strain is characterized by immediate acute pain, and exercise too soon after strain can lead to a more disabling injury.

A preliminary search of the literature found that no systematic reviews currently exist investigating the benefit of eccentric training on the primary and secondary prevention of hamstring strains. Thus, the objective of this systematic review is to evaluate the existing evidence to determine effectiveness of eccentric exercise on primary and secondary prevention of hamstring muscle strains.

Movement of the ankle may result in a reduction in foot volume secondary to a muscle pumping action moving fluid out of the area. Results of this study may help health care practitioners prescribe a more appropriate exercise mode when addressing the cardiovascular health of the active geriatric individuals.

METHODS
The Question
This systematic review was undertaken to determine if eccentric strength training was effective in the prevention of hamstring strains in otherwise healthy individuals. Studies included were those in which the subjects underwent an eccentric strength training intervention for the primary or secondary prevention of hamstring strains. When appropriate, comparisons were made between groups receiving eccentric strength training and groups receiving alternative interventions. The primary outcome measure of interest was incidence of hamstring strains, which included first-time muscle strains and strain recurrences. The secondary outcome measure was the severity of hamstring strain.

Search Strategy
Electronic databases searched for the purpose of this systematic review included: MEDLINE, PubMed, EMBASE, CINAHL, the Cochrane Central Register of Controlled Trials, the Cochrane Database of Systematic Reviews, SPORTDiscus, PEDro, and Web of Science. In addition, reference lists of all studies included in the review, additional articles published by leading authors in this area of research, and other relevant academic journals were hand searched. Grey literature resources were also hand searched, including: CIRRIE Database of International Rehabilitation Research, NARIC’s REHAB-DATA Literature Databases, and Critically Appraised Topics. Grey literature materials are not formally published in regularly accessible, peer-reviewed journals or indexed in major electronic databases. Common formats of grey literature include: works in progress, unpublished theses, statistical reports, and conference proceedings. All databases were searched from the earliest date to March 2007 to ensure the comprehensive identification of all relevant publications. The search was limited to articles in English or French.

The search began with the identification of MeSH terms referring to hamstring strains. These MeSH terms were "exploded" in all databases in order to tailor the search terms to each specific database. Databases were searched using MeSH terms and keywords such as: “athletic injuries,” “sprains and strains,” “leg injuries,” AND “hamstring,” “semimembranosus,” “semitendinosus,” “biceps femoris,” AND “eccentric.”

Study Selection
A list of citations was accrued from the database searches and assessed for eligibility by two independent reviewers. Citations must have included: 1) “strain” or “injury” AND 2) one of “hamstring,” “eccentric,” “prevention,” “exercise,” or “training,” or some variation thereof. Reviewers selected citations they deemed eligible, and abstracts were obtained for any citations selected by at least one reviewer. Abstracts were evaluated for eligibility by two independent reviewers based on predetermined selection criteria. Study selection criteria included: diagnosis of hamstring strain (any grade), otherwise healthy individuals, and at least one group receiving eccentric exercise intervention. Full text articles were retrieved for all abstracts deemed eligible by at least one reviewer. When an abstract was not available, the full text article was retrieved. Finally, full text articles were evaluated by two independent reviewers using a customized article screening form. Reviewers discussed their decisions and reached a consensus regarding whether or not to include each full text article. If two reviewers were unable to reach a consensus, a third reviewer evaluated the full text article and made a final tie-break decision.

Search Results
Results of the overall search strategy are summarized in Figure 1. An initial 354 primary articles were identified...
for potential inclusion. Of these articles, 259 were excluded after citation screening, leaving 95 citations. For the remaining 95 citations, abstracts were obtained and screened for eligibility. Seventy-four abstracts were excluded in the second phase of screening, leaving 21 eligible full text articles. Some reasons for abstract exclusion included: lack of eccentric training intervention, no report of hamstring strains, and limitation in study design (i.e., a review article). Of the 21 full text articles included in the final phase of screening, a further 16 were excluded. Reasons for exclusion included: lack of specified eccentric exercise intervention (n=12) and lack of reported hamstring strain incidence or severity (n=4). Studies were not excluded on the basis of study design.

In total, five full text articles were included after the systematic review of the literature. Following hand searching of relevant journals and recent grey literature searches, two additional articles were subjected to the same process and deemed eligible for inclusion, for a total of seven included full text articles. Of the seven included full text articles, three were randomized controlled trials (RCTs). The RCTs are prospective trials in which eligible participants are randomly assigned to one or more treatment groups or a control group. The remaining four articles were cohort studies which followed groups of individuals and examined the relationship between an intervention (eccentric strengthening) and the incidence of the outcome of interest (hamstring strain) in study participants.

### Data Extraction and Synthesis

Using a customized data extraction form, two independent reviewers extracted data regarding subject characteristics, type of eccentric intervention and controls, study design, and results. Discrepancies were resolved by discussion between the two reviewers. If additional study information was required prior to determining eligibility, the primary author was contacted via e-mail. Pertinent data were qualitatively summarized in both text and tabular forms.

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**Table 1. PEDro scores and inter-rater reliability**

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* = consensus reached by changing this score
Quality Assessment

The Physiotherapy Evidence Database (PEDro) Scale was used by two independent reviewers to assess the methodological quality of each included full text article. A third reviewer acted as a tie-breaker when necessary. The PEDro Scale is scored out of ten with a single point awarded when a specified criterion is met. Criteria evaluated include: random allocation, concealed allocation, baseline similarity, blinding, reported outcome measures, intention to treat analysis, statistical comparisons, and measures of variability. Table 1 summarizes the quality assessment scores of included full text articles. Of the seven included full text articles, three were randomized controlled trials (RCTs) with PEDro scores ranging from 6 to 7. Scores greater than 6 are considered strong evidence. The remaining four articles were cohort studies and achieved PEDro scores ranging from 2 to 5. The average kappa value for inter-rater reliability of PEDro scores was 0.89 (range 0.62 to 1.00), indicating strong agreement between reviewers.

Methodological rigor of included articles was also evaluated using Oxford Centre for Evidence-based Medicine Levels of Evidence. Levels of evidence categorizations ranged from 2b to 4, where 2b represented individual cohort studies or low quality RCTs and 4 represented case-series, poor quality cohort, and case-control studies. Results of this analysis are summarized in Table 2.

RESULTS

A summary of included studies is displayed in Table 3. A concise summary of results is available in Table 4. A lack of similar methodologies negated a quantitative meta-analysis of results. The seven included studies were grouped by eccentric intervention type: "hamstring lowers" protocol (n=3), isokinetic strengthening protocol (n=2), and other strengthening protocols (n=2). A best-evidence synthesis of pooled data is qualitatively described below.

Effect of Eccentric Exercise - "Hamstring Lowers" Protocol

Three studies (two cohorts, one RCT) examined the effects of eccentric exercise, using a "hamstring lowers" protocol, on the prevention of hamstring muscle strain injuries and their severity. The "hamstring lowers" protocol involved participants kneeling on the floor with upright trunk perpendicular to floor (Figure 2). Feet were supported under a low bench or held by a partner. Arms were kept folded across chest and body was lowered forward. Participants lowered their body until they were no longer able to hold the position, at which point the participant was allowed to relax and use their arms to catch themselves as they reached the floor. This protocol was employed in conjunction with other conservative treatments including stretching, combined eccentric and concentric strengthening exercises, and range of motion of the lumbar spine.

Arnason et al examined the effect of eccentric "hamstring lowers" and contract-relax proprioceptive neuro-muscular facilitation (PNF) stretching on incidence (i.e., number of hamstring strains) and severity (i.e., duration of absence from play) of hamstring strains in male soccer players from top Icelandic and Norwegian soccer leagues during the 1999 to 2002 soccer seasons. Participants completed one of three interventions, which included combinations of warm-up PNF stretching, PNF flexibility exercises, and eccentric strength training. Results from the intervention teams were compared to results from baseline seasons (1999 and 2000) and to control teams. Control teams did not partake in the intervention programs during the 2001 and 2002 soccer seasons. Incidence of hamstring strains in the "hamstring lowers" group was less compared to baseline seasons among intervention teams. Differences in injury severity and re-injury rates, however, were not statistically significant between baseline seasons amongst intervention teams. When compared to control teams (0.62 ± 0.05 hamstring strains per 1000 player hours), the overall incidence of hamstring strains was 65% lower in the "hamstring lowers" group (0.22 ± 0.6 hamstring strains per 1000 player hours). However, the severity of injury and re-injury rates were not significantly different between "hamstring lowers" and control groups.

Brooks et al examined the effectiveness of "hamstring lowers" and hamstring stretching on
### Table 3. Summary of included studies

<table>
<thead>
<tr>
<th>Author &amp; Study Design</th>
<th>Prevention</th>
<th>Participants</th>
<th>Groups</th>
<th>Intervention</th>
<th>Results</th>
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<tr>
<td>Arnason et al. 36</td>
<td>Combined 1’ &amp; 2’ Prevention</td>
<td>Icelandic and Norwegian elite league male soccer teams (elite)</td>
<td>Warm-up stretching, flexibility, strength training n=8 teams (age: not reported)</td>
<td>Warm-up stretching of hamstrings using contract-relax Warm-up: throughout entire season before each training session and game Flexibility for hamstrings based on partner contract-relax stretching Flexibility: after training 3x/week during preseason, 1-2x/week during competitive season Eccentric strength training using “hamstring lowers” Eccentric: 5-week intro period, 3 sets of 12, 10, 8 reps; during preseason 3x/week, during competitive season 1-2x/week</td>
<td>Incidence of hamstring muscle strain Eccentric training: Overall incidence of hamstring strains was 65% lower compared to control* (0.22 ± 0.06 vs. 0.62 ± 0.05; RR 0.35; 95% CI 0.19-0.62, p&lt;0.001). Incidence of hamstring strains was lower compared to baseline (RR 0.42 [0.21-0.84], p=0.009). Flexibility training: No significant difference was found in the incidence of hamstring strains between intervention and control (0.54 ± 0.12 vs. 0.35 ± 0.10; relative risk 1.53; 95% CI 0.76-3.08, p=0.22) No difference in re-injury rates between “hamstring lowers” group compared to control and baseline. Severity of hamstring muscle strain No difference in injury severity between “hamstring lowers” group compared to control. Injuries in the “hamstring lowers” group were less severe compared to baseline.</td>
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<tr>
<td>Askling et al. 30</td>
<td>Combined 1’ &amp; 2’ Prevention</td>
<td>Premier league male soccer players from Sweden (elite)</td>
<td>Training group n=15 (age: 24±2.6 yrs)</td>
<td>General training &amp; eccentric hamstring strength training using YoYo Flywheel ergometer General training not described Eccentric: 4 sets x 8 reps; 16 sessions over 10 weeks</td>
<td>Incidence of hamstring muscle strain Incidence of hamstring strains decreased in trained group (3/15) when compared to control group (10/15).</td>
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<td>Brooks et al. 2</td>
<td>Combined 1’ &amp; 2’ Prevention</td>
<td>Professional male rugby players in the English Premiership rugby union club (elite)</td>
<td>Strengthening (S) n=148 (age: 25.5±4.1 yrs)</td>
<td>Regular concentric &amp; eccentric hamstring strengthening Strength: 1.2 sessions/wk; 3.6 sets x 8.2 reps (Exercises not described)</td>
<td>Incidence of hamstring muscle strain S: 1.1 (95% CI 0.74-1.4) injuries/1000 player hours; 26% proportion of recurrences SS: 0.59 (95% CI 0.34-0.84) injuries/1000 player hours; 28%</td>
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*RR* = relative risk, *CI* = confidence interval.
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<th>Study</th>
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<th>Participant Details</th>
<th>Injury Details</th>
<th>Study Details</th>
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<tr>
<td>Croisier et al. 1 (prospective)</td>
<td>2' Prevention&lt;br&gt;National or international male soccer, track &amp; field, martial arts athletes (elite)</td>
<td><em>n</em>=18&lt;br&gt;(age: 25±8 yrs)</td>
<td>Initial individualized isokinetic concentric, eccentric, or combined eccentric and concentric programs 10-30 sessions; 3x/week, 4-8 reps at 30° or 120°/s² Followed by 12-month standardized maintenance program, including manual muscle strengthening and static stretching</td>
<td>Incidence of hamstring muscle strain&lt;br&gt;No participants sustained a hamstring strain after return to their respective sports for 12 months. Pain of initial hamstring muscle strain&lt;br&gt;Before rehabilitation, pain VAS was 5.9±1.1. On return to activity pain VAS was 0.9±0.6. Intervention significantly reduced pain at P &lt; 0.001.</td>
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<td>Gabbe et al. 29 (RCT)</td>
<td>Combined 1' &amp; 2' Prevention&lt;br&gt;Senior or reserve grade male team from VAPA 2004 (competitive)</td>
<td><em>n</em>=106&lt;br&gt;(age: 23.4; range 18.0-35.0 yrs)</td>
<td>Controlled hamstring lowers&lt;br&gt;5 sessions/12 weeks; 12 sets x 6 reps</td>
<td>Incidence of hamstring muscle strain&lt;br&gt;Intervention group not at decreased risk for hamstring injury when intention to treat was analyzed (RR 1.2, 95% CI 0.5-2.8) Of participants who completed at least two training sessions, 4% of the eccentric strengthening group and 13.2% of stretching and ROM exercise group sustained a hamstring strain (RR 0.3, 95% CI 0.1-1.4; p=0.098)</td>
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reducing incidence (i.e., number of injuries per player hours) and severity (i.e., number of days lost per injury) of hamstring muscle strains in 546 professional rugby players. One hundred and forty-eight players were in the strengthening group, 144 players in the conventional strengthening and stretching group, and 200 players in the intervention group, which combined conventional strengthening and stretching with “hamstring lowers.” The incidence of hamstring strains in the intervention group (0.39 injuries per 1000 player hours) was reported as significantly lower than in the strengthening group (1.1 injuries per 1000 player hours) and the conventional strengthening and stretching group (0.59 injuries per 1000 players). Although a difference in hamstring strain severity existed across the three training groups, this difference was not significant.

Gabbe et al 29 examined the effect of eccentric muscle strengthening on the prevention of hamstring strains in 220 male football players from the Victorian Amateur Football Association. Participants in this Oxford level 2b RCT were divided into two groups: eccentric strengthening (“hamstring lowers”), and stretching and range of motion. A high number of dropouts were reported in this study. Results of the intention to treat analysis suggested the eccentric strengthening group was not at decreased risk for hamstring strains. However, amongst players who completed at least two training sessions, a trend existed towards a protective effect from eccentric strengthening. Incidence of hamstring strains in the eccentric strengthening group and in the stretching and range of motion group was 4% and 13.2%, respectively.

**Effect of Eccentric Exercise - Isokinetic Strengthening Protocol**

Two prospective cohort studies investigated the incidence of hamstring strains following eccentric exercise using isokinetic strengthening protocols. Croisier et al 1 observed the recurrence of hamstring muscle strains in 26 male athletes with pre-existing unilateral strains. Participants' baseline isokinetic profiles of hamstring and quadriceps muscle function were assessed on a Kintrex 500® dynamometer (Puidoux, Switzerland) before individualized rehabilitation programs were prescribed. Rehabilitation programs involved isokinetic eccentric exercise using the same dynamometer. During the 12-month follow-up period, no participants sustained a clinically diagnosed recurrent hamstring strain. Initial injury severity (i.e., rating of muscle pain and discomfort on a 10-point
visual analogue scale) decreased from 5.9±1.1 points pre-intervention to 0.9±0.6 post-intervention (p<0.001) and remained constant for 12 months.

A more recent study by Queiros Da Silva et al. explored the use of eccentric exercise using an isokinetic strengthening protocol with a Cybex Medway, MA isokinetic dynamometer coupled with “classical kinesiotherapy” (i.e., cryotherapy, “physiotherapy,” non-steroidal anti-inflammatory, deep transverse massage, progressive passive musculotendinous stretching, manual eccentric exercise, and proprioception exercises) for the secondary prevention of thigh muscle injuries. Of the eight participants with hamstring strains, none sustained a recurrent strain during the 8-month follow-up period post-intervention.

**Effect of Eccentric Exercise - Other Strengthening Protocols**

Two RCTs investigated the use of other eccentric exercise strengthening protocols on the incidence of hamstring strains. Askling et al. examined the effects of pre-season overloading using a YoYo™ flywheel ergometer (Stockholm, Germany) on incidence of hamstring muscle strains in 30 Swedish elite male soccer players. As described in Askling et al., rotation of the flywheel was initiated with a concentric contraction of the hamstrings. An eccentric contraction of the hamstring muscle group was subsequently required to decelerate the movement of the flywheel. Eccentric overloading of the hamstrings required the performance of an eccentric contraction over a smaller angular displacement. The training group completed general training combined with concentric and eccentric hamstring strength training using a YoYo™ flywheel ergometer, while the control group completed general training only. Results showed a decreased incidence of hamstring strains in trained (n=3) compared to control (n=10) groups. Six of the 13 participants who sustained a hamstring strain reported a previous hamstring injury. Of these participants, two were in the training group and four in the control group.
In 2004, Sherry Best¹⁴ examined the effectiveness of two rehabilitation protocols. Stretching and strengthening (STST, n=11) were compared to progressive agility and trunk stability (PATS, n=13) in 24 male and female subjects with acute hamstring strains. Eccentric strengthening (STST group) for the hamstring muscles was performed using “standing foot catches.” Participants contracted their quadriceps muscle to perform a rapid knee kick. Eccentric loading of the hamstring occurred when participants “caught” or stopped the lower leg from reaching full extension by eccentrically contracting their hamstrings.¹⁴ Hamstring strain recurrence was significantly lower for athletes in the PATS group when compared to the STST group at 16 days after return to sport. At one year following return to sport, one additional participant in each group sustained a hamstring strain.

Adverse Effects and Dropouts
Intervention-related muscle soreness was reported during the initial phases of training in three of the seven included studies.²⁸-³⁰ The majority of subjects in Askling et al¹⁰ (n=11/15) reported muscle soreness lasting 1-3 days after training sessions. A large dropout rate was observed across all training groups in the Gabbe et al¹⁵ study. With the primary reason for non-compliance, reported by players, being DOMS.²⁸ Less than half of participants (46.8%) completed at least two of the five training sessions, and less than 10% completed all required sessions over the 12-week period. Adherence in the eccentric strengthening group was lower than in the stretching and range of motion group.²⁸ Arnason et al³⁰ reported that DOMS was also the principle factor underlying the dropout of one team. This team opted not to follow the prescribed “hamstring lowers” protocol and adopted a program that was much more intensive.

Other reasons for non-adherence reported in the included studies were unrelated to study design. One participant in the Croisier et al¹ study was excluded following lack of improvement in his isokinetic strength profile following nerve compression related to ectopic calcification. In Sherry Best,¹⁴ four participants did not complete the prescribed training for reasons unrelated to the intervention (e.g., death in a motor vehicle accident).

Diagnosis of Hamstring Strain
The methodology employed to diagnose hamstring strains varied amongst included studies (Table 5). In all seven included studies, sport clinicians (i.e. physiotherapists and other medical personnel) completed the assessment and diagnosis of hamstring strains.¹,²,¹³,¹⁴,²⁸-³⁰ Criteria for clinical diagnoses included tenderness on palpation of the musculotendinous junction, pain with isometric contraction, mechanism of injury that resulted in sudden onset of posterior thigh pain, limitation of activities, and pain with stretching.²,¹³,²⁸-³⁰

DISCUSSION
After a thorough review of the literature, seven studies were included and qualitatively analyzed in the systematic review, including cohort studies and RCTs with Oxford Centre for Evidence-based Medicine Levels of Evidence ranging from 2b to 4. Due to this low level of evidence,³⁰ limited support exists for the use of “hamstring lowers,” isokinetic exercises, and other eccentric strengthening exercises as effective training protocols to reduce the incidence and subsequent recurrence of hamstring strains.
Effect of Eccentric Exercise - “Hamstring Lowers” Protocol

Three included studies \(^2,^{20,21}\) examined effects of eccentric exercise using “hamstring lowers” protocols, in conjunction with other conservative treatments (e.g., stretching, combined eccentric and concentric strengthening exercises, and range of motion of the lumbar spine), on the prevention of hamstring strains and reduction of their severity. The prospective cohort studies showed a lower incidence of hamstring strains with eccentric training, but no significant difference in severity of injury.\(^2,^{20}\) Conversely, the RCT by Gabbe et al\(^{29}\) found that the “hamstring lowers” group was not at decreased risk for hamstring strains following intention to treat analysis. However, participants in this intervention group who completed at least two training sessions sustained fewer hamstring injuries.

These three studies included competitive to elite level athletes.\(^2,^{20,21}\) In the study of male Premier League soccer players, Askling et al\(^{30}\) contended that care should be taken when extrapolating findings from elite athletes as they train at a higher intensity and frequency than recreational athletes, and may therefore be at greater risk for hamstring injury.\(^30,41\) Moreover, they argued that significant findings of a protective effect in elite athletes are more remarkable and robust since these athletes are typically closer to a theoretical ceiling effect for eccentric strength gains. Furthermore, Heidt et al\(^{4}\) suggest the risk of injury may actually increase with progressively higher levels of play.

Poor adherence and high dropout rates plagued two of the three “hamstring lowers” studies.\(^2,^{20}\) Gabbe et al\(^{29}\) attributed their high dropout rate to participants’ subjective responses to DOMS. Arnason et al\(^{26}\) noted none of the teams that performed the progression of “hamstring lowers” as prescribed, complained of DOMS. However, one team employed a more intensive training protocol than prescribed and consequently incurred considerable DOMS and dropped out of the study.\(^29\) Gabbe et al\(^{29}\) followed a “hamstring lowers” protocol as described in Brockett et al:\(^{27}\) 12 sets of 6 repetitions, with 10 seconds of rest between repetitions and 2-3 minutes of rest between sets, in five sessions over a 12-week period. Conversely, Arnason et al\(^{26}\) followed a protocol proposed by Mjolsnes et al.\(^{26}\) This protocol involved a 5-week introductory period, increasing from two sets of five repetitions one time in the first week, to three sets of 8-10 repetitions three times per week by the end of the fourth week.\(^26\) Thereafter, participants performed three sets of 8-12 repetitions three times per week for weeks 5-10.\(^26\) It stands to reason that the progressive nature of the program suggested by Mjolsnes et al,\(^{26}\) which incorporated a lower intensity introductory period, may explain why fewer participants reported DOMS in the Arnason et al\(^{26}\) study compared to Gabbe et al.\(^{29}\)

Based on the low level of evidence and paucity of published “hamstring lowers” studies, these results should be interpreted cautiously. While the included studies suggest that “hamstring lowers” appear to provide a clinically useful and inexpensive means of loading the hamstring muscles eccentrically to help protect against strain, none
of the three studies adequately controlled for concurrent training methods (e.g., combined stretching and strength training). Consequently, it is impossible to isolate the effects of the “hamstring low- ers” protocols. Thus, additional research isolating “hamstring lowers” from other interventions needs to be conducted in order to draw any definitive conclusions with respect to their effectiveness in the primary and secondary prevention of hamstring strains.

Effect of Eccentric Exercise - Isokinetic Strengthening

Two studies investigated the use of isokinetic eccentric strengthening for preventing recurrent hamstring strains - both showed protective effects. No participants in the Croisier et al study examining male athletes sustained a hamstring strain during the first 12 months after returning to sport, and rehabilitation seemed to be successful in reducing self-reports of muscle pain and discomfort. Likewise, during a six-to-nine month follow-up period in the Queiros Da Silva et al study of athletes, no recurrent hamstring strains were reported.

Both of the foregoing studies were prospective cohort studies with no control groups. In addition, they incorporated isokinetic eccentric strengthening in conjunction with other interventions. As a result, data need to be interpreted with caution. Due to weak study design, it is unclear exactly how much protection against recurrent hamstring strains was due to isokinetic eccentric strengthening and how much was due to other factors. Possibly, other physiotherapy interventions used in these studies (i.e., concentric strengthening and stretching of the quadriceps and hamstring muscles, trans-cutaneous electrical nerve stimulation, “kinesiotherapy,” and sport specific activities) contributed to the observed protection against recurrent hamstring strains. Another limitation of both studies was small sample size, leading to a lack of precision to provide reliable answers to the questions investigated by reducing the likelihood of observing any significant effect. As well, neither study conducted follow-up beyond one year, so longer term outcomes are not known.

Despite the inherent limitations and lack of supporting evidence in these studies, both Croisier et al and Queiros Da Silva et al recommended that eccentric exercise should be included in the rehabilitation of hamstring strains to help prevent recurrent strains. More specifically, Croisier et al concluded that persistence of muscle strength abnormalities may give rise to recurrent hamstring strains and pain, and that “classic rehabilitation” may be improved by including individualized isokinetic eccentric strengthening exercises.

Results of these two studies suggest that adequate warm-up followed by isokinetic eccentric strengthening at low velocities (5-30°/second) is necessary to avoid DOMS. However, without an established means of differentiating muscle strain from DOMS, it is not possible to distinguish hamstring strain and DOMS from these results. Treatment should be progressed by increasing eccentric

Table 5. Criteria for hamstring strain diagnosis

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velocity, and should ideally be performed three times per week, which is in agreement with Cotte,\(^4\) in order to minimize time to return to sport.\(^1,40\) Isokinetic eccentric strength values can also be used to determine when return to sport is appropriate. Both studies agreed that bilateral strength differences should be no less than 5% before returning to competition. This 5% value has been repeatedly cited in the literature\(^1,2,4,44\) since it is believed that hamstring strength deficits are a risk factor for strain.\(^1,3,4,44\)

Due to study limitations (i.e., no control groups, isokinetic strengthening not examined in isolation, and small sample sizes), these protocols and recommendations must be interpreted carefully. Additional high-level research examining primary prevention and involving larger sample sizes is needed. Also, incorporating better controls, such as isokinetic eccentric strengthening in isolation compared with no exercise, concentric exercise or stretching, is necessary to accurately assess the degree to which hamstring strain incidence may be decreased using isokinetic eccentric training.

**Effect of Eccentric Exercise - Other Strengthening Protocols**

Two RCTs included in the systematic review utilized other eccentric strengthening protocols.\(^1,4,30\) Using a YoYo\(^\text{™}\) flywheel ergometer, Askling et al\(^30\) examined the effects of pre-season hamstring strengthening, incorporating concentric and eccentric overload, on the occurrence and severity of hamstring strains in elite Swedish male soccer players. The eccentric training group had a significantly lower number of injuries compared to the control group. The results of this study suggest a pre-season eccentric strengthening program may reduce the incidence of hamstring strains. One major limitation of the Askling et al\(^30\) study was the inability to differentiate between the concentric and eccentric phases of the YoYo\(^\text{™}\) flywheel ergometer exercise. Therefore, the effects of eccentric training in isolation are unknown. Also, the small sample size may have decreased the reliability of the reported results by reducing its power to detect small size effects. It should also be noted that participants involved in the study were all elite male athletes. As previously discussed, research has suggested that elite level athletes may be at greater risk for hamstring injury,\(^4\) thus limiting the extrapolation of these results to other populations.

Sherry Best\(^14\) investigated the effectiveness of two different rehabilitation programs for the secondary prevention of hamstring strains. This study demonstrated that a rehabilitation program consisting of progressive agility and trunk stabilization (PATS) exercises was significantly more effective than a program of hamstring stretching and concentric-eccentric strengthening (STST). Of note, the interventions in both the PATS and STST groups incorporated multiple training modes. The use of agility training, which involved considerable eccentric loading through stopping and starting, was not identified as a specific eccentric intervention, which may be a confounding factor explaining why the PATS group sustained fewer hamstring strains. Furthermore, no attempt was made to measure trunk stability, making it difficult to determine the extent that trunk stabilization had on preventing hamstring strains. A small sample size and lack of therapist blinding also reduced the methodological rigor of this study. Because of the limitations in these two studies, it is not possible to affirmatively support the use of other eccentric strengthening protocols in hamstring strain prevention.

Additionally, Sherry Best\(^14\) were the only investigators to include both male and female participants. Numerous studies have shown sex differences in muscle response to eccentric exercise.\(^1,2,3,4,4,47\) For example, MacIntyre et al\(^2\) found sex differences in severity of DOMS, muscle torque, and inflammatory markers following eccentric exercise. Therefore, eccentric training protocols designed to prevent hamstring strains may have to be modified to address these sex differences. It is imperative that the results of studies utilizing only male participants not be generalized to females. Furthermore, the effect of sex differences on the incidence of hamstring strains following eccentric training should be investigated in more rigorous controlled trials.

**Adverse Effects and Dropouts**

As previously discussed, YoYo\(^\text{™}\) flywheel ergometry and "hamstring lowers" both resulted in increased participant dropout due to occurrence of muscles soreness and DOMS.\(^25,30\) The lack of adherence to eccentric training protocols and subsequent adverse effects reported in Arnason et al\(^21\), Gabbe et al\(^26\) and Askling et al\(^30\) may restrict the implementation of these protocols in clinical settings. However, it is interesting to note the eccentric isokinetic intervention used in the Croisier et al\(^1\) study seemed to decrease the severity of initial injury.

**Diagnosis of Hamstring Strains**

Hamstring strains are typically diagnosed through clinical examination by a team physician or physical therapist.\(^5,48\) Verrall et al\(^7\) confirmed that the common clinical features of hamstring strains are sudden onset associated with running or acceleration, pain, posterior thigh tenderness, and pain on
resisted muscle contraction. Other clinical features include loss of function and pain provocation with range of motion. Therefore, it can be assumed that clinical assessment was an appropriate method to diagnose hamstring strains in the seven included studies.

**CONCLUSION**

Previous investigations show improvements in the structural integrity and performance of the hamstring muscles with eccentric training. Although authors of these studies advocated the use of eccentric exercise to prevent hamstring strains, limited evidence exists to support its use. A lack of high-level trials impedes the ability to effectively generalize these findings to the clinical settings.

The studies included in this review varied in methodological rigor, population, sample size, and most notably, type of eccentric intervention. While the interventions varied in their prescription, no studies examined the effect of eccentric training in isolation. The coupling of eccentric training with other interventions may have limited, or conversely enhanced, the observed effects of eccentric training on the incidence and severity of hamstring strains. Thus, results of the included studies must be interpreted with caution.

In summary, seven studies were included in this review following a comprehensive appraisal of the available literature. This limited number of relevant articles highlights the need for future well-designed randomized controlled trials to conclusively evaluate the effectiveness of eccentric training in the prevention of hamstring muscle strains. Until more evidence becomes available, concrete recommendations to support or counter the use of eccentric training protocols for the primary and secondary prevention of hamstring strains cannot be made.

**REFERENCES**


ABSTRACT

Background. Shoulder injuries account for up to 17% of all golf related musculoskeletal injuries. One cause may be the repetitive stresses applied to the lead shoulder during the backswing and follow-through phases, which may contribute to the frequency of these injuries. The “elite” golfer may be predisposed to developing a shoulder injury based upon the reported adaptations to the glenohumeral joint.

Objective. To examine and compare bilateral glenohumeral joint rotational range of motion in elite golfers using standard goniometric procedures.

Methods. Twenty-four “elite” male golfers were recruited for this study. Glenohumeral internal (IR) and external rotation (ER) passive range of motion was measured bilaterally at 90° of abduction using a standard universal goniometer. Paired t-tests were utilized to statistically compare the rotational range of motion patterns between the lead and the trailing shoulder.

Results. No statistical differences existed between each shoulder for mean IR or mean ER measures. This finding was consistent throughout different age groups. External rotation measurements were greater than IR measurements in both extremities.

Discussion and Conclusion. Unlike other sports requiring repetitive shoulder function, the “elite” golfers sampled in this pilot investigation did not demonstrate a unique passive range of motion pattern between the lead and trailing shoulders. Factors, including subjects’ age, may have confounded the findings. Further studies are warranted utilizing cohorts of golfers with matching age and skill levels. Additional shoulder range of motion measures should be evaluated.

Key Words: golf, passive shoulder range of motion, glenohumeral joint, shoulder injuries

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INTRODUCTION
People of all ages and skill levels play golf worldwide.1-3 For a golfer to improve to the level of an elite player, a combination of natural athletic ability and dedicated practice is required.4 To stay at the top of one’s game, an elite golfer will routinely practice daily for hours on end.4 Competitive golfers may perform up to 2000 swings each week.5 Due to the high volume of swings performed during practice and in competition golfers are at risk of developing overuse injuries.5-18

Shoulder injuries have been shown to account for 8% to 17.6% of all golf injuries.6,12-15 Injuries to the shoulder rank 3rd behind injuries to the low back and the left wrist in professional male golfers.6,13 For male amateur golfers shoulder injuries rank 4th following injuries to the low back, the elbow, and the hand and wrist.4,16

The modern golf swing consists of five phases: the takeaway, the backswing, the downswing, acceleration, and follow-through.8 It has been proposed that the repetitive stresses applied during the backswing and follow-through phases contribute to the development of golf related overuse injuries.17 The lead shoulder (the left shoulder for the right hand dominant golfer) tends to experience more injuries than the trailing shoulder.7-9,11 Impingement, rotator cuff disease, acromioclavicular joint pain, acromioclavicular osteoarthritis, and distal clavicular osteolysis have been reported in the golfer’s lead shoulder.4,8,18 Golfers may also be at risk for developing posterior glenohumeral instability.7,9

Posterior Glenohumeral Instability in Golfers
Posterior shoulder instability occurs less frequently than anterior shoulder instability accounting for only 2% to 12% of all glenohumeral instability cases.19-21 Traumatic and repetitive overuse mechanisms for the development of posterior shoulder instability have been reported in the literature.19,20,22,23 In contact sports, the mechanism for traumatic posterior shoulder instability is the result of a force directed toward the flexed, adducted, and internally rotated arm.20,24 Posterior shoulder instability may also be the result of attenuation of the posterior shoulder structures through repetitive mechanisms.19,25

Two investigations have reported the presence of posterior shoulder instability in “elite” golfers.7,9 Hovis et al7 retrospectively reviewed eight cases of golfers who were experiencing pain in the lead shoulder. Each “elite” golfer (handicap of 5 or less) reported experiencing pain and “a sense of instability at the top of the backswing (Figure 1) when their lead arm was fully adducted across the body.”7 A diagnosis of posterior glenohumeral instability was established in each golfer’s lead shoulder with six of the eight also receiving a secondary diagnosis of subacromial impingement.7 Mallon and Colosimo9 published a retrospective review of 35 cases of shoulder injury in “elite” golfers. Each golfer was defined as either being a professional or a competitive golfer with a handicap of 3 or less.9 The lead shoulder was involved in 34 of the 35 cases with 12% of the patients experiencing posterior glenohumeral subluxation.9

Glenohumeral Joint Range of Motion Patterns in Overhead Athletes
Overhead athletes present with unique rotational range of motion (ROM) patterns.26-32 For example, javelin throwers and collegiate water-polo players tend to have significantly greater external rotation (ER) motion in their dominant (throwing) arm than their nondominant arm.28,29 Ellenbecker et al26 found elite junior tennis players demonstrate significantly less internal rotation (IR) motion with the dominant extremity. Range of motion patterns of the glenohumeral joint have been extensively researched in baseball pitchers.27,30,32,36-41 Baseball pitchers typically demonstrate increased passive ER range of motion that is significantly greater in the dominant throwing arm and significantly less passive IR range of motion in the throwing shoulder as compared with the contralateral side.27,30,32,36,38,39 It has been proposed that the repetitive stresses to the shoulder experienced by the overhead athlete may lead to attenuation of the anterior shoulder capsule and ligaments.39,40 While this may be the case in many of the aforementioned sports, recent published reports suggest that osseous adaptations may play a significant role in the ROM presentations in the baseball pitcher.32,33,34,37,41

For some overhead athletes the extremes of gleno-
humeral joint motion that occur during overhead
sports activities increase their risk of injury to the
shoulder. Appreciating the unique ROM patterns in
competitive athletes may assist sports medicine profes-
sionals when developing injury prevention strength
training programs and rehabilitation strategies for the
injured athlete. While golf specific rehabilitation pro-
grams have been published in the literature, a paucity
of injury prevention programs exist. Unfortunately,
published reports of conservative treatment programs
for golfer’s with a diagnosis of posterior shoulder insta-
bility has only helped to return a minority of athletes
successfully back to sport. In response to failed
conservative treatments physicians have prescribed
nonsteroidal medication, injected the shoulder with
steroids, and performed surgery to help return golfers
back to sport.

Pathomechanics of the Golf Swing
Previous reports have suggested that the biomechanics
of the golf swing may contribute to the development of
posterior shoulder instability. During the backswing
phase, the golfer’s lead shoulder elevates and horizon-
tally adducts (Figure 1). Mitchell et al found that the
lead shoulder horizontally adducts during the golf
swing upwards of 126º ± 7º. It is plausible that attenu-
ation of the posterior structures of the lead shoulder
may occur in response to performing a high volume of
golf swings.

Hovis et al proposed that the development of posterior
instability in elite golfers is a result of two factors: serru-
tus anterior muscle fatigue and repetitive internal
shoulder rotational forces created by subscapularis
muscle activity. Kao et al utilizing dynamic elec-
tromyography and cinematography found that the
serratus anterior muscle on the lead arm side is active
during the entire swing. Due to this fact, the serratus
anterior muscle on the lead arm side is believed to be
at risk of muscular fatigue during practice or competi-
tion. Muscular fatigue of the serratus anterior (or other
scapular muscles) will affect the normal biome-
chanical relationship between the scapula and the
humerus. Alterations to scapular position may impair
the ability of the external rotators of the shoul-
der to provide stability at the glenohumeral joint. Hovis
et al propose that continuing to play golf, in the
presence of scapular muscular fatigue, will allow the
subscapularis muscle to impart an internal rotation
stress to the shoulder contributing to the attenuation of
the posterior shoulder.

The purpose of this pilot study was to compare the pas-
sive rotational ROM patterns of the glenohumeral joint
in the trailing (dominant) and lead (nondominant)
shoulders in a group of elite golfers. To the date, the
rotational range of motion patterns of the glenohumeral
joint have not been studied in the elite golfer.

METHODS

Subjects
Twenty-four right hand dominant male golfers with
a handicap of 5 or less (mean = 2.13; SD = 1.43) vol-
teered to participate in the study. The golfers,
ranging in age from 24 to 57 years (mean = 39.67;
SD = 9.78), were recruited at the Oregon Golf
Association course in Woodburn, Oregon on June
3rd, 2006. A golfer was excluded from participation
in the study if he had a handicap greater than 5, if he
was experiencing a current episode of shoulder pain,
or had a previous history of a traumatic shoulder
injury or a surgical procedure to either shoulder.
None of the subjects who volunteered were exclud-
ed. The Institutional Review Board of Pacific
University approved this study prior to data collec-
tion; informed consent was obtained from each sub-
ject.

Procedure
The lead examiner, blinded to the lead shoulder of
each golfer, performed all measurements. Range of
motion testing was performed in a manner similar to
other studies investigating range of motion patterns
in athletic populations. Subjects were asked to lie
in a supine position on a portable physical therapy
treatment table. The shoulder was positioned in 90º
of shoulder abduction with the elbow flexed to 90º
and the forearm in a neutral position. Range of
motion measurements were recorded using a
standard universal goniometer. The axis of the
goniometer was placed at the olecranon process with
the stationary arm directed vertically and the mov-
ing arm aligned with the ulna.
Starting from a position of neutral shoulder rotation, the subject's extremity was passively externally rotated with slight overpressure added at the end range to appreciate the end feel.\textsuperscript{49} The end feel, as defined by Cyriax,\textsuperscript{50} is the sensation experienced by the examiner at the terminal ROM during passive motion testing.\textsuperscript{49,50} Scapula stabilization was maintained through manual contacts on the anterior shoulder and from the weight of the subject's body against the table. Once the limit of ER motion was achieved, the angle was measured. Passive internal rotation was performed in a similar manner with the tester internally rotating the extremity with a stabilizing force manually applied to the coracoid and anterior shoulder in order to prevent scapular movement. Three measurements were recorded for both IR and ER with means calculated for each.

Intrarater reliability was established prior to data collection. Passive shoulder external and internal rotation ROM was measured bilaterally in five elite-level golfers with 48 hours between the two tests. An intraclass correlation coefficient (ICC 3,3) and standard error of measurement (SEM) were used to quantify the test-retest reliability of both measurement procedures. Intrarater reliability was found to be very good; the ICC for measuring ER was .99 with a SEM of .28° and .99 for IR with a SEM of .53°.

Data Analysis
Data was analyzed comparing the golfer's lead and trailing shoulders as well as the total rotation range of motion. Additional analysis was performed by dividing the golfers into two groups by age: group 1 (24-39 years) and group 2 (40+ years). Paired t-tests were used to analyze the passive range of motion for lead and trailing shoulders and total rotation range of motion. The alpha level was set at 0.05.

RESULTS
Tables 1-3 present the passive range of motion measures for the entire group of elite golfers and by each age category. No significant differences existed between the lead and the trailing shoulders for either IR or ER passive ROM for the entire cohort or within each individual group. In addition, no significant difference for total rotation ROM existed between extremities for the entire group or within each individual group.

In general, ER passive ROM measurements were greater than internal rotation measurements in both extremities (Table 1). This relationship (ER > IR) was consistent throughout each age group (Table 2-3).

| Table 1. Shoulder Passive Range of Motion Measurements for the 24 Male Elite Golfers. The right arm was the dominant (trailing) arm in all of the golfers. All PROM measurements recorded in degrees. NS = not significant. |
|-----------------|-------|-------|------|-------|-------|-------|
| External Rotation | Mean | SD | p Value | t value | Significance |
| Trailing Arm | 91.04° | 7.85° | .466 | .74 | NS |
| Lead Arm | 90.32° | 6.54° |
| Internal Rotation | | | | | |
| Trailing Arm | 50.11° | 9.34° | .334 | .99 | NS |
| Lead Arm | 51.76° | 10.40° |
| Total Rotation | | | | | |
| Range of Motion | | | | | |
| Trailing Arm | 141.15° | 10.87° | .61 | .53 | NS |
| Lead Arm | 142.08° | 13.67° |

DISCUSSION
If “elite” level golfers had an increased risk of posterior glenohumeral instability, it was thought that a statistically significant difference in either ER or IR motion between the lead and the trailing shoulders would be found. The results of this study demonstrate that within this sample of “elite” golfers, no significant difference existed between the lead and the trailing shoulder for either glenohumeral ER or IR passive ROM.

Several challenges were faced in attempting to research the “elite” golfer including subject recruit-
The first challenge encountered was recruiting a high number of “elite” golfers with a 5 or lower handicap. Team sports provide researchers a large subject population in a central location to test at one time. Unlike team sports, golf is an individual sport (except at the high school or collegiate level), allowing the golfer to practice and play whenever or wherever one chooses. This obviously increases the challenge of locating the target population.

Several options were discussed for obtaining our target population including recruiting golfers from local colleges, recruiting local golf professionals, and recruiting members from a local course. The greater Portland, Oregon region is devoid of NCAA division I universities, but has numerous smaller division III colleges. While golfers at these schools were readily accessible, their skill level consistently fell short of the “elite” definition (as defined in literature by Hovis et al7 as 5 or below). In addition, many of the division III collegiate golfers were unaware of their handicap level. Measuring the ROM of local golf professionals appeared to be a means to recruit subjects, but this endeavor would have been too time intensive. Recruitment of golfers during one session at the Oregon Golf Association course was decided. Based upon professional contacts, it was determined that golfers at the Oregon Golf Association course would meet the inclusion criteria. Twenty four golfers participated in this study. Despite the limited time commitment to testing, some golfers declined participation. The subject population, based upon handicap level, is similar to those reported by Mallon et al⁹ and Hovis et al.⁷

The second challenge encountered was in deciding how many passive shoulder motions to measure. The initial goal for this study was to collect passive

<table>
<thead>
<tr>
<th>Table 2. Shoulder Passive Range of Motion Measurements for Male Golfers Age Range 24 to 39 Years (n = 13). The right arm was the dominant (trailing) arm in all of the golfers. All PROM measurements recorded in degrees. NS = not significant.</th>
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<tbody>
<tr>
<td><strong>External Rotation</strong></td>
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<td>Trailing Arm</td>
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<td>Lead Arm</td>
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<td><strong>Internal Rotation</strong></td>
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<td>Lead Arm</td>
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<td><strong>Total Rotational</strong></td>
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<td><strong>Range of Motion</strong></td>
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<td>Trailing Arm</td>
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<td>Lead Arm</td>
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<td>143.63°</td>
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<td>144.90°</td>
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<th>Table 3. Shoulder Passive Range of Motion Measurements for Male Golfers Age Range 40 Years or Older (n = 11) The right arm was the dominant (trailing) arm in all of the golfers. All PROM measurements recorded in degrees. NS = not significant.</th>
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<tr>
<td><strong>External Rotation</strong></td>
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<td>Trailing Arm</td>
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<td>Lead Arm</td>
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<td><strong>Internal Rotation</strong></td>
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<td><strong>Total Rotational</strong></td>
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<td>Mean</td>
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<td>138.22°</td>
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<td>138.76°</td>
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</table>
ROM measurements bilaterally for shoulder ER, IR, and horizontal adduction. Based upon where and how to conduct the study, it was decided to only measure glenohumeral ER and IR for this pilot investigation. These measurements can be performed quickly with minimal positional changes and minimal equipment requirements. It was believed that conducting the horizontal adduction measures might affect the recruitment potential of volunteers due to the time requirements associated with the positional changes and additional measurements. Adequate testing environment (space, equipment, and staff) to appropriately perform the horizontal adduction measurements would also have been a challenge.

Future research is suggested to build upon this investigation by testing bilateral glenohumeral rotation ROM patterns as well as horizontal adduction. Recruiting subjects from the professional ranks, NCAA division I schools, and from the American Junior Golf Association is also suggested. Reported ROM patterns observed in golfers may be the result of age specific changes versus sport related adaptations. Compared to other team and individual sports, golf can be “picked up” with participants achieving success (low handicap) at any age. Range of motion patterns observed in the 30-, 40- or 50-year old “elite” golfer may be due to sport or occupational pursuits from an earlier age. Range of motion patterns should also be investigated in junior and collegiate aged golfers, excluding those who had previous participation in overhead sports. If unique ROM patterns were identified in these populations then subsequent longitudinal testing should be conducted.

CONCLUSION
This study was an initial investigation of the anthropometric characteristics of the shoulders in “elite” golfers. The results demonstrated no statistical difference between extremities for each rotation pattern. Further testing is warranted to measure additional shoulder measures in specific “elite” golfer samples. A comprehensive appreciation of the golfers’ shoulder may lead to advances in injury prevention training strategies and rehabilitation programs.

REFERENCES


Concentric Internal and Eccentric External Fatigue Resistance of the Shoulder Rotator Muscles in Female Tennis Players

Yvonne Niederbracht, MS
Andrew L. Shim, EdD

ABSTRACT

Background. Shoulder muscle imbalance is a potential shoulder injury risk factor in athletes performing overhead sports. While normative functional peak strength of concentric external to concentric internal shoulder muscle fatigue data is available, comparisons of functional eccentric external to concentric internal shoulder rotator muscle fatigue resistance, which impacts muscle imbalance throughout the duration of play, have not been studied in this population.

Objectives. To assess fatigue resistance of the internal and external shoulder rotator muscles in female tennis players.

Methods. Fifteen female collegiate tennis players were tested bilaterally for shoulder concentric internal and eccentric external peak torque production throughout 20 maximal repetitions on a Kin-Com isokinetic dynamometer. Twelve t-tests were conducted to evaluate for differences in peak torque, relative fatigue ratios, and functional peak torque ratios between extremities and mode of activation during the first, as well as, last five repetitions that were conducted.

Results. Non-dominant concentric internal and eccentric external peak torque production significantly decreased throughout the twenty repetitions. Neither dominant concentric internal peak torque decrements and eccentric peak torque decrements were not significantly different across the twenty contractions.

These changes in peak torque upon subsequent repetitions resulted in relative fatigue ratios of dominant eccentric external rotation that were significantly greater than non-dominant eccentric external rotation. Relative fatigue ratios of dominant concentric internal rotation did not differ from non-dominant concentric internal rotation.

Conclusions. The data suggest that eccentrically activated external shoulder rotator muscles could possibly adapt to overhead activities by becoming more fatigue resistant.

Key Words: muscular fatigue, muscle imbalance, injury risk factor

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INTRODUCTION

Shoulder muscle imbalance, indicated by a low external to internal shoulder rotator muscle strength ratio, has been observed in patients with glenohumeral joint instability and impingement, and is considered to be a shoulder injury risk factor for athletes performing overhead activities. Early studies on amateur, elite junior, as well as professional tennis players have isokinetically assessed the shoulder rotator musculature concentrically, showing that shoulder muscle imbalance often occurs as the result of an adaptation to frequent overhead motions, which causes greater increases in concentric internal rotator muscle strength than in concentric external rotator strength.

While assessment of concentric internal and concentric external shoulder rotator strength provided early isokinetic normative values, researchers increasingly acknowledged the need to test the strength of the external shoulder rotator musculature eccentrically, which is the dominant mode of activation of the external shoulder rotator muscles during overhead motions. McCarrick and Kemp showed that while mean peak torque of the internal rotator muscles was similar when tested eccentrically as compared to concentrically, eccentric external rotation mean peak torque was significantly greater as compared to concentric external rotation mean peak torque. Consequently, functional muscle eccentric external to concentric internal rotation strength ratios were found to be significantly greater than concentric external to concentric internal strength ratios in athletes performing overhead activities. Data by Noffal further supported these findings leading to the suggestion that functional eccentric assessments of the external rotation muscles rather than concentric assessment might be a better identifier of possible muscular imbalance. Normative data of eccentric and concentric peak strength of internal and external rotation, as well as functional ratios have since been published for various groups of athletes. Results vary depending on sex, angular velocity, range of motion and testing position, as well as the type of athletic involvement of the subjects.

In contrast to the growing body of normative peak strength data, very few studies have attempted to assess isokinetic muscular fatigue of the shoulder internal and external rotator musculature. Chandler et al. as well as Ellenbecker and Roetert assessed concentric internal and concentric external fatigue of the shoulder rotator muscles and found that concentrically activated external rotator muscles fatigue faster than concentrically activated internal rotator muscles. These authors suggested that shoulder muscle imbalances increase upon prolonged activity, thereby, potentially increasing the risk of injury to the athlete throughout the duration of play.

Furthermore, only one study is currently available that assessed relative fatigue of eccentrically activated external shoulder rotator muscles on athletes who did not perform overhead activities. Similar to the studies that assessed concentric external shoulder rotator muscle fatigue, the study by Mullaney and McHugh showed no significant difference in fatigue of the concentrically activated internal rotator muscles versus eccentrically activated external rotator muscles in athletes participating in recreational sports. Data on eccentric fatigue of the external rotator muscles in comparison to concentric internal rotator muscle fatigue in athletes performing overhead activities, however, was not reported. Since such a functional fatigue ratio potentially provides a better indicator of the change in shoulder muscle imbalance throughout the duration of play and, hence, is a potential predictor for sustaining shoulder injuries, normative data on functional relative fatigue ratios in athletes performing overhead activities are warranted. The purpose of this study was to assess the effects of fatigue on concentric internal and eccentric external shoulder rotation strength in a group of female collegiate tennis players.

METHODS

Subjects

Fifteen collegiate Division II and National Association of Intercollegiate Athletics tennis players without a history of previous shoulder injury were recruited for this study (Table 1). All subjects completed a brief personal history form including age, years played, and arm used to serve. Weight and height measurements were also recorded. The study was approved by the Institutional Review Board of Indiana at the University of Pennsylvania. Informed consent was obtained and the rights of all subjects were protected prior to and after the data collection process.

Assessing Isokinetic Shoulder Strength

Assessment of muscular strength was conducted using the Kin-Com AP Muscle Testing System (Chattecx Corp., Hixson, Tennessee). Testing employed maximum contractions during concentric internal and eccentric external shoulder rotation. An angular velocity of 120°/second was selected to minimize variance as well as to reduce the risk of injury to the subjects. The subjects completed 10 submaximal contractions to familiarize themselves with the procedure and to aid in a specific neuromuscular warm-up.
Throughout the assessment, the subjects were seated without the legs touching the ground and the trunk secured to the chair. To approximate shoulder and elbow positioning throughout an actual overhead motion and in accordance with previous studies, the shoulder was abducted to 90° and the elbow was flexed to 90°. The elbow was then secured in a custom-made support. The range of motion completed during the test was between 90° external rotation and 30° internal rotation. While the external range of motion stop was chosen based on prior studies, the internal range of motion stop was chosen based on established passive range of motion limits that were as low as 30° of internal rotation for the same subjects. Hence, greater internal rotation range of motion stops during isokinetic testing as employed in prior studies would have increased the risk of injury to the subjects and were, consequently, avoided. Imitating the sequence of muscle involvement in a serve, concentric internal rotation was decided upon to always be tested first, immediately followed by eccentric external rotation. Each subject performed 20 maximal contractions during the test. To calculate a relative fatigue ratio, the total peak torque produced in the last five repetitions was divided by the total peak torque produced throughout the first five repetitions.

Data Analysis
Means (± standard deviations) of isokinetic peak torque on the dominant and non-dominant extremity were calculated for each condition. Twelve t-tests were conducted to evaluate for differences in peak torque, relative fatigue ratios, and functional peak torque ratios between extremities and mode of activation during the first, as well as last five repetitions that were conducted. A Bonferroni adjustment was used to correct for the multiple comparisons. Originally, the data were considered significantly different at the 0.05 level if the p value was less than 0.05 / 12 = 0.00416 within any of the subsets.

RESULTS
Peak Torque Protection
The results of eccentric external and concentric internal isokinetic peak torque on the dominant and non-dominant extremity are summarized in Table 2. The data of the following t-test discussion are provided in Table 3.

Subjects showed a tendency to reach a lower peak torque during eccentric external rotation on the dominant extremity (15.42 ± 4.46) than on the non-dominant extremity (17.78 ± 2.94; t = 2.946; df = 14, p = 0.0053) but the difference was not significant. Concentric internal rotation peak torque was not significantly different between extremities (dominant internal rotation 13.98 ± 3.05; non-dominant internal rotation 15.58 ± 2.78; t = 1.464; df = 14, p = 0.0826).

Throughout the twenty repetitions, concentric internal and eccentric external peak torque production on the non-dominant extremity significantly decreased (p ≤ 0.008). Concentric internal peak torque decrements on the dominant extremity were not significant (Mean ± standard deviation: dominant internal rotation 1-5 = 13.98 ± 3.05, dominant internal rotation 15-20 = 12.08 ± 2.80; p = 0.0092), and dominant eccentric external peak torque did not significantly change upon subsequent
repetitions, as well (dominant external rotation 1-5 = 15.42 ± 4.46; dominant external rotation 15-20 = 15.15 ± 4.41; p = 0.3444).

Relative Fatigue Ratios and Functional Peak Torque Ratios
While the relative fatigue ratios for concentric internal rotation of the dominant extremity (88.78 ± 20.03) were not significantly different from the relative fatigue ratios for concentric internal rotation on the non-dominant extremity (84.08 ± 18.13; t = 0.590; df = 14; p = 0.2822), relative fatigue ratios for eccentric external rotation on the dominant extremity (100.48 ± 21.76) were significantly less than relative fatigue ratios for eccentric external rotation on the non-dominant extremity (82.71 ± 13.25; t = 3.151; df = 14; p = 0.0035). Additionally, dominant extremity eccentric external rotation peak torque (100.48 ± 21.76) showed a tendency to decrease less than concentric internal rotation peak torque (88.78 ± 20.03; t = 2.387; df = 14; p = 0.0158). Decrements in eccentric external rotation peak torque on the non-dominant extremity (82.71 ± 13.25) were not significantly different from decrements in concentric internal rotation peak torque (84.08 ± 18.13; t = 0.210; df = 14; p = 0.4184). As a result, eccentric external rotation to concentric internal rotation peak torque ratios on the dominant extremity during the last five repetitions tended to increase from 1.11 ± 0.24 to 1.27 ± 0.37 (t = 2.515; df = 14; p = 0.0124) whereas eccentric external to concentric internal rotation peak torque ratios on the non-dominant extremity did not change (non-dominant external rotation / internal rotation Ratio 15-20: 1.17 ± 0.25; non-dominant external rotation / internal rotation Ratio 1-5: 1.19 ±

<table>
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<th>Measurement</th>
<th>DER 1-5</th>
<th>NDER 1-5</th>
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<td>0.0092</td>
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DISCUSSION
The subjects in this study exhibited weakness of eccentric external rotation on the dominant extremity compared to the non-dominant extremity. This weakness is in accordance with findings of previous studies on eccentric external peak torque differences between the dominant and non-dominant extremity in athletes performing overhead activities and is thought to be an adaptation to frequent overhead motions. Increased concentric internal peak torque in the dominant extremity, another common adaptation to frequent overhead motions, was not observed in this study. Conversely, athletes in this study tended to display increased fatigue resistance of the eccentrically activated external rotator muscles compared to the concentrically activated internal rotator muscles on the dominant extremity. Moreover, fatigue resistance of the eccentrically activated external rotator muscles on the dominant extremity was significantly increased as compared to the non-dominant extremity.

The present study is the first available study to observe greater fatigue resistance of the eccentrically activated external rotator muscles of the dominant extremity in athletes performing overhead activities and stands in contrast to previous findings on fatigue resistance of the shoulder rotator muscles. Previous studies by Ellenbecker et al. and Chandler et al., however, differed from this study as their assessment employed concentric instead of eccentric contractions of the external rotator muscles as well as several other varying parameters of angular velocity and range of motion being assessed.
Employing concentric external contractions at an angular velocity of 300°/sec, the study by Ellenberger et al.\textsuperscript{18} demonstrated decreased fatigue resistance of the concentrically activated external rotator muscles as compared to the concentrically activated internal rotator muscles. Furthermore, no difference in concentric external fatigue resistance of the contralateral extremity was observed.\textsuperscript{16} Similarly, the study by Chandler et al.\textsuperscript{4} which assessed fatigue of the shoulder rotator muscles on the dominant extremity only, also employed concentric contractions of the external rotator muscles at an angular velocity of 300°/sec. That particular study observed no difference in fatigability between the concentrically activated external and internal rotator muscles.

The only available study on fatigue resistance of concentrically activated internal rotator muscles together with eccentrically activated external rotator muscles by Mullaney et al.\textsuperscript{17} focuses on a group of 10 non-athletes. In that study, fatigue resistance was determined by the change in peak torque between the first and last five of a total of 32 repetitions at an angular velocity of 120°/sec. Like Ellenberger et al.\textsuperscript{18} and Chandler et al.\textsuperscript{4} Mullaney et al.\textsuperscript{17} did not observe a significant difference in fatigue of the eccentrically activated external rotator muscles versus the concentrically activated internal rotator muscles. Since Mullaney et al.\textsuperscript{17} accessed the dominant extremity only, no statements could be made regarding fatigue resistance of the eccentrically activated external rotator muscles on the dominant as compared to the non-dominant extremity.

Considering that fatigue ratios for concentric internal rotation in the present study were similar to those observed in prior studies, the authors hypothesize that the greater relative fatigue ratios for eccentric external rotation observed in this study were primarily due to the eccentric instead of concentric mode of activation of the external rotator muscles, rather than varying ranges of motion, angular velocities, or positioning of the body. This hypothesis is supported by previous studies that showed that muscular adaptations are contraction specific. McCarrick et al.\textsuperscript{19} for example, showed that mean peak torque of the external rotator muscles is increased after a 12 week resistance training program if tested eccentrically but not if tested concentrically. Based on this finding, as well as the present data, the authors suggest that eccentric fatigue measures instead of concentric fatigue measures of the external rotator muscles might provide rehabilitation professionals with further functional data of shoulder muscle fatigue relevant to athletes performing overhead activities.

Furthermore, the authors hypothesize that the difference in fatigue of the eccentrically activated external rotator muscles on the dominant extremity observed in this study compared to the study by Mullaney et al.\textsuperscript{22} could be attributed to specific adaptations of the shoulder rotator musculature in response to frequent overhead motions among the present group of tennis players versus the group of non-athletes studied by Mullaney et al.\textsuperscript{22} Such an eccentric external rotation fatigue resistance in these athletes performing overhead activities would be in accordance with previously reported data on eccentric fatigue resistance of the knee extensors, plantarflexor and the dorsiflexor muscles. Tesch et al.\textsuperscript{23} showed a 34 - 47 % decrement in strength during 96 concentric contractions of the knee extensors without any fatigue occurring during 96 eccentric contractions. Hortobagyi et al.\textsuperscript{24} found fatigue of the plantarflexors during 50 maximal isometric and concentric contractions to be 41 % and 32%, respectively, but found no change in force during 50 eccentric contractions. Eccentric fatigue resistance was also observed in dorsiflexors with a strength decrement of 31.6 % during concentric contractions but only 23.8% during eccentric contractions.\textsuperscript{25} All of these cases of eccentric fatigue resistance have been found in the lower extremity and concern segments that are trained in daily activities such as walking, jogging, or biking. Eccentric fatigue resistance could be hypothesized to be an adaptation to regular eccentric activation of a given muscle, suggesting that it might also be a prevalent adaptation in athletes performing overhead activities which is absent in athletes who do not perform overhead activities.

Assuming that the present data provides an accurate reference of functional muscle fatigue during repetitive overhead motions, the authors make the following conclusions. First, since muscle fatigue of the eccentrically activated external rotator muscles have not been found to be greater than muscle fatigue of the concentrically activated internal rotator muscles, perhaps, muscle balance is not exacerbated throughout repetitive overhead motions, and appears that no need exists for further exercises to improve fatigue resistance of the external rotator muscles in healthy athletes. Second, peak torque muscle strength imbalance assessments during only a few repetitions can potentially be used to assess a healthy athlete’s possible risk of injury due to muscle imbalance without having to consider a potentially increased risk due to differential fatigue throughout prolonged overhead activities. Finally, increased fatigue resistance of the eccentrically activated external rotator muscles might be an adaptation to frequent overhead activities that protects the athlete performing overhead activities from overuse injuries to the shoulder. More research is warranted regarding the role of increased fatigue resistance of the eccentrically activated external rotator muscles in injury prevention. Potentially, athletes returning to overhead activities after shoulder
injury could benefit from specific strength training to increase fatigue resistance of the eccentrically activated external rotator muscles. Lastly, testing of relative fatigue ratios of concentric internal and eccentric external rotator strength could possibly be applied to evaluate a rehabilitating athlete's readiness to return to the sport.

CONCLUSION
Contrary to previous studies, this study was the first to show increased fatigue resistance of the eccentrically activated external shoulder rotator muscles in adult and uninjured athletes performing overhead activities. The authors hypothesize that this adaptation might protect athletes performing overhead activities from sustaining overuse shoulder injuries. Athletes returning to play after injury might benefit from specific strength training exercises to increase fatigue resistance of the eccentrically activated external rotator musculature. Isokinetic testing of fatigue resistance of the shoulder rotator musculature might also be useful to determine an athlete's readiness to return to competition.

REFERENCES
ABSTRACT

**Objectives.** To measure short-term post surgery glenohumeral internal and external rotation strength, shoulder range of motion (ROM), and subjective self-report ratings following arthroscopic superior labral (SLAP) repair.

**Background.** Physical therapists provide rehabilitation for patients following arthroscopic repair of the superior labrum. Little research has been published regarding the short-term results of this procedure while the patient is typically under the direct care of the physical therapist.

**Methods.** Charts from 39 patients (7 females and 32 males) with a mean age of 43.4±14.9 years following SLAP repair were reviewed. All patients underwent rehabilitation by the same therapist using a standardized protocol and were operated on and referred by the same orthopaedic surgeon. Retrospective chart review was performed to obtain descriptive profiles of shoulder ROM at 6 and 12 weeks post surgery and isokinetically documented internal and external rotation strength 12 weeks post surgery.

**Results.** At 12 weeks post-surgery, involved shoulder flexion, abduction, and external rotation active ROM values were 2-6 degrees greater than the contralateral, non-involved extremity. Isokinetic internal and external rotation strength deficits of 7-11% were found as compared to the uninjured extremity. Patients completed the self-report section of the Modified American Shoulder Elbow Surgeons Rating Scale and scored a mean of 37/45 points.

**Conclusion.** The results of this study provide objective data for both glenohumeral joint ROM and rotator cuff strength following superior labral repair at time points during which the patient is under the direct care of the physical therapist. These results show a nearly complete return of active ROM and muscular strength following repair of the superior labrum and post-operative physical therapy.

**Key Words:** glenohumeral joint, labrum, rehabilitation

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INTRODUCTION

The glenoid labrum serves several important functions including deepening the glenoid fossa to enhance the concavity and serving as the attachment for the glenohumeral capsular ligaments. Injury to the labrum can compromise the concavity compression phenomena by as much as 50%. Individuals with increased capsular laxity and generalized joint hypermobility have increased humeral head translation which can subject the labrum to increased shear forces. In the athlete performing overhead throwing, large anteriorly directed translational forces are present at levels up to 50% of body weight during arm acceleration of the throwing motion with the arm in 90 degrees of abduction and external rotation. This repeated translation of the humeral head against and over the glenoid labrum can lead to labral injury. Labral injury can occur as either tearing or as actual detachment from the glenoid and can occur in virtually any location around the circumference of the glenoid fossa. Two of the most common areas for labral detachment encountered by physical therapists in orthopaedic and sports rehabilitation are the Bankart and SLAP lesion. In 1906, Perthes was the first to describe the presence of a detachment of the anterior inferior labrum in patients with recurrent anterior instability. Bankart initially described a method for surgically repairing this lesion that now bears his name.

In addition to labral detachment in the anterior inferior aspect of the glenohumeral joint, similar labral detachment can occur in the superior aspect of the labrum and have been defined as superior labrum anterior posterior (SLAP) lesions. Snyder et al. classified superior labral injuries into four main types. Type I shows labral degenerative changes and fraying at the edges, but no distinct avulsion. Type II are the most commonly reported superior labral injuries and have been described as complete labral detachment from anterosuperior to posteroinferior glenoid rim with instability of the biceps long head tendon noted. Morgan et al. have further sub-classified the type II superior labral lesion into type II anterior, type II posterior and type II anterior and posterior. Of significance is the increased (three times more) likelihood of type II posterior or SLAP lesions in athletes that throw, as well as the finding of the Jobe subluxation relocation test as the most accurate and valuable test to identify the type II posterior lesion. Type II anterior SLAP lesions are most commonly associated with trauma and are less likely to be found in athletes performing overhead activities. A type III labral injury involves the displacement of the free margin of the labrum into the joint in a bucket-handle type fashion with no instability of the biceps long head tendon noted. A type IV labral lesion is similar to a type III lesion with a bucket handle displacement of the glenoid labrum, however, a type IV lesion involves a partial rupture in the direction of its fibers of the the biceps long head tendon.

Consequences of a superior labral injury include significant losses in the static stability of the human shoulder. Cheng and Karzel demonstrated the important role the superior labrum and biceps anchor play in glenohumeral joint stability by experimentally creating a SLAP lesion between the 10 and 2 o’clock positions in cadaveric shoulders. They found 11 to 19% decreases in the glenohumeral joints ability to withstand rotational force, as well as 100 to 120% increases in strain on the anterior band of the inferior glenohumeral ligament after a SLAP lesion. These changes demonstrate a significant increase in the load on the capsular ligaments in the presence of superior labral injury.

Arthroscopic surgical repair of the detached superior labral lesion has evolved from the use of bioabsorbable tacs to the use of direct suture techniques using suture anchors. Cadaveric research has shown that increases in glenohumeral translation created with experimentally induced labral detachment are only partially restored during repair of the human labrum. Patients are referred to physical therapy following arthroscopic SLAP repair to restore both range of motion and important muscular strength to provide dynamic stabilization following the repair.

The purpose of this descriptive study was to objectively measure and report shoulder range of motion (ROM) and muscular strength following arthroscopic SLAP repair the results of the study will show the effectiveness of rehabilitation using a standardized rehabilitation protocol.

METHODS

Patients

A retrospective review was undertaken of patients who underwent arthroscopic SLAP repair and were referred to Physiotherapy Associates Scottsdale Sports Clinic over a three year period (2003-2006) for rehabilitation by the senior author (TE) using a standard rehabilitation protocol for
rehabilitation following superior labral repair (Appendix). Subjects were not included in the chart review if concomitant procedures were performed including rotator cuff repair, thermal capsulorrhaphy, or capsular plication. To be included in the study, subjects had to free from injury or surgery in the contralateral extremity as that extremity served as the baseline for bilateral testing in this investigation. To be included in this study, subjects had to have a type II labral tear which required arthroscopic surgical repair using direct suture technique and suture anchors. Patients with labral debridement were not included in this investigation. The research procedure was reviewed and approved by the Institutional Review Board of Physiotherapy Associates (Memphis, TN).

Rehabilitation Program
Additional information regarding the post-operative rehabilitation protocol is described to provide insight into the specific treatment each patient received following the arthroscopic SLAP repair. Sling use was directed by the physician with the recommendation for use in precarious situations (such as when outside the home or work environment) and to provide comfort. No specific objective criterion were used to monitor and direct sling use. Due to the possible attenuation of the superior labral repair during forceful muscular contraction of the biceps brachii, patients were instructed to avoid lifting objects and to wear the sling to prevent and minimize biceps muscle contraction in the immediate post-operative period. The time interval between surgery and the initial visit of physical therapy post surgery was 2.6 ± 1.93 weeks for the 39 patients in this study. Patients were given instructions for gentle active assistive ROM including Codman’s pendulum exercises by the referring physician to perform until reporting for their initial post surgical rehabilitation visit.

Early passive, active assistive, and active ROM and gleno-humeral joint mobilization was initiated in all planes of motion. Basic science research has provided guidance to the provision of early range of motion for patients following superior labral repair. Morgan and Burkhart14 have identified the concept of the “peel back” mechanism. The peel back mechanism occurs with the gleno-humeral joint in 90 degrees of abduction and external rotation; in a position simulating the throwing motion. In this position, the biceps tendon force vector has been found to assume a more vertical and posterior direction creating the peel back of the superior labrum.

In the first 6 weeks following surgery, all patients were not placed in the abduction - external rotation position with any external load applied to minimize the effects of the peel back mechanism. Kuhn et al15 tested cadaveric specimens in the abduction-external rotation “peel back position” as well as simulating the “follow-through phase” of the throwing motion (60 degrees abduction and 15 degrees horizontal adduction). They found significantly less load to failure of the biceps labral complex in the peelback position as compared to the follow-through position, thereby, supporting the vulnerability of the shoulder and, specifically, the biceps labral complex in the abducted externally rotated position. Glenohumeral external rotation range of motion and stretching was performed in 0-45 degrees of abduction during this time period. Terminal ranges of motion were targeted in all other planes of motion using primarily physiological mobilization and end range stretching techniques. The use of
accessory mobilization during this time period was limited to minimize glenoid shear over the repaired labral structure.

Patients also performed active assistive range of motion on a multiple daily basis (2-3 times a day) at home using an overhead pulley to address elevation range of motion in the scapular plane. In addition, a stick or cane was used in the supine position.

In the early post-surgical phase (weeks 1-3) submaximal resistive exercise was initiated for the rotator cuff. The primary movements initiated were internal and external rotation, and prone shoulder extension and horizontal abduction. These movements were targeted due to activation of the infraspinatus, teres minor, and subscapularis muscles and use of protective positions below 90 degrees of elevation, short lever arms, and positioning of the glenohumeral joint in or anterior to the scapular plane. Use of tan level Thera-band tubing (Hygenic Corp, Akron, OH) and little or no added weight to the extremity was recommended initially to minimize substitution. Moncrief et al have shown how the use of these resistive exercise patterns can lead to increases in rotator cuff strength using a low resistance high repetition format utilized in this study.

In the early post-operative rehabilitation phase, patients performed isolated manual resistance of the scapula in the motions of protraction and retraction. Exercises emphasizing scapular retraction and depression were given to recruit the serratus anterior and lower trapezius force couple without the use of rowing and other traditional scapular exercises that utilize substantial elbow flexion muscle activity. Use of early active shoulder flexion in the balance point position refers to the use of a supine patient position with the extremity in 90 degrees of flexion. In this position the patient is able to balance their extremity with minimal muscular activation and perform short active motions of flexion and extension and horizontal abduction/adduction with the therapist guiding the patient's ROM. At 6 weeks post surgery, progression of the balance point work to the integration of rhythmic stabilization to this balance point position is also followed using the command “hold, don’t let me move you” while the patient holds the 90 degree flexed extremity stabilizing against external challenges in multiple directions of movement by the therapist. A position of scapular protraction or “plus” position is employed with this exercise, as well, based on the concepts of Mosley et al and Decker et al to increase activation of the serratus anterior.

The use of shoulder flexion initially in an active assistive role and then active and eventually resisted role is warranted based on the work of Yamaguchi et al and Levy et al. These studies have shown minimal levels (1.7-3.6% of maximal voluntary contraction) of muscle activation of the biceps long head during multiple directions of shoulder movement such as scapular plane elevation and gleno-humeral rotational movements. This basic science research helps to differentiate early exercise and active range of motion patterns for clinicians to utilize while protecting the repaired superior labrum and biceps long head anchor. Resitive exercise for the elbow flexors is delayed until between 6-8 weeks post-surgery and is applied in the form of rowing variations, upper body ergometry, and isolated elastic and isotonic resistance exercise.

At 10-12 weeks post-surgery, patients were introduced to the isokinetic dynamometer at submaximal intensities. The accommodative resistance, ability to exercise via a sequence of progressively increasing contractile velocities, and objective feedback all provide the rationale for inclusion of this type of resistive exercise. Additionally, previous studies have reported significant increases in glenohumeral joint internal and external rotation following isokinetic training. Upper extremity plyometrics were also introduced during this time interval to provide both concentric and eccentric muscle activation.

**Outcome Measures**

Variables included in the retrospective review were, subject age, dominant arm, estimated time from injury to surgery, time from surgery to initiation of physical therapy, as well as objective measures of ROM and strength. Range of motion was measured passively in the supine position at 6 weeks post-surgery for forward flexion and abduction with a universal goniometer and standardized measurement techniques. Internal and external rotation was measured actively with 90 degrees of glenohumeral joint abduction and scapular stabilization. At 12 weeks post-surgery, active ROM measurements were taken with the subject in a seated position such that antigravity forward elevation and abduction were measured, in addition to supine active internal and external rotation with 90 degrees of abduction with scapular stabilization.
identical active ROM procedure was used to document the ROM of the uninjured extremity during the initial postoperative evaluation. Measurements were recorded to the nearest degree. All measures were taken by the senior author as part of the rehabilitation process with prior test-retest reliability of the glenohumeral joint rotational measures published previously.30

Isokinetic strength testing was performed on all 39 patients 12 weeks post-surgery using a Cybex 6000 Isokinetic dynamometer (Stoughton, MA). Testing was performed with the patient in a standing position with the dynamometer placed in 30 degrees of tilt from the horizontal base position and placed the patient’s shoulder in 30 degrees of elevation in the scapular plane.26 A ROM of 70 degrees of internal rotation and 30 degrees of external rotation was set using ROM stops. Four gradient (ie 50, 75, 90 and 100% of maximal effort) submaximal warm-up repetitions were used followed by five maximal effort repetitions for data collection at the testing speeds of 90, 210 and 300 degrees per second with 30 seconds rest between testing speeds followed. Testing was performed at three test speeds to provide information from the patient’s ability to generate resistance at slow, intermediate, and a fast testing speed. Testing was performed on the uninjured extremity first without randomization of testing speed sequence to enhance reliability.32

Following testing on the uninjured extremity, identical set-up and testing procedures were used on the post-operative extremity. Isokinetic parameters chosen to represent muscular strength in this sample were the single repetition work value calculated by the Cybex 6000 software as the area under the torque curve versus joint angle curve for the best repetition of the five performed by the subject. Additionally, the external/internal rotation unilateral strength ratio was recorded as calculated by the Cybex 6000 software by dividing the external rotation work value obtained at each speed by the corresponding internal rotation value. The reliability of the Cybex 6000 concentric isokinetic dynamometer has been previously published,33 as has the reliability specific to the application of isokinetic testing to the glenohumeral joint.34

The self report section of the modified American Shoulder Elbow Surgeons (ASES) rating scale was administered at 12 weeks post-surgery.35,36 Patients answered the series of 15 questions following standardized instructions estimating their ability to perform the activities with their injured extremity at time the instrument was completed. Each patient’s responses were tallied to form a composite score against 45 possible points. The modified ASES rating scale has been studied and found to have excellent test-retest reliability and responsiveness in patients with shoulder pain.35,36 The modified ASES rating scale compared favorably to other shoulder rating scales and was found to be more sensitive to change than a generic questionnaire and was chosen for use in this investigation.35

RESULTS

The mean ± standard deviation (SD) age of the 39 patients (6 females and 41 males) studied was 43±14.9 years. The mean time from initial injury to surgical repair of the superior labrum was 23 ± 26.83 weeks with a range of 4 weeks to 92 weeks. Patients were seen for their first visit of physical therapy and evaluated 2.6 ± 1.93 weeks post-surgery. Surgery was performed on the dominant arm in 27 of 39 cases.

Passive ROM measures for forward flexion and abduction taken in the supine position and active internal and external rotation measures also taken in the supine position 6 weeks following arthroscopic rotator cuff repair are presented in Table 1. In addition the active ROM values of the contralateral limb taken during the initial evaluation are listed for reference. Passive ROM values measured in the supine position at 6 weeks post surgery showed greater forward flexion than active anti-gravity measures from the uninjured extremity and less than 10 degree differences in movement for abduction and external rotation. The largest difference in ROM at 6 weeks post surgery was in the motion of internal rotation measured with 90 degrees of glenohumeral joint abduction.

Table 2 contains the active ROM measures taken at 12 weeks following superior labral repair as well as the number of degrees of difference relative to the uninjured extremity. Values obtained for forward flexion, abduction, and external rotation actually exceeded those measured on the uninjured extremity by 2-6 degrees at the 12 week post surgery. Mean deficits of 12 degrees in internal rotation were measured at 90 degrees abduction and compared to the uninjured extremity.
Table 3 contains the isokinetic single-repetition work values. In addition, Table 3 presents isokinetic bilateral strength comparisons, expressed as the percent deficit of the injured extremity relative to the uninjured extremity for shoulder internal and external rotation at the three testing speeds. Results show deficits of 7-11% for external rotation compared to the uninjured extremity. Internal rotation strength deficits of 8-9% were measured at 90 and 210 degrees per second, with 4% greater strength identified on the injured extremity at 300 degrees per second.

Table 4 contains the external/internal rotation work ratios for the injured and uninjured extremity. Mean external/internal rotation ratios ranged between 48 and 61% similar to that measured on the contralateral extremity. The self report section of the modified ASES rating scale administered 12 weeks post surgery produced mean values of 37 out of 45 possible points.

**DISCUSSION**

This study provides descriptive information on the short-term outcome following a common surgical procedure seen in orthopaedic and sports physical therapy clinics. The ROM findings reported in this patient series suggest the value of limited immobilization post-surgery and early physical therapy and ROM exercise. The use of this rehabilitation protocol produced ROM values in nearly all planes of motion within 5-10 degrees of the contralateral uninjured extremity as early as 6 weeks post-surgery. By 12 weeks post-surgery, the ROM values actually exceeded baseline contralateral ROM values in all planes except for internal rotation. One possible explanation for the decrease in internal rotation ROM measured at 90 degrees of glenohumeral joint abduction with scapular stabilization was the demographic that 19 of the 39 patients in this series were former or current competitive baseball, tennis, or softball players (athletes performing overhead activities). Since pre-operative measures were not performed on this series of patients, the assumption for the purpose of this study was that subjects had bilaterally symmetric glenohumeral joint ROM values. However, research has consistently shown in athletes performing overhead activities, reductions in dominant arm internal rotation ROM from osseous adaptations such as humeral retroversion and musculotendinous and...
capsular tightness which may explain the larger internal rotation ROM mean difference in this series of patients following superior labral repair.

Comparison of this series to others with respect to specific objective measurement of glenohumeral joint ROM is limited. Most studies following arthroscopic superior labral repair use composite functional outcome ratings and return to specific activity statistics with limited objective data on range of motion or muscular strength. Kim et al evaluated 34 patients at a mean 33 months following superior labral repair using a UCLA rating score. Repair of the superior labrum resulted in satisfactory UCLA scores in 94% of the patients with 91% reporting a full return to pre-injury shoulder function. Despite the long-term follow-up, no objective data on ROM or strength was reported. Ide et al reported on 40 patients 41 months following superior labral repair using suture anchors. A modified Rowe score was used showing improvement from 27.5/100 preoperatively to 92.1 points. Seventy five percent of the patients were rated as excellent on the modified Rowe score with 75% reporting a return to pre-injury level athletic activity. While long-term outcomes research such as these studies do provide valuable information that can be disseminated to patients regarding their overall recovery following surgery, little can be gained regarding the objective parameters directly affected during post-operative rehabilitation while the physical therapist has direct contact with the patient.

Cadaveric research has highlighted the importance of dynamic musculotendinous stabilization in the glenohumeral joint following simulated SLAP lesion and subsequent repair. A complete restoration of glenohumeral joint stability requires the addition of muscular stabilization, which is a key component of shoulder rehabilitation programs in physical therapy. Kim et al evaluated 34 patients at a mean 33 months following superior labral repair using a UCLA rating score. Repair of the superior labrum resulted in satisfactory UCLA scores in 94% of the patients with 91% reporting a full return to pre-injury shoulder function. Despite the long-term follow-up, no objective data on ROM or strength was reported. Ide et al reported on 40 patients 41 months following superior labral repair using suture anchors. A modified Rowe score was used showing improvement from 27.5/100 preoperatively to 92.1 points. Seventy five percent of the patients were rated as excellent on the modified Rowe score with 75% reporting a return to pre-injury level athletic activity. While long-term outcomes research such studies have shown a high rate of return to overhead sports following SLAP repair which indirectly infer the return of dynamic stabilization to the shoulder. However, studies using objective documentation of muscular strength during long-term follow-up are lacking.

The present study shows a return of internal and external rotation strength documented isokinetically within 10% of the contralateral extremity during dynamic testing. External/internal rotation ratios which are used to quanti-
fy muscle balance between opposing muscle groups, were also calculated and measured in this study. Normal values for the external/internal rotation ratio in healthy uninjured shoulders have been reported to be 66% in descriptive studies.\textsuperscript{30,45,46} Ratios measured in the patients 12 weeks following superior labral repair ranged between 48 to 61%, well below the normal range targeted in post-operative rehabilitation. Continued emphasis on posterior rotator cuff strengthening to improve external/internal rotation muscular balance is recommended for these patients both during continued rehabilitation and in home programming following discharge. Further research, including long term follow-up, with documentation of specific muscular strength relationships beyond the 12 week post-operative time interval is presently needed.

Another important component measured in this study was the patient's perception of their function captured using the modified ASES rating scale. The self-report section totaled 37/45 possible points 12 weeks following surgery. The compares closely to patients following mini-open rotator cuff repair 12 weeks post-surgery who measured 38.7/45 points.

A limitation of this study is that the study was performed retrospectively, and followed patients for a limited time interval post-operatively while they were undergoing outpatient physical therapy. An additional limitation is that the study design included only a single surgeon and physical therapist. Therefore, the ability to generalize this information beyond this surgical technique and rehabilitation protocol used in this study is cautioned. One strength of the use of a single physical therapist in this study was that this therapist performed all goniometric measures increasing reliability of recording over other studies using multiple examiners. An additional strength was the use of an objective reliable measurement instrument for internal and external rotation strength.

CONCLUSION
The data collected 12 weeks following superior labral repair show deficits of 10 degrees in internal rotation Active ROM and a full return of flexion, abduction, and external rotation relative to the contralateral extremity. Deficits in muscular strength of 7-11% were found in the internal and external rotators 12 weeks following surgery. Self reported data from the modified ASES Rating Scale showed patients to score 37/45 points. These results show a nearly complete return on active ROM and strength following repair of the superior labrum and post-operative rehabilitation.

REFERENCES


Appendix

ARTHROSCOPIC SUPERIOR LABRAL (SLAP) REPAIR POST-OPERATIVE PROTOCOL

• Note: Specific alterations in post-operative protocol if SLAP repair is combined with thermal capsulorrhaphy, capsular plication, rotator interval closure or repair of full thickness rotator cuff repair.

• Sling use as needed for precarious activities and to minimize bicep muscle activation during initial post-operative phase. Duration and degree of sling use determined by physician at post-op recheck.

• Early use of stomach rubs, sawing, and wax-on/wax-off exercise to stimulate home based motion between therapy visits recommended.

PHASE I - EARLY MOTION (Weeks 1 - 3):

1. Passive range of motion of the glenohumeral joint in movements of flexion, scapular and coronal plane abduction, cross arm adduction, internal rotation in multiple positions of elevation. External rotation performed primarily in the lower ranges of abduction (<60 degrees) to decrease the stress on the repair from peel-back mechanism. Cautious use of glenohumeral joint accessory mobilization unless specific joint hypomobility identified on initial post-operative examination. Use of pulleys and supine active assistive elevation using a cane applied based on patient tolerance to initial passive range of motion post-op.

2. Patient to wear sling for comfort as needed.

3. Range of motion of elbow, forearm, and wrist.


5. Initiation of submaximal internal and external rotation resistive exercise progressing from manual resistance to very light isotonic and elastic resistance based on patient tolerance using a position with 10-20 degrees of abduction in the scapular plane.

6. Manual resistance for elbow extension, forearm pronation/supination, and wrist flexion/extension as well as the use of theraputty or ball squeezes for grip strengthening. ** NOTE: No elbow flexion resistance or bicep activity for the first 6 weeks post-op to protect the superior labral repair.

7. Modalities to control pain in shoulder as indicated.
PHASE II – PROGRESSION OF STRENGTH AND ROM (Weeks 4-6):

1. Continue with previous exercise guidelines.

2. Begin to progress gentle passive range of motion of the glenohumeral joint with 90 degrees of abduction to terminal ranges with full external rotation with 90 degrees of abduction expected between 6 and 8 weeks post-op. All other motions continue from in Phase I, with continued use of both physiological and accessory mobilization as indicated by the patient’s underlying mobility status.

3. Advance rotator cuff progression using movement patterns of sidelying external rotation, prone extension, prone horizontal abduction using a light weight or elastic resistance.

4. Initiate upper body ergometer for scapular and general upper body strengthening.

5. Rhythmic stabilization performed in 90 degrees of shoulder elevation with limited flexion pressure application to protect SLAP repair.

PHASE III – TOTAL ARM STRENGTH: (Weeks 6 - Week 10):

1. Initiation of elbow flexion (biceps) resistive exercise.

2. Initiate seated rowing variations for scapular strengthening.

3. Advance rotator cuff and scapular progressive resistive exercise using oscillation based exercise to increase local muscular endurance. Initiation of 90 degree abducted exercise in scapular plane for internal and external rotation if patient requires extensive overhead function at work or in sport.

4. Progression to closed chain exercises by week 8 including step-ups, quadruped rhythmic stabilization, and progressive weightbearing on unstable surface.

5.

6. Initiate upper extremity (two arms) plyometric program progressing from Swiss ball to weighted medicine balls as tolerated.
PHASE IV: ADVANCED STRENGTHENING (Weeks 10 – 12/16):

1. Begin isokinetic exercise in the modified neutral position at intermediate and fast contractile velocities.
   - Criterion for progression to isokinetics:
     a. completion of isotonic exercise with a minimum of a 3# weight or medium resistance with elastic tubing.
     b. pain-free range of motion in the isokinetic training movement pattern

2. Isokinetic test performed after 2-3 successful sessions of isokinetic exercise. Modified neutral test position.

3. Progression to 90 degree abducted isokinetic and functional plyometric strengthening exercises for the rotator cuff (shoulder internal and external rotation) based on patient tolerance.

4. Continue with scapular strengthening and range of motion exercises listed in earlier stages.

PHASE V - RETURN TO FULL ACTIVITY:

1. Return to full activity is predicated on physician’s evaluation, isokinetic strength parameters, functional range of motion, and tolerance to interval sport return programs.
ABSTRACT

Knee pain is one of the most common problems encountered by recreational and competitive athletes. Pain over the lateral aspect of the knee can be the result of intra or extra articular conditions. The purpose of this clinical suggestion is to present the modification of a traditional clinical test to aid in the differential diagnosis of lateral knee pain. This method has not been described elsewhere and anecdotally has been helpful in the evaluation of patients with lateral knee pain.

Key Words: differential diagnosis, iliotibial band, Noble compression test, Ober test

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PROBLEM

Functional limitations due to knee pain are among the most common problems encountered by physically active individuals. For healthcare professionals, a thorough history and physical exam will often enable accurate medical diagnosis. In some cases, however, differentiation among multiple pathologies is difficult.

One area in which differential diagnosis can be difficult is in determining the source of lateral knee pain in the active individual. For individuals experiencing lateral knee pain as a result of high volume training (e.g., running, biking), patellofemoral syndrome (PFS) and iliotibial band syndrome (ITBS) are common. In addition to these common overuse conditions, a myriad of other possibilities should be considered (Table 1).

To narrow down the list of possibilities, special tests are commonly utilized. For the diagnoses listed in Table 1, numerous special tests exist to confirm these conditions. Many of these tests, although stated for a specific pathology, have not been proven to yield satisfactory sensitivity and specificity.

Table 1. Potential causes of lateral knee pain

- Patellofemoral syndrome
- Iliotibial band syndrome
- Popliteus syndrome
- Lateral meniscus tear
- Discoid lateral meniscus
- Lateral collateral ligament sprain
- Lateral compartment osteochondral injury/arthritis
- Proximal fibular joint sprain or instability
- Patellar instability
- Hamstring strain
- Common fibular (peroneal) nerve injury
- Popliteal artery entrapment
- Lumbar radiculopathy
- Distal femur bone stress injury

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specificity. Apley’s compression and McMurray tests, advocated in the evaluation for a meniscus injury, will often yield a pain response in individuals with PFS or ITBS. To evaluate extra-articular lateral knee pain the Noble compression test and Ober test are commonly recommended for the differential diagnosis of ITBS. The Noble compression test is begun with the patient supine and the knee flexed to 90 degrees. The clinician applies and maintains pressure to the lateral femoral epicondyle while extending the knee. A positive test is indicated if the patient complains of pain over the lateral femoral epicondyle at approximately 30 degrees of flexion, the approximate point at which the iliotibial band moves over the lateral femoral epicondyle.

The Ober test is performed by positioning the patient on their side with the extremity being tested facing upward. The clinician flexes the knee to 90 degrees and abducts and extends the hip to place the thigh in line with the trunk. From this starting position the clinician allows the thigh to adduct as far as possible. The “modified Ober test” is performed in the same manner as the original Ober test but the knee is fully extended at the start of the test and knee extension is maintained as the lower extremity is allowed to drop into adduction. The Ober test, while assessing for flexibility, does not frequently reproduce the patient’s symptoms.

While the iliotibial tract (ITT) insertion is often listed as localized to the lateral tubercle of the tibia (Gerdy's tubercle), a recent anatomical study of the anatomy of the ITT has demonstrated a complex network of distal insertions to various structures about the knee joint. In addition to the insertion at Gerdy's tubercle, the ITT also has insertions at the linea aspera, lateral epicondyle, lateral patella, as well as a broad capsular-osseous insertion.

In many patients with subacute or infrequent symptoms, these two tests may be of marginal benefit in reproducing patient symptoms. Since the onset of symptoms experienced during running may not present within the early stages of lower-level activity, a movement placing more stress on the implicated tissue has proven helpful.

**SOLUTION**

In order to better localize iliotibial band related pain from other conditions about the lateral knee, is suggested combining the Ober’s and Noble compression test into a singular special test. Begin by taking the patient into the Ober’s position with the knee flexed to 90 degrees. With the knee flexed to 90 the clinician should passively extend and flex the knee, while applying direct pressure over the lateral femoral epicondyle, monitoring the patient for a pain response. If this combination does not reproduce the patient’s symptoms some modifications can be added to further strain the iliotibial band while moving the knee. Testing is progressed from passive extension and flexion of the knee to active flexion and extension of the knee. Evaluation through an arc of motion is supported by Orchard et al who reported that iliotibial band impingement, at the lateral femoral epicondyle, occurred at different angles of knee flexion. Furthermore, the addition of a medially or laterally directed patellar glide during passive or active flexion and extension of the knee may further impact symptom reproduction and localization. (Figure 2) Medial patellar glide commonly results in an increase of symptoms while application of lateral patellar glide more commonly reduces the patients symptoms. Application of internal rotation of the tibia while moving from flexion to extension may also aide in symptom reproduction. (Figure 3) When the side-lying technique does not adequately reproduce the patient's
symptoms the same test movement can be performed in weight bearing, either partially unloaded (Figure 4) or with full weight acceptance. The movement pattern in standing is similar to a drop-step or “corkscrew” lunge with the unininvolved leg passing behind the involved leg. Caution is recommended if performing this movement in full weight bearing due to the increased load placed on the lateral compartment of the knee and the potential for adversely impacting intra-articular pathology.

DISCUSSION
As with many special tests, a key component is accurate reproduction of the patient’s symptoms. Not only has this testing sequence been helpful for differentiating iliotibial band pain but also for reproduction and localization of lateral patellofemoral joint pain.

Critical review of clinical tests combined with advancing knowledge of anatomy and orthopedic pathology may lend itself to further modifications of currently accepted physical examination techniques. Clinical research would be helpful to further substantiate the aforementioned techniques along with other orthopedic special tests and their modifications.

REFERENCES
This summer brings great anticipation as the world’s best athletes prepare to compete in Beijing, China for the Olympic and Paralympic Summer Games. Athletes, coaches, technical staff, and sport medicine specialists are all hard at work, carefully planning the final phases of training and competition strategy.

Canada is paying special attention to these Games, as we eagerly await our turn in hosting the world! The 2010 Winter Olympic/Paralympic Games will take place in beautiful Vancouver, BC. Although the Winter Games are still in the future, we can definitely feel the spirit and momentum building!

Canada and the United States have shared a proud sport medicine history of supporting our national athletes during international competition. Each country provides an accomplished Integrated Support Team (IST) to manage the health and wellness needs of its athletes. Sport Physiotherapy Canada (SPC) is one of the Expert Provider Groups through which sport physiotherapists are selected to the Canadian Olympic and Paralympic Games’ medical teams. We know that our athletes will be in very competent hands! However, we also recognize the need for on-going professional development of our members and are committed to leaving a strong sport medicine legacy for the future.

One upcoming educational initiative will demonstrate the evidence-based approach to elite level physiotherapy for Paralympic Athletes. SPC and the Vancouver Olympic/Paralympic Organizing Committee (VANOC) are pleased to present *High Performance Preparation for Athletes of Diverse Abilities*. This course will be offered as a post-congress course to the Canadian Physiotherapy Association’s (CPA’s) Annual Congress (May 29-June 1, 2008) in Ottawa, Ontario on June 2, 2008.

**Course Objectives**

This course will introduce physiotherapists to the unique area of Paralympic and Olympic winter sport. The classification system used in para-sport will be outlined and the role of physiotherapists working with athletes with a physical difference will be identified. Physiotherapists will be provided with resources to use in their communities to promote sport participation for individuals of all abilities. The epidemiology of injury in Paralympics and Olympics past will be examined. Physiotherapists will also be updated on the sport medicine team preparations for the winter 2010 Paralympic and Olympic Games. An evidence-based review of high performance preparation and recovery techniques for these athletes will also be featured. Our keynote presenters are Nancy Quinn, Chief Canadian Therapist for the Beijing Paralympic Games and Rick Celebrini, Chief Therapist for the 2010 Olympic Winter Games.

**Learning Outcomes**

Upon completion of this workshop participants will

1. Increase awareness and expertise specific to the unique physiotherapy management of Paralympic and Olympic athletes.
2. Maximize knowledge and expertise in preparation for the unique role as a Paralympic and Olympic team therapist.
3. Increase knowledge related to an evidence-based approach to high performance sport preparation and recovery techniques for athletes of diverse abilities.
4. Have resources to take back to their communities to promote sport participation for individuals of all abilities.

We warmly welcome our American Sports Physical Therapy Section (SPTS) colleagues and students to participate! Learn more about the program and register for the course at the CPA website www.physiotherapy.ca, or contact information@physiotherapy.ca for assistance.
LITERATURE REVIEW
THE ROLE OF MASSAGE IN SPORTS PERFORMANCE AND REHABILITATION: CURRENT EVIDENCE AND FUTURE DIRECTION

Jason Brummitt, MSPT, SCS, ATCa

ABSTRACT

Background. Massage is a popular treatment choice of athletes, coaches, and sports physical therapists. Despite its purported benefits and frequent use, evidence demonstrating its efficacy is scarce.

Purpose. To identify current literature relating to sports massage and its role in effecting an athlete’s psychological readiness, in enhancing sports performance, in recovery from exercise and competition, and in the treatment of sports related musculoskeletal injuries.

Methods. Electronic databases were used to identify papers relevant to this review. The following keywords were searched: massage, sports injuries, athletic injuries, physical therapy, rehabilitation, delayed onset muscle soreness, sports psychology, sports performance, sports massage, sports recovery, soft tissue mobilization, deep transverse friction massage, pre-event, and post exercise.

Results. Research studies pertaining to the following general categories were identified and reviewed: pre-event (physiological and psychological variables), sports performance, recovery, and rehabilitation.

Discussion. Despite the fact clinical research has been performed, a poor appreciation exists for the appropriate clinical use of sports massage.

Conclusion. Additional studies examining the physiological and psychological effects of sports massage are necessary in order to assist the sports physical therapist in developing and implementing clinically significant evidence based programs or treatments.

Key Words: sports massage, sports rehabilitation, sports performance, sports recovery

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INTRODUCTION
Massage has been utilized in the treatment of illness and injury for thousands of years by health care practitioners. Chinese writings dating back to 2500 BC describe the use of this modality for a variety of medical purposes. Massage has been promoted as a treatment of choice for numerous conditions such as musculoskeletal injuries, cancer, stress, relaxation, and pregnancy.

Physical therapists who specialize in sports medicine often utilize massage techniques to aid an athlete’s recovery from intense exercise or as a treatment option when performing clinical rehabilitation. Sports massage has been suggested as a means to help prepare an athlete for competition, as a tool to enhance athletic performance, as a treatment approach to help the athlete recover after exercise or competition, and as a manual therapy intervention for sports-related musculoskeletal injuries.

While massage is frequently performed by physical therapists (and other healthcare or alternative medicine practitioners) and is popular with athletes and coaches, its actual efficacy is questionable.

The purpose of this paper is to review and present the current literature relating to sports massage and its roles in effecting an athlete’s psychological readiness, in enhancing sports performance, in recovery from exercise and competition, and in the treatment of sports-related musculoskeletal injuries. Recommendations are discussed highlighting the need for additional research in sports massage.

METHODS
Selection of Papers
The following electronic databases were used to identify papers relevant to this review: Medline (from 1950-present), CINAHL (1982-present), PsycINFO (1985-present), Cochrane Database of Systematic Reviews, and SPORTDiscus (1830-present). Table 1 presents the Medical Subject Headings (MeSHs) and textwords (tw) utilized in the search strategy for this paper. If fewer than 300 articles were identified by a search strategy, the study abstracts were reviewed from that category in order to identify potentially relevant papers. The reference list of each of the selected papers was also reviewed in order to identify additional relevant publications.

Study Selection
Inclusion Criteria
1) The report’s study design must have been one of the following: randomized controlled trial, quasi-experimental, single-case design, non-randomized historical cohort comparisons, case-series, or case report.
2) The report was published in a scientific peer-reviewed journal.
3) The sports massage protocol described in the report must have included at least one or more of the following techniques: effleurage, petrissage, or deep transverse friction massage (also known as cross-friction massage).
4) The purpose of the massage intervention was to impact one or more of the following facets of athletics: pre-event (warm-up and psychological readiness), sports performance, recovery from exercise and competition, or the treatment of sports-related injuries.

Exclusion Criteria
1) Papers that were not published within a peer-reviewed scientific journal.
2) Reports that detailed the use of massage for non-sports related injuries or functions.

The rationale for these inclusion and exclusion criteria was to identify papers that investigate the use of massage in all facets of athletic care. The massage techniques included for review in this paper were based upon their prevalence within the literature and their preference among physical therapists. In specific situations where there was paucity in the literature, complementary paper(s) were presented (but not included in the overall review). Massage protocols investigating efficacy for non-sports related injuries or chronic conditions were considered beyond the scope of this review.

Description of Selected Massage Techniques
Sports massage is defined as a collection of massage techniques performed on athletes or active individuals for the purpose of aiding recovery or treating pathology. Three forms of massage are frequently reported in the sports medicine literature: effleurage, petrissage, and deep transverse friction massage (DTFM).

Effleurage techniques are performed along the length of the muscle, typically in a distal to proximal sequence. These techniques are executed throughout a massage routine, with the strokes performed slowly utilizing light or gentle pressure. The petrissage techniques include kneading, wringing, and scooping strokes. These
Techniques are generally performed with deeper pressure to patient tolerance. Deep transverse friction massage (also known as cross-friction massage) is performed by using the fingers to apply a force moving transversely across the target tissue.

**Description of Tables**
The information about to be presented is summarized in Table 3-6. Part of each of these tables includes a column called “level of evidence.” The definition of these levels is defined in Table 2. The reader should refer to Table 2 when referring to the information on Tables 3-6.

**Efficacy of a Pre-Event Massage**
Athletes routinely prepare both physically and psychologically prior to competition. Athletes typically incorporate one or more of the following pre-competition preparation strategies: static stretching, warm-up drills, game simulations, and mental imagery.

A pre-event massage has been suggested as a strategy to decrease pre-competition anxiety and to prepare the muscles for competition. Currently a paucity in the literature exists addressing the effects of a pre-event massage in order to reduce injury risk or enhance psychological readiness (Table 3).

**Effect on Blood Pressure**
Camborn et al. investigated the effect of massage on a recipient’s blood pressure (BP). Twenty five massage therapy students provided massage treatments to 150 current massage therapy clients. The length of the massage and the techniques performed by the students were not controlled, but were instead based upon the students’ perception of the clients’ needs. The massages ranged in time from 30 to 90 minutes. Six different massage techniques were used including Swedish, deep tissue, myofascial release, sports, trigger point, and craniosacral.

<table>
<thead>
<tr>
<th>MeSH or tw</th>
<th>MeSH or tw Defined</th>
<th>Number of Articles Identified</th>
<th>Number of Articles Determined as Potentially Relevant</th>
<th>Number of Articles Included in Critical Appraisal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) MeSH or tw</td>
<td>Massage</td>
<td>14032</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>2) MeSH or tw</td>
<td>Sports Injuries</td>
<td>4675</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>3) MeSH or tw</td>
<td>Athletic Injuries</td>
<td>23785</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>4) MeSH or tw</td>
<td>Physical Therapy</td>
<td>53602</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>5) MeSH or tw</td>
<td>Rehabilitation</td>
<td>169190</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>6) MeSH or tw</td>
<td>Delayed Onset Muscle Soreness</td>
<td>764</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>7) MeSH or tw</td>
<td>Sports Psychology</td>
<td>1512</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>8) MeSH or tw</td>
<td>Sports Performance</td>
<td>1423</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>9) MeSH or tw</td>
<td>Sports Massage</td>
<td>253</td>
<td>22</td>
<td>13</td>
</tr>
<tr>
<td>10) MeSH or tw</td>
<td>Sports Recovery</td>
<td>90</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>11) MeSH or tw</td>
<td>Soft Tissue Mobilization</td>
<td>46</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>12) MeSH or tw</td>
<td>Deep Transverse Friction Massage</td>
<td>6</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>13) MeSH or tw</td>
<td>Pre-event</td>
<td>312</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>14) MeSH or tw</td>
<td>Post Exercise</td>
<td>2099</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

1 and 2 | 34 | 2 | 1 |
1 and 3 | 81 | 4 | 1 |
4 and 9 | 5 | 0 | 0 |
5 and 9 | 6 | 0 | 0 |
6 and 9 | 8 | 4 | 4 |
7 and 9 | 1 | 1 | 1 |
8 and 9 | 11 | 4 | 4 |
9 and 10 | 8 | 4 | 2 |
9 and 11 | 0 | 0 | 0 |
9 and 13 | 1 | 0 | 0 |
9 and 14 | 5 | 2 | 2 |

MeSH: Medical Subject Heading
tw: textword
n/a: not assessed
The authors found that clients receiving Swedish massage (effleurage and petrissage) experienced the greatest reduction in blood pressure, whereas those who had received trigger point therapy and sports massage experienced an increase in blood pressure. While this research provides findings that may have clinical significance, the study design challenges the overall strength of the findings. A large sample size was collected (n = 150), but 25 massage therapy students performed the non-uniform interventions to clients who were already receptive to this form of treatment. The study also lacked controls for the duration of the massage (30 to 90 minutes) and the massage techniques performed.

Although this study did not directly focus on an athletic population, a vigorous massage may be less desirable than a “Swedish” (or relaxation) type of massage in specific situations. Theoretically, an athlete who is experiencing pre-game anxiety or stress may increase his or her risk of sustaining an injury or of having a sub-par performance. Future investigations should be performed with specific athletic populations receiving massages just prior to participating in a stressful simulation or actual competition.

### Effect on Mood and Anxiety

Leivadi et al evaluated the effects of massage on mood and anxiety states in female dancers (mean age = 20.1 years, SD = 1.8 years). The dancers were randomly assigned to either a massage therapy (n = 15) group or a relaxation therapy (n = 15) group. The massage therapy group received a 30-minute treatment twice a week for a five week period. The massages consisted of effleurage, petrissage, and friction techniques with a treatment emphasis on the upper torso. Those assigned to the relaxation therapy group performed a series of muscle tensing and relaxation exercises while listening to a recorded tape. Both groups demonstrated significant effects between the first and last treatment sessions for lowered anxiety levels and improved mood scores. Additional studies have investigated how massage effects an athlete's perception of recovery and regeneration. While these investigations support the beneficial psychological effects of massage; overall study design threatens the strength of the conclusions.

### EFFECTS OF MASSAGE ON SPORTS PERFORMANCE

Athletes and coaches are constantly fine tuning their training strategies in order to develop a competitive edge. The use of therapeutic modalities, such as thermal agents, electrical stimulation, and massage are often performed for this purpose. Despite the frequency that cortisol levels compared to the relaxation group. Limitations in study design threaten the strength of the findings. Additional studies have investigated how massage effects an athlete's perception of recovery and regeneration.
<table>
<thead>
<tr>
<th>Study (Year)</th>
<th>Study Design</th>
<th>Level of Evidence</th>
<th>Participants</th>
<th>Professional(s) Conducting the Intervention</th>
<th>Techniques</th>
<th>Treatment Time</th>
<th>Results and Authors’ Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cambron et al15</td>
<td>Quasi-experimental pre-test post-test design</td>
<td>3</td>
<td>150 massage therapy clients (mean age 42.5 years, range 19-79)</td>
<td>25 massage therapy students; 12 in their 2nd trimester and 13 in their 3rd (final) trimester</td>
<td>Swedish, deep tissue, myofascial release, sports, trigger point, craniosacral</td>
<td>One treatment session. 30 – 90 minutes per practitioner preference.</td>
<td>1) Nonsignificant decrease in systolic blood pressure (BP): average 1.8 (range: -24-34) mmHg and an average increase in diastolic BP of 0.1 (range: -53-18). 2) No association between BP and any of the following variables: duration, amount of pressure, and the massage therapy intern experience. 3) Swedish massage was associated with a nonsignificant decrease in systolic BP. 4) Systolic BP increased with trigger point and sports massage. When the two techniques were performed in combination both systolic and diastolic BP increases were statistically significant.</td>
</tr>
<tr>
<td>Leivadi et al18</td>
<td>Randomized controlled trial: Pre-test/Post-test group design</td>
<td>2</td>
<td>30 female adult dance majors (mean age 20.1 years, SD 1.8)</td>
<td>“Different trained massage therapists”</td>
<td>Effleurage, petrissage</td>
<td>Two sessions a week for 5 weeks. 30-minute sessions.</td>
<td>1) Significant pre-test/post-test treatment measures for anxiety levels, less depressed moods, less neck and shoulder pain, less low back pain for both groups. 2) Significant decrease in cortisol levels for the massage intervention group. 3) Those receiving massage treatment experienced a significant improvement in neck extension and shoulder abduction at the end of the study.</td>
</tr>
<tr>
<td>Micklewright et al19</td>
<td>Within subjects experimental design with counterbalanced design</td>
<td>3</td>
<td>16 university and students (10 male 6 female) mean age 22 years, SD 4.8</td>
<td>One massage therapist</td>
<td>Effleurage, petrissage</td>
<td>30-minute standardized massage protocol</td>
<td>The massage treatment prior to Wingate Anaerobic Cycling Test significantly enhanced performance but had no effect on mood state.</td>
</tr>
<tr>
<td>Hemmings et al20</td>
<td>Within subjects experimental design with counterbalanced design</td>
<td>3</td>
<td>Eight amateur boxers (mean age 24.9 years, SD 3.8)</td>
<td>Sports massage therapist</td>
<td>Effleurage, petrissage</td>
<td>20-minute standardized protocol consisting of 8-minutes for the legs, 2-minutes for the back, and 10-minutes for the shoulders and arms</td>
<td>1) No significant difference between groups for performance. 2) Massage program significantly increased perceptions of recovery. 3) No statistical difference in blood lactate or glucose levels after either intervention. 4) Blood lactate concentration was significantly higher after the massage program.</td>
</tr>
<tr>
<td>Hemmings21</td>
<td>Within subjects experimental design with counterbalanced design</td>
<td>3</td>
<td>Nine Royal Navy boxing squad members (mean age 22 ± 3.1 years).</td>
<td>Sports massage therapist</td>
<td>Effleurage, petrissage</td>
<td>20-minute standardized</td>
<td>1) After massage, boxers’ perceived recovery was significantly greater than resting and the touching control. 2) Massage did not affect saliva flow.</td>
</tr>
<tr>
<td>Hemmings22</td>
<td>Within subjects experimental design with counterbalanced design</td>
<td>3</td>
<td>Nine Royal Navy boxing squad members (mean age 22 ± 3.1 years)</td>
<td>Sports massage therapist</td>
<td>Effleurage, petrissage</td>
<td>20-minute standardized protocol</td>
<td>1) After massage intervention, significant main effects were found in the fatigue subscale and a trend towards significance in the tension subscale. 2) No main effects noted in the vigor, depression, and anger subscales.</td>
</tr>
<tr>
<td>Study (Year)</td>
<td>Study Design</td>
<td>Level of Evidence</td>
<td>Participants</td>
<td>Professional(s) Conducting the Intervention</td>
<td>Techniques</td>
<td>Treatment Time</td>
<td>Results and Authors’ Conclusions</td>
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</tr>
<tr>
<td>Leivadi et al.27</td>
<td>Randomized controlled trial: pre-test/post-test group design</td>
<td>2</td>
<td>30 female adult dance majors (mean age 20.1 years, SD 1.8)</td>
<td>“Different trained massage therapists”</td>
<td>Effleurage and petrissage techniques</td>
<td>2 sessions a week for 5 weeks. 30-minute sessions</td>
<td>1) Significant pre-post treatment measures for anxiety levels, less depressed moods, less neck and shoulder pain, less low back pain for both groups. 2) Significant decrease in cortisol levels for the massage intervention group. 3) Those receiving massage treatment experienced a significant improvement in neck extension and shoulder abduction at the end of the study.</td>
</tr>
<tr>
<td>Brooks Randomized controlled trial</td>
<td>2</td>
<td>52 volunteer massage school clients, staff, faculty, and students (mean age 30 years, SD 13.63, range 18-71)</td>
<td>Two senior therapeutic massage students</td>
<td>Effleurage, friction</td>
<td>5 minutes</td>
<td>Massage intervention facilitated a significant improvement in grip strength recovery as compared to other interventions.</td>
<td></td>
</tr>
<tr>
<td>Hemmings et al.24</td>
<td>trial: pre-test/post-test and field hockey players (consisting of 8-minute classic improved hamstring length</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mancinelli Randomized controlled trial</td>
<td>2</td>
<td>22 NCAA Division I women basketball and volleyball players (mean age 20 ± 0.93 years)</td>
<td>Two massage therapists</td>
<td>Effleurage, petrissage, vibration</td>
<td>17-minute standardized protocol</td>
<td>1) Significant slowing in shuttle run times for the control group. 2) Significant changes in vertical jump displacement, perceived soreness, and algometer levels for the massage group.</td>
<td></td>
</tr>
<tr>
<td>Hilbert et al.28</td>
<td>Randomized controlled trial: pre-test/post-test group design</td>
<td>2</td>
<td>18 volunteers (male and female), mean age 20.4 years ±1.0</td>
<td>A senior physical therapy student</td>
<td>Classic Swedish techniques (effleurage, percussion, petrissage)</td>
<td>20 minute standardized protocol</td>
<td>1) The massage protocol did not impact any of the following variables: range of motion, peak torque, neutrophil count, mood, or unpleasantness of soreness. 2) The massage protocol led to a significant decrease in intensity of soreness (Differential Descriptor Scale) in the massage group as compared to the control group.</td>
</tr>
</tbody>
</table>

Table 4. Table Summarizing Studies Related to the Effects of Massage on Sports Performance
It is commonly believed that massage can increase an athlete’s flexibility, which in turn may enhance performance. While there is some evidence supporting this belief, the effects of massage on flexibility are not always as clear-cut as one might hope. A recent study investigated the immediate effects of massage on hamstring flexibility in physically active young men. The study found that massage did not have a significant effect on hamstring flexibility, but the results were not maintained after 24 hours.

In a subsequent investigation by Hopper et al., they reported significant increases in hamstring flexibility after performing a dynamic treatment approach. The DTSM program was also performed for 8 minutes. The passive straight leg raise (PSLR) and passive knee extension (PKE) tests were used to measure hamstring length prior to the treatment intervention, immediately after the massage, and 24 hours later. Both techniques immediately created statistically significantly changes in hamstring lengths as measured by the PKE test. The flexibility changes though were not maintained at 24 hours in either group.

In another study by Barlow et al., they investigated the immediate effects of massage on hamstring flexibility in physically active young men. They concluded that massage did not have a significant effect on hamstring flexibility, but the results were not maintained after 24 hours.

While Barlow et al. failed to demonstrate a statistically significant change in flexibility, Hopper et al. found massage made significant short term changes in hamstring flexibility. Female field hockey players from Western Australia’s Premier League were recruited for the study. The study's inclusion criteria of experiencing a stretching sensation on the posterior thigh at an angle less than 70° during a straight leg raise (SLR), having full knee extension range of motion, and having full ankle plantarflexion were met by the study's population.

Athletes were randomized into one of two treatment groups; a group receiving a “classic” massage and a group receiving dynamic soft tissue mobilization (DSTM). The classic massage consisted of effleurage, kneading (petrissage), and shaking techniques for an 8-minute treatment. The DSTM treatment consisted of classic massage strokes and a dynamic treatment approach. The dynamic technique was performed using a “long slow stroke” with a fist-ed hand applied both longitudinally and across the muscle fibers. This technique was applied while first passively extending the subject’s knee, then while the subject actively extended their own knee, and finally while the therapist passively extended the knee while the subject performed an eccentric contraction of their hamstring muscle. The DSTM program was also performed for 8 minutes. The passive straight leg raise (PSLR) and passive knee extension (PKE) tests were used to measure hamstring length prior to the treatment intervention, immediately after the massage, and 24 hours later. Both techniques immediately created statistically significantly changes in hamstring lengths as measured by the PKE test. The flexibility changes though were not maintained at 24 hours in either group.

In a subsequent investigation by Hopper et al., they reported significant increases in hamstring flexibility after performing the DSTM program when compared to a classic massage approach or a control group. In this investigation, the subject sample was 45 healthy males (mean age = 23.7 years, SD = 4.6, range = 18 to 35 years), whereas, the previous study's population consisted of female athletes. The “classic” massage protocol utilized effleurage, kneading, picking up, and shaking techniques performed for 5 minutes. The DSTM program was similar to the one described in Hopper et al. The DTSM group demonstrated significantly greater increases in hamstring flexibility as compared to the classic approach or the control group. While the DTSM protocol had a greater effect on immediate hamstring flexibility gains (post-test measurements conducted 90-seconds after treatment), the clinical significance of these results is difficult to extrapolate.

While it appears that some athletes may experience improvements in hamstring flexibility after one massage, these changes appear to be transient. If a short term goal is to increase an athlete's flexibility, more efficient methods may exist (especially in the absence of an adequately staffed sports medicine team). Future research should investigate which athletes are ideal candidates for massage intervention, how long each massage intervention should be performed, and what duration is necessary to establish permanent flexibility changes.
Massage Effects on Strength
Brooks et al. assessed the effects of massage on power grip performance after maximal exercise in healthy adults. The authors conducted a pre-test and post-test study design with subjects randomized to one of four intervention groups. The testing protocol consisted of a pre-test grip strength measurement, the exercise protocol to fatigue the muscles of the hand, the intervention, a 5-minute rest period, and the post-test strength measurement. To fatigue the muscles of the hand and the forearm, participants isometrically squeezed a hand exerciser until performance had declined to 60% of their baseline measurement. After the exercise period, the subjects were randomized to one of the following treatment groups: a 5-minute standardized massage to the dominant hand, a 5-minute standardized massage to the non-dominant hand, 5-minutes of passive shoulder and elbow range of motion, or 5-minutes of rest. The 5-minute massage protocol, consisting of effleurage and circular friction strokes, was performed by two senior therapeutic massage students. The authors found the massage intervention to be significantly superior to the non-massage interventions for post exercise grip performance. It was also observed that grip performance after massage was significantly greater in the non-dominant versus the dominant arm.

The most clinically relevant outcome was that the massage intervention demonstrated better results than the natural recovery of the control group. The authors surmise that applying massage (in this case for 5-minutes) shortly after fatiguing exercise is beneficial.

Mancinelli et al. investigated the effects of massage on female collegiate athletes when performed at the beginning of the basketball and volleyball seasons. Twenty-two NCAA division I women's basketball or volleyball players were recruited (11 allocated to the treatment group and 11 serving as controls). A 17-minute massage consisting of effleurage, petrissage, and vibration techniques was performed on the day of predicted peak soreness (as predicted by the strength coach). The authors found that the massage intervention helped to significantly improve vertical jump, led to a significant increase (a slowing) of shuttle run times, and significantly decreased the athlete's perceived soreness. While the results suggest that performing a massage at an opportune time will have positive functional outcomes, the results of this study are in question due to significant design flaws. These flaws include a small sample size, the inability to control for the pre-season conditioning levels of the athletes, and the reliance upon the subjective prediction by the strength coach as to the date of expected peak muscle soreness.

EFFECTS OF SPORTS MASSAGE ON RECOVERY FROM EXERCISE AND COMPETITION
Effects on Delayed Onset Muscle Soreness
Delayed onset muscle soreness (DOMS) is a common physiological response experienced by athletes after initiating or resuming an exercise routine, after increasing exercise intensity, or after performing eccentric forms of training (i.e. downhill running). Delayed onset muscle soreness has been associated with minor to severe pain occurring 24 to 72 hours after the exercise bout. Athletic performance may be hampered due to DOMS, loss of range of motion, and decreased muscle strength. While these symptoms may be temporary and part of the natural process of strength and conditioning training, the ramifications for sports performance during competition may be staggering. Theoretically, it would be beneficial to prescribe modalities that could either prevent the onset or decrease the impact of DOMS.

Six theories have been proposed to explain the mechanisms of DOMS. The six theories are: lactic acid, muscle spasm, connective tissue damage, muscle damage, inflammation, and enzyme efflux. Researchers have specifically investigated the effects of massage upon blood lactate levels and changes in blood flow (Table 5).

Effect of Massage on Blood Flow
Massage has been proposed as a treatment modality to increase blood flow. Proponents of massage argue that local circulatory changes occur as evidenced by the changes in skin temperature and superficial hyperemia. Initial studies measuring Xe-133 isotope clearance and venous occlusion plethysmography indicated that massage had an effect on blood flow, whereas more recent studies using Doppler ultrasound techniques have found that massage had no effect on arterial or venous blood flow.

Blood Lactate Clearance
The rationale behind the lactic acid theory is that lactic acid produced after exercise contributes to the pain and soreness experienced by the athlete. Massaging a muscle or muscle group experiencing DOMS could, theoretically, help to facilitate the removal of lactic acid from those areas.
Many amateur sports (such as track and field, boxing, and swimming) may require athletes to participate in several events or matches during a short period of time. Hemmings et al.20 studied the effects of massage on both physiologic and perceived recovery in eight amateur boxers. The investigators designed a testing protocol to examine if massage performed between bouts of simulated boxing matches would help to improve physiologic variables (blood glucose and lactate concentrations), performance, and the athlete's perception of recovery. The experimental design consisted of a 10-minute active warm up period, five 2-minute rounds of simulated boxing matches with 1-minute rest periods between each round, an intervention period (20-minute massage or no massage), a 35-minute rest period (a time period representative of the period of time between events or matches), a second 10-minute active warm up period, and a repeat of the aforementioned boxing simulation. Four of the eight boxers served as controls during the first round of testing. During the second round of testing, the boxers switched groups.20

During the intervention period, the athlete either received a massage or rested lying on a mat. The 20-minute massage (effleurage and petrissage) protocol consisted of 8 minutes of treatment performed on the legs, 2 minutes on the back, and 10 minutes for the shoulders and arms. Blood lactate testing was performed
before and after each boxing simulation and after the intervention. During the rest period, each boxer completed a perceived recovery scale. The authors chose to measure performance by comparing mean peak punching force per round.20

The authors found that regardless of whether the athlete received a massage or had rested in a supine position, the mean punching force decreased during the second boxing simulation. As previously indicated the authors found that the massage intervention had a statistically significant effect on the boxers’ perception of recovery. Massage intervention also did not affect blood lactate concentrations and, surprisingly, boxers who had received the massage intervention did not affect blood lactate concentrations during the second simulation.20 This finding was unexpected, for which the authors proposed that the perceived psychological recovery might have affected the boxers’ later effort and energy expenditure.20

Robertson et al32 examined the effects of massage on lactate clearance, muscular power output, and fatigue after bouts of high intensity training. Nine male athletes (rugby, football, or field hockey) were recruited for the study. A testing protocol began with a standardized warm up period consisting of 5-minutes of cycling and 3-minutes of static stretching for the hamstrings, calf, and quadriceps muscles.32 Six 30-second bouts of high intensity training were performed on a cycle ergometer (with 30 seconds of active recovery between sets). Upon completion of the high intensity repetitions, the athletes performed 5-minutes of active recovery followed by a 20-minute intervention. Subjects were randomized into one of two interventions: a 20-minute massage or 20-minutes of “passive supine rest.” The massage intervention was performed each time by the same physiotherapist. The massage sequence consisted of effleurage and petrissage techniques performed in a standardized protocol sequence of 5 minutes to the back of the left leg, 5 minutes to the back of the right leg, 5 minutes to the front of the right leg, and 5 minutes to the front of the left leg. After the intervention period, the athlete performed the same 8-minute warm up (5-minutes of cycling and 3-minutes of static stretching) followed by one 30-sec-

Table 5. Table Summarizing Research Related to the Effects of Sports Massage on Recovery from Exercise and Competition (cont’d)

<table>
<thead>
<tr>
<th>Lightfoot et al42</th>
<th>Randomized controlled trial: pre-test/post-test design</th>
<th>2</th>
<th>31 college-age subjects (12 men and 19 female)</th>
<th>Massage therapist</th>
<th>Petrissage</th>
<th>10-minute to the left calf</th>
<th>Massage intervention to the left calf demonstrated no difference for soreness levels or leg volumes as compared to the control group.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weber et al43</td>
<td>Randomized controlled trial: pre-test/post-test design</td>
<td>2</td>
<td>40 untrained volunteer female subjects, group mean age 23.7 years, SD 4.0</td>
<td>Physical therapist</td>
<td>Effleurage, petrissage</td>
<td>8-minute standardized protocol</td>
<td>No statistical difference between massage, active recovery, microcurrent, and controls for soreness ratings and force generation.</td>
</tr>
<tr>
<td>Hart et al44</td>
<td>Within subjects experimental design with counterbalanced design</td>
<td>3</td>
<td>19 college aged volunteers (10 men, 9 women), mean age 20.6±1.2 years</td>
<td>Certified athletic trainer</td>
<td>Petrissage (kneading) and effleurage (broad stroking)</td>
<td>5-minute standardized “sports” massage</td>
<td>The sports massage protocol did not significantly reduce either leg girth or pain as compared to the control leg within 72 hours of exercise.</td>
</tr>
<tr>
<td>Monedero et al45</td>
<td>Within subjects experimental design with counterbalanced design</td>
<td>3</td>
<td>18 healthy trained male cyclists, mean age 25±0.9 years</td>
<td>Certified masseur</td>
<td>Effleurage, stroking, and tapotement</td>
<td>Massage group: 15-minute massage Combined recovery group: 7.5 minutes of massage and 7.5 minutes of active recovery</td>
<td>1. Combined recovery significantly better at removing blood lactate at 12-minutes (as compared to all interventions); 2. Combined recovery was a superior approach to maintaining performance over passive recovery and active or massage interventions.</td>
</tr>
<tr>
<td>Dawson et al46</td>
<td>Quasi-experimental pre-test/post-test</td>
<td>3</td>
<td>12 runners (8 males, 4 females), mean age 35.2±8.3 years</td>
<td>Massage therapists</td>
<td>Effleurage, petrissage</td>
<td>30-minute standardized protocol</td>
<td>The use of massage, when compared to the control leg, did not facilitate a faster return to baseline measures for strength, soreness, or leg circumference.</td>
</tr>
<tr>
<td>Hilbert et al47</td>
<td>Repeated measures pre-test/post-test RCT</td>
<td>2</td>
<td>18 volunteers (male and female), mean age 20.4±1.0 years</td>
<td>A senior physical therapy student</td>
<td>Classic Swedish techniques (effleurage, percussion, petrissage)</td>
<td>20 minute standardized protocol</td>
<td>1. The massage protocol did not impact any of the following variables: range of motion, peak torque, neutrophil count, mood, or unpleasantness of soreness. 2. The massage protocol led to a significant decrease in intensity of soreness (Differential Descriptor Scale) in the massage group as compared to the control group.</td>
</tr>
<tr>
<td>Smith et al48</td>
<td>Randomized controlled trial: pre-test/post-test design</td>
<td>2</td>
<td>14 untrained males; massage group (n=7; mean age 20±1.1), and control group (n=7; mean age 18.8±0.3)</td>
<td>Physical therapist</td>
<td>Effleurage (stroking), shaking, petrissage (kneading), wringing, cross-fiber massage</td>
<td>30-minute standardized “sports” massage performed 2 hours after exercise</td>
<td>A significant trend analysis for treatment by time interaction effect with 1) the massage group reporting lower levels of muscle soreness; 2) reduced CK levels in the massage group; 3) massage group demonstrating elevated neutrophil levels.</td>
</tr>
</tbody>
</table>

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<tr>
<th>Table Summarizing Research Related to the Effects of Sports Massage on Recovery from Exercise and Competition (cont’d)</th>
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<tr>
<td>Hilbert et al47</td>
</tr>
<tr>
<td>Smith et al48</td>
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</table>
ond high intensity bout (Wingate test). Blood samples were collected prior to testing, after the first high intensity training, after 10- and 20-minutes of the intervention time period, and 3 minutes after the final high intensity test. The authors found no statistical difference between the massage and passive rest interventions for blood lactate concentrations and power. A significant difference did occur between the massage intervention and the rest group for the fatigue index. The fatigue index is the percentage change in power output between the first 5-seconds and the last 5-seconds in a 30-second period. The authors suggested that additional investigations were necessary to identify the role of massage on an athlete’s fatigue profile.

Jonhagen et al recruited 16 people (8 men and 8 women, mean age 28 years) in order to assess if sports massage can improve recovery after an eccentric exercise protocol. Subjects performed 300 maximal eccentric quadriceps contractions with each leg on a Kin-Com dynamometer (Harrison, TN). A massage program was initiated 10 minutes after exercise, with one leg from each subject randomized to receive the massage treatment. The massage program consisted of 4-minutes of effleurage and 8-minutes of petrissage. The massage protocol was also performed daily each of the next two days. Testing was performed before the exercise protocol, after exercise, and on the third day. Strength testing was performed on the Kin-Com dynamometer, a vertical long jump was performed to measure functional changes, and a visual analog scale (VAS) was used to measure a subject’s pain. The VAS was performed before and after exercise and before and after the massage treatment. Microdialysis was also performed in the vastus lateralis muscle to analyze levels of the neuropeptide Y (NPY) and calcitonin gene-related peptide (CGRP). Both NPY and CGRP are neuropeptides involved in the vasodilatation of skin tissue and the modulation of pain. The authors found that sports massage failed to influence any of the dependent variables. Resultant strength loss was significant in both treatment groups, even on the third day. Sports massage also failed to impact functional recovery. Both groups’ demonstrated significantly lower long jump scores, with a normalization of scores occurring by day three. No statistical difference was observed either in pain scores between legs or for changes in CGRP and NPY levels.

Additional studies evaluating the effects of massage on athletes experiencing DOMS have also failed to demonstrate positive effects. Active recovery techniques have been shown to be consistently superior to massage for lactate clearance. In addition, massage interventions have failed to effect post-exercise limb girth. Subjects who received massage generally experienced no improvement in pain or soreness perception as compared with controls. Hilbert et al suggested massage can positively affect subjects' perceived intensity of DOMS related soreness, but not until 48 hours post exercise.

Although it is commonly thought that lactic acid accumulation after exercise leads to the pain associated with DOMS, this theory has been recently rejected. Any increased lactic acid levels after exercise return to baseline in approximately one hour after exercise. Lactic acid likely only contributes to acute pain versus the pain experienced 24 to 48 hours after exercise.

**Massage Effects on Creatine Kinase and Neutrophil Levels**

Smith et al designed a study to investigate the effects of massage on variables other than lactic acid. The authors theorized a massage intervention performed two hours after exercise interferes with neutrophil emigration which may reduce the intensity of pain due to inflammation. Initial results indicated that the 30-minute massage protocol applied two hours after the exercise program helped to reduce DOMS and creatine kinase levels. This particular protocol appeared to demonstrate promising results, but the results are challenged by a small sample size (n=14). Although the authors called for continued studies, to date, no further clinical studies have been published on this aspect.

**ROLE OF SPORTS MASSAGE IN THE TREATMENT OF SPORTS INJURIES**

Both classic massage techniques and deep transverse friction massage (DTFM) are performed in clinical rehabilitation settings. Despite the popularity of these forms of massage by both therapists and patients, very few studies have been conducted on this intervention, making it a challenge to draw conclusions regarding the efficacy of their use.

**Paucity of Sports Massage Reports**

Despite the prevalence of low back pain, a review of the literature was unable to identify any randomized controlled trials or quasi-experimental studies investigating the role of massage in the treatment of sports-related back injuries. Two “non-sports” massage papers are presented...
here to demonstrate the challenges in interpreting the literature.

Preyde\textsuperscript{49} researched the application of massage in the treatment of patients with subacute low back pain. In this study, subjects were randomized to one of four groups: a comprehensive massage therapy group (CMT), a soft tissue mobilization only group, a remedial exercise and postural education only group, and a placebo group who received a sham ultrasound. Subjects in the CMT group experienced a statistically significant improvement in function, reported less intense pain, and experienced a decrease in the quality of pain as compared to the other three groups.\textsuperscript{49}

Even though the author concluded that patients with subacute low back pain benefited from massage therapy, the CMT group received massage (utilizing a non-standardized treatment protocol), exercise prescription consisting of a lower extremity stretching program, were encouraged to walk, swim, do aerobics, and strengthening exercises, and received education on posture and body mechanics. While at the 1-month follow up period, a significant number of patients in the CMT group had no pain; it would be a leap to attribute all of this to the massage (only 27% of subjects in the massage only group were pain free at one month). Rather this research may demonstrate that those who receive posture/body mechanics education, perform exercises, and receive massage have better outcomes versus those who only receive one treatment modality.\textsuperscript{49}

A recent Cochrane Collaboration Back Review has concluded that the use of massage might benefit patients with subacute and chronic nonspecific low back pain, especially when the massage is combined with patient education and exercise prescription.\textsuperscript{50} Despite this conclusion, the panel highlights the need for additional studies to confirm the efficacy of massage for subacute and chronic LBP and to assess the effect of massage on returning-to-work.\textsuperscript{50}

Pettitt et al\textsuperscript{51} reported the use of massage in the management of a 19-year old female middle distance runner suffering from sport-related chronic knee pain. The patient underwent an iliotibial band release after initial failure of conservative treatment. Despite a course of postoperative therapy, the patient continued to experience symptoms. The authors implemented a treatment program consisting of joint and soft tissue (massage) mobilization, therapeutic exercise, and neuromuscular electric stimulation. The massage protocol consisted of effleurage strokes. The authors reported that the subject was able to return to running and complete an entire season of indoor track and field after receiving this 10-week course of rehabilitation. While massage was one component of the

<table>
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<tr>
<th>Study (Year) Design</th>
<th>Level of Evidence</th>
<th>Participants</th>
<th>Professional(s) Conducting the Intervention</th>
<th>Techniques</th>
<th>Treatment Time</th>
<th>Results and Authors’ Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preyde et al\textsuperscript{49}</td>
<td>Randomized controlled trial</td>
<td>2</td>
<td>Four groups: comprehensive massage therapy (n=25, mean age 47.9±16.2); soft tissue manipulation (n=25, mean age 46.5±18.4); remedial exercise and education (n=22, mean age 46.4±12.9); placebo (n=26, mean age 41.9±16.6)</td>
<td>Two massage therapists (each &gt; 10 years experience)</td>
<td>Friction, trigger points, neuromuscular therapy</td>
<td>30 to 35 minutes each session.</td>
</tr>
<tr>
<td>Furlan et al\textsuperscript{50}</td>
<td>Systematic Review</td>
<td>1</td>
<td>MEDLINE, Embase, Cochrane Controlled Trials Register, HealthSTAR, CINAHL, and dissertation abstracts</td>
<td>Not applicable</td>
<td>Any type of massage (using the hands or mechanical device)</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Pettitt et al\textsuperscript{51}</td>
<td>Case report</td>
<td>5</td>
<td>19-year old female distance runner</td>
<td>Athletic trainer</td>
<td>Effleurage</td>
<td>5-minutes each weekday</td>
</tr>
<tr>
<td>Blackman et al\textsuperscript{52}</td>
<td>One group-repeated measures design</td>
<td>3</td>
<td>Seven athletes (6 men and 1 woman), Mean age not provided (range 21 to 29 years)</td>
<td>Not provided</td>
<td>Longitudinal gliding, transverse gliding, digital ischemic pressure, myofascial release</td>
<td>15-minute standardized protocol. Each patient received 6 treatments over a 5 week period.</td>
</tr>
</tbody>
</table>

Table 6. Table Summarizing Research Related to the Role of Sports Massage in the Treatment of Sports Injuries
rehabilitation program, the authors acknowledge the fact that the unique role of any one treatment cannot be known.51

Blackman et al52 investigated the effects of massage on chronic exertional compartment syndrome (CECS). This study again highlighted the design challenges that researchers investigating massage effects have experienced. Athletes suffering from CECS complain of cramping or aching pain that develops with exercise and resolves with cessation of activity.53,54 The authors recruited seven athletes (age range 21 to 29 years) with a confirmed diagnosis of anterior CECS.52 Each athlete participated in a 5-week rehabilitation program. A standard massage intervention consisted of various techniques for 15-minutes each session. Massage was performed two times a week during the first two weeks and one time a week for the remaining three weeks.52 Patients were also instructed to perform a standard stretching program for both anterior and posterior musculature twice a day. After the 5 week course of therapy, no significant changes were found in compartment pressures after exercise. The authors did find a significant change in the amount of exercise that could be performed prior to pain onset. Study limitations included the small sample size and the prescription of multiple treatments.52

Efficacy of Deep Transverse Friction Massage
Deep transverse friction massage (DTFM) has been suggested as a treatment option for tendon injuries such as tennis elbow.9 Paucity in the literature exists regarding the use of DTFM in the treatment of sports-related injuries. Despite the popularity of its use,9 a review of the available research literature fails to support the use of DTFM,55,56 whereas, eccentric exercise has demonstrated efficacy in the conservative management of tendinopathies.57,58

DISCUSSION
Despite the fact that massage has been used as a treatment modality for centuries, a poor appreciation for its clinical effectiveness exists. Although several unique studies have been designed to investigate the effects of sports massage, further investigations are warranted.

Indirect evidence exists suggesting that massage may be beneficial on factors related to an individual’s psychological state. While these investigations demonstrated improvements in blood pressure,18 mood states,18,29 and perception of recovery,20-22 study design flaws limit the strengths of the conclusions. Future research should investigate the application of massage immediately prior to stressful sports performance situations, the effects of massage on an athlete’s perception of recovery between bouts or events, and the effects of massage on an athlete’s mood state throughout an entire season.

Massage has generally failed to demonstrate positive effects upon sports performance.20,32,40 One study utilizing massage at the beginning of the season demonstrated an increase in the experimental groups’ vertical jump, but the study’s conclusions are threatened by several design flaws.28 Researchers have demonstrated an association between massage and temporary changes in hamstring flexibility23,25 and grip performance.27 While the results from these studies do not predict future sports performance, these studies should provide guidance in the development of future investigations. Additional research should be directed at performing a massage prior to immediate athletic performance (e.g. massage to the upper extremity prior to a discus throw).

Massage has also generally failed to effect physiological parameters related to DOMS.20,32,33,40-45 The few studies that have reported positive effects from massage on a subject’s pain or soreness perception have had study design flaws and no follow-up investigations to date.47,48 To account for the individuals who report decreased pain or a perceived improvement after a massage, future research should investigate local concentrations of chemo-inflammatory factors.

Minimal studies have been performed investigating the role of massage in sports rehabilitation.51,52 Paucity in the literature exist related to sports massage and the management of sports-related injuries. Evidence appears to suggest that massage is efficacious for use with patients with subacute and chronic low back pain.49,50 Clinical research and case reports are greatly needed to help guide physical therapy decision making when rehabilitating sports injuries.

CONCLUSION
Research evidence has generally failed to demonstrate massage significantly contributing to the reduction of pain associated with delayed onset muscle soreness, or significantly enhancing sports performance and recovery, or playing a significant role in the rehabilitation of sports injuries. Design flaws in research have challenged some of the positive outcomes. Additional studies examining the physiological and psychological effects of sports massage are necessary in order to enhance the sports physical ther-
apists’ ability to develop and implement clinically significant evidence based programs or treatments.

REFERENCES


ABSTRACT

The purpose of this manuscript is to provide an expedient means of immobilizing a glenohumeral dislocation in neutral rotation. This technique for post-reduction immobilization of a glenohumeral dislocation is inexpensive and easy to fabricate. Anterior glenohumeral dislocations often involve an avulsion of the labrum from the glenoid rim. In contrast to immobilization in internal rotation, positioning the shoulder in 0-45º of external rotation approximates the labrum and glenoid rim. It is hypothesized that placing the shoulder in a more externally rotated position could allow for better healing and increased joint stability. This technique places the shoulder in neutral rotation, because 45º of external rotation is awkward and may interfere with certain activities of daily living. Structural aluminum malleable (SAM) splints are used as an alternative to a bolster sling. The SAM splints are lightweight, simply shaped, and easily stored.

Key Words: glenohumeral dislocation, immobilization, neutral rotation

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ACKNOWLEDGEMENTS
The author would like to acknowledge Specialist Jose Yenderrozos (Combat Medic) for his ingenuity in conceptualizing and fabricating the sling and splints for immobilizing a shoulder in neutral rotation.

The views expressed in this manuscript are those of the author and do not reflect the official policy of the U.S. Army, Department of Defense, or U.S. Government.
PROBLEM
Anterior glenohumeral dislocations are a common athletic injury. Initial treatment can include immobilization followed by physical therapy for range of motion and strengthening exercises, immediate surgery, or delayed surgery.1-4 Following a traumatic dislocation, many patients report glenohumeral joint instability.2-5 Anterior glenohumeral dislocations often involve an avulsion of the labrum from the glenoid rim.6-11 Immobilization in a standard arm sling places the glenohumeral joint in internal rotation and adduction. This position does not allow the avulsed labrum to contact the glenoid rim which could result in the labrum not healing, possibly leading to chronic glenohumeral instability. Positioning the shoulder in 0-45° of external rotation approximates the labrum and glenoid rim.6-9 It is hypothesized that placing the shoulder in a more externally rotated position could allow for better healing and increased joint stability.11 Physical therapists may encounter a traumatic glenohumeral dislocation on the playing field or on the battlefield and not have a bolster sling readily available to immobilize the joint in an optimal position post-reduction.

SOLUTION
The shoulder can be immobilized in neutral rotation using two structural aluminum malleable (SAM) splints (SAM Medical Products, Portland, OR), one standard arm sling, and one ace bandage (Figure 1). The two SAM splints are shaped into a triangle, and one is placed inside the other. Additionally, the edges should be slightly C-curved for increased strength and molded to the patient's flank and forearm (Figure 2). The patient's affected arm is placed in the standard sling and secured to one side of the SAM splint using the ace bandage. The other side of the SAM splint rests against the patient's flank. The arm is effectively immobilized in neutral rotation (Figure 3). This technique places the shoulder in neutral rotation, because 45° of external rotation is awkward and may interfere with certain activities of daily living.
DISCUSSION

The materials used in this technique are inexpensive, easy to use, and can be easily stored in a sports medicine bag. The splinting materials are lightweight, so as not to impart a significant traction force to the healing joint. This technique allows for efficient and effective immobilization of the glenohumeral joint in neutral rotation, which may contribute to improved healing and decreased instability following a dislocation.11

REFERENCES

THE EFFECTS OF TWO ADHESIVE ANKLE-TAPPING METHODS ON STRENGTH, POWER, AND RANGE OF MOTION IN FEMALE ATHLETES

Katherine E. Quackenbush, BKin
Paula R.J. Barker, BKin
Shauna M. Stone Fury, BSc
David G. Behm, PhD

ABSTRACT

**Background.** Taping is a ubiquitous strategy to help prevent ankle sprains. The restrictive qualities of various taping methods may impair athletic performance.

**Objective.** The objective of the study was to compare the Gibney closed basket weave taping method with heel-locks to heel-locks and figure-eights in order to determine their effect on vertical jump performance and active range of motion (ROM) before and after exercise.

**Methods.** Eleven female varsity basketball athletes were subjected to three conditions of no ankle support (control), heel-locks, and figure-eights. The dependent variables of ankle active ROM, plantarflexor maximum voluntary contraction and jump height for the countermovement jump (CMJ), drop jump (DJ), and concentric only squat jump (COSJ) were randomly ordered. Following taping or control conditions, participants were pre-tested, completed a ten-minute treadmill run at 9.6 km/hr with a 3 minute cool down and then repeated the testing procedures.

**Results.** There were no significant differences in jump performance between taping methods or the effect of exercise. However significant differences for pre-/post-exercise for plantarflexor (p < 0.0001) and dorsiflexor (p = 0.007) active ROM and between no support and taping for plantarflexor ROM (p = 0.004) was found.

**Conclusions:** Despite plantarflexor active ROM being restricted by both taping procedures compared to the control, no effect on jump performance occurred.

**Key words:** flexibility, drop jump, countermovement jump, squat jump, ankle sprain

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METHODS
Experimental Design
Participants were tested before and after the application of a Gibney closed basketweave with heel locks (HL), Gibney closed basketweave with heel locks and figure-eights, and a control condition. Following the application of the tape, participants ran on a treadmill for 10 min at 9.6 km.h⁻¹ with a level grade and then were re-tested with the same cadre of tests used in the pre-test. These measures consisted of ankle active range of motion (ROM); drop, countermovement, and concentric only squat jumps; and plantarflexor maximal voluntary contraction.

Subjects
Eleven female college basketball athletes (height = 172.1 ± 6.7 cm, weight = 69.2 ± 12.9 kg, age = 20.6 ± 1.4, range, 19 to 25 years) with no ankle injury in the past three months volunteered to participate in this study. The attending athletic therapist assessed all subjects for healthy ankle function. Approval from the Interdisciplinary Committee in Ethics in Human Research (ICEHR) at Memorial University of Newfoundland was obtained and written informed consent was obtained from all subjects.

Instruments
All vertical jumps were performed using a contact mat (Innervations, Muncie, IN) and analyzed using the Kinematics Measurement Systems (Innervations, Muncie, IN) software program. The software program recorded jump height based on flight time. In order to ensure validity of the test, participants were asked to have their knees as fully extended as possible and ankles completely plantarflexed at both take off and landing. Subjects performed plantarflexor maximal voluntary control while seated in a straight-backed chair with hips and knees at 90°. Isometric contractions were performed with their leg secured in a modified boot apparatus with their ankles flexed at 10° of dorsiflexion. All torques were detected by strain gauges, amplified (Biopac Systems Inc., DA 100: analog-digital converter; Holliston, MA) and monitored on a computer (Sona Phoenix, St. John’s, Newfoundland). Data were stored on a computer at a sampling rate of 2000 Hz. Data were recorded and analyzed with a commercially designed software program (AcqKnowledge III, Biopac Systems Inc., Holliston, MA).
Taping Method

The same certified athletic therapist applied the tape bilaterally to each subject. Cramer® Tuf-Skin tape adherent (Gardner, Kansas) was initially sprayed on the feet of each participant. Next, Cramer® heel and lace pads (Gardner, Kansas) were applied to both feet at the posterior calcaneus and dorsum of the foot at the ankle (talocrural joint) to help prevent blistering from friction associated with the tape application. Cramer® Skin Lube lubricating ointment (Gardner, Kansas) had been placed on the heel and lace pads prior to application. The tape, 1½ inch zinc oxide Johnson and Johnson Coach® athletic tape (Princeton, New Jersey), was then applied bilaterally to the participants in either the heel-lock or figure-eight methods, as according to Perrin.18

The Gibney closed basketweave with HL taping procedure had the ankle positioned at 90º of dorsiflexion. Two anchor strips were placed on the distal leg (foot anchors were left out as they frequently cause constriction and discomfort).18 A stirrup was applied from the medial aspect of the leg and pulled under the heel to the lateral aspect of the leg using the malleoli as landmarks. A horizontal horseshoe strip was placed from the medial to lateral aspect of foot, while another stirrup was placed in a weaving fashion. The horseshoe and then the stirrup process were continued until three stirrups were applied. The leg was enclosed with horizontal strips ensuring no skin was visible. Heel-locks were applied in a single manner (pulling in upward direction).

The other taping condition included the Gibney closed basketweave with heel-lock as well as a figure-eight. The additional figure-eight taping started on the lateral malleolus and continued down and under the medial aspect of the foot pulling up over the dorsum of the foot to the medial malleolus and around the back of the Achilles tendon and returning to the lateral malleolus. This process was repeated twice for the Figure 8 option.

Testing

Testing was conducted before and after exercise under three conditions: control, heel-locks and figure-eights. The treatment order was randomly assigned. Each testing condition occurred on separate days. Separate testing conditions were conducted within a range of 24–72 hours. Measurements included ankle joint active ROM, plantarflexor maximal voluntary control, and vertical jump tests involving concentric only squat jump (COSJ), countermovement jump (CMJ), and drop jumps (DJ). Ankle active ROM was always tested initially since dynamic jumping movements could loosen the tape adhesion. All jump measures were completed in a randomized order to prevent any effects from fatigue or learning.

Measurements of active ROM at the ankle joint were taken between full dorsiflexion and full plantarflexion for both feet (Figures 1 and 2). The focus of the paper was on the effects of these two adhesive ankle-taping methods on performance (strength, power, and ROM). Thus, changes in the plantarflexor and dorsiflexor ROM could possibly affect jump performance by hindering impulse (force x time) and work (force x distance) performed. Dorsiflexion (Figure 1) and plantarflexion (Figure 2) active ROM were measured as the participant sat with their leg hanging from a bench. Participants then contracted either their dorsiflexors or plantarflexors maximally in order to achieve the greatest active ROM possible. A goniometer was used with one lever of the goniometer placed on the proximal fibular head, while the other was placed on the fifth metatarsal. The pivot was positioned on the lateral malleolus. The ROM was recorded based on the position of the lever on the fifth metatarsal. The same certified athletic therapist completed all active ROM measurements.
first two trials) another three-minute rest was allocated.

The CMJ is similar to sport specific situations, therefore, emphasizing game-like maneuvers. Participants stood with their feet shoulder width apart and flat on the contact mat. With hands on hips, they were instructed to jump as high as possible by using their own choice of depth and pace. Allowing the subject a choice ensured that participants were using a comfortable jumping technique that they would normally utilize in an athletic setting. An athletic population was utilized due to their familiarity with the jumping technique, thereby, reducing variability.

The DJ, which emphasized the stretch-shortening cycle of the ankle, was performed with the participants standing with both feet flat on a 30cm high platform. This height has been used in previously published studies\(^{16,19,20}\) to ensure an optimal combination of jump height and minimum contact time. With hands on hips, participants were instructed to drop off the platform by stepping forward with whichever foot felt most comfortable. This foot was then used to initiate the DJ for all further testing. Upon contacting the mat with both feet, they were told to jump as high and as fast as possible. Subjects attempted to limit excessive knee flexion such that the ankle was emphasized to a greater extent in the generation of the jump forces.

The COSJ was tested due to its emphasis on impulse generation.\(^{16}\) With hands on hips, participants stood with feet shoulder width apart and flat on the contact mat with their knees flexed at 90°. This position was held for two seconds. After the two-second period they were told to jump as high as possible.

A thirty-second recovery was provided between all jump trials. Jump height was used as the indicator of best performance for all jumps. The three jumps were chosen to ascertain the effect of taping on three physiological parameters. This particular form of DJ was performed with specific instructions to mainly involve a rapid stretch-shortening cycle action of the ankles.\(^{14,19,20}\) In contrast, the CMJ used a moderate speed stretch-shortening cycle (angular speed dependent on participant’s preference) which emphasized both knees and ankles which contrasted with the COSJ that lacked a significant stretch-shortening cycle.

Previous research from our laboratory\(^{22}\) has reported the following intraclass correlation coefficients (ICC) for plantarflexor range of motion (0.94), squat jump (0.96), countermovement jump (0.93) and drop jump (0.89) respectively. Other research from our laboratory utilizing the plantarflexor maximal voluntary control has shown ICC values ranging from 0.91 – 0.99.\(^{17}\)

Participants then completed a ten-minute exercise protocol on a treadmill (9.6 km.h\(^{-1}\)) at a level grade followed by a three minute cool down (4.5 km/hr) to initiate the loss of the tape’s restrictive properties. The treadmill speed was chosen to provide a typical pace used in a pre-competition warm-up by these athletes. This speed was based on pilot studies utilizing the same athletes. At completion of the exercise protocol the testing procedures were repeated in a randomized order with active ROM again being completed first. Only two trials of each testing procedure were necessary unless there was more than a five percent difference between the two measurements and then a third measurement was conducted. All measurements were recorded with the best performance (maximal voluntary control force and jump heights) used for the data analysis.

**Data Analysis**

The data was analyzed using a two way ANOVA (two times: pre- and post-exercise x 3 tape conditions: control, heel-locks, figure-eights) with repeated measures. An alpha level of \(p < 0.05\) was considered statistically significant. If significant differences were found, a Bonferroni-Dunn’s procedure was conducted to identify where the significant change occurred. Effect sizes (ES = mean change / standard deviation of the sample scores) were
RESULTS
Overall, for all dependent variables tested (maximal voluntary contraction force, CMJ, DJ, COSJ), except the active ROM, no significant differences existed for the taping method or the effect of exercise when comparing any of the independent variables (control, heel-locks, figure-eights). The control condition exhibited 24.9% and 27.5% significantly (p < 0.05) greater plantarflexion active ROM as compared to HL (ES = 0.99) and F8 (ES = 1.11) tape methods respectively (Figure 3). In addition, 25.7% and 9.6% significantly greater plantarflexion (p < 0.05; ES = 0.85) and dorsiflexion (p < 0.05; ES = 0.5) active ROM for both ankles were detected following exercise independent of the taping method (Figure 4).

DISCUSSION
The results of our study indicate that a significant reduction in plantarflexion active ROM occurred as a result of the two different tape application methods (heel-lock and figure-eight) as compared to the control. This is in agreement with other studies that reported similar conclusions as a result of the utilization of external ankle supports. It had been theorized that tape restriction would impede the force generated by the plantarflexors. However, the present study indicated that maximum force production was not reduced as a result of tape application as no significant maximal voluntary control differences existed between the type of taping method (heel-locks or figure-eights) and the control, pre-, or post-exercise groups.

Table: Pre- and post-exercise means and standard deviations for all variables. The following definitions are defined as df = degrees of freedom, F = F ratio and p = probability value, MVC = maximal voluntary control.

<table>
<thead>
<tr>
<th></th>
<th>Heel lock Pre-exercise</th>
<th>Heel lock post-exercise</th>
<th>Figure 8 Pre-exercise</th>
<th>Figure 8 post-exercise</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Countermovement jump (cm)</td>
<td>24.9 ± 3.6</td>
<td>24.7 ± 5.6</td>
<td>23.6 ± 3.2</td>
<td>25.3 ± 2.8</td>
<td>df = 32, F = 0.04, p = 0.43</td>
</tr>
<tr>
<td>Drop jump (cm)</td>
<td>20.7 ± 4.3</td>
<td>21.4 ± 4.7</td>
<td>21.2 ± 4.4</td>
<td>22.1 ± 4.6</td>
<td>df = 32, F = 0.05, p = 0.94</td>
</tr>
<tr>
<td>Drop jump contact time (ms)</td>
<td>232.9 ± 38.7</td>
<td>230.1 ± 31.1</td>
<td>216.6 ± 46.1</td>
<td>241.2 ± 30.1</td>
<td>df = 32, F = 0.07, p = 0.48</td>
</tr>
<tr>
<td>Concentric only squat jump (cm)</td>
<td>24.2 ± 3.4</td>
<td>23.5 ± 2.2</td>
<td>23.7 ± 3.4</td>
<td>24.7 ± 4.1</td>
<td>df = 32, F = 1.44, p = 0.25</td>
</tr>
<tr>
<td>Plantarflexors MVC (Newtons)</td>
<td>251.7 ± 55.6</td>
<td>253.6 ± 51.8</td>
<td>232.9 ± 51.1</td>
<td>217.3 ± 69.5</td>
<td>df = 17, F = 0.35, p = 0.71</td>
</tr>
<tr>
<td>Dorsiflexion ROM (degrees)</td>
<td>10.4 ± 1.0</td>
<td>11.1 ± 1.8</td>
<td>10.1 ± 0.6</td>
<td>11.5 ± 0.7</td>
<td>df = 32, F = 8.19, p = 0.007</td>
</tr>
<tr>
<td>Plantarflexion ROM (degrees)</td>
<td>27.9 ± 10.8</td>
<td>35.5 ± 11.8</td>
<td>26.0 ± 8.5</td>
<td>35.3 ± 11.6</td>
<td>df = 32, F = 37.8, p &lt; 0.0001</td>
</tr>
</tbody>
</table>
These results concur with previous research that has tested maximum force production when ankles have been taped.\textsuperscript{3,7}

Cordova et al\textsuperscript{1} reviewed the literature indicating that taping did not decrease the magnitude of the forces produced, but the rate at which they were produced was slower. Alternatively, the present research did not find a significant difference in DJ contact time with taping. Muscle force and power have been reported to be compromised with increased muscle compliance.\textsuperscript{22,23} The elongation of tendinous tissues can also have a deleterious effect on force output.\textsuperscript{24} Belli and Bosco\textsuperscript{25} suggested that a stiffer musculotendinous unit would enhance the work performed during stretch-shortening cycle movements. Perhaps the restricted ROM of the taping methods contributed to a stiffer or less compliant ankle joint which permitted a more rapid stretch-shortening cycle during the DJ contact time. Hence, although the tape restricted ankle ROM, the tape did not decrease the maximal voluntary contraction force generated by the ankle-foot complex during the DJ.

Plantarflexion is required for propulsion\textsuperscript{16} and during the push off phase\textsuperscript{11} of a vertical jump. The results of the present study indicate that no significant reductions in vertical jump height occurred with any condition tested. Similar research also reports a lack of change in vertical jump height with the application of external ankle supports.\textsuperscript{7,10,11,15} Verbrugge\textsuperscript{7} utilized the heel-lock method while Paris\textsuperscript{10} utilized the figure-eight method. Neither study recorded a significant reduction in vertical jump height with taping.

**Figure 3.** The asterisk (*) indicates a significant ($p<0.05$) difference in plantarflexors (PF) ROM between the control (NS: no support) and type of taping (HL: heel lock, F8: heel lock, and figure 8) method. The acronyms PF, DF, HL and F8 refer to plantarflexors, dorsiflexors, Gibney closed basket weave with heel lock, and Gibney closed basket weave with heel lock and figure 8, respectively.

**Figure 4.** The asterisk (*) indicates a significant difference ($p<0.05$) between plantarflexors (PF) ROM pre- and post-exercise. The number sign (#) indicates a significant difference ($p=0.05$) between dorsiflexors (DF) ROM pre- and post-exercise. The acronyms PF and DF refer to plantarflexors and dorsiflexors, respectively.
height under these conditions. Other studies however have recorded significant reductions in vertical jump heights as a result of external ankle supports.\textsuperscript{1,8} Possible reasons for the lack of vertical jump impairment would include the aforementioned insignificant effects of ankle taping on maximal voluntary contraction force and the possible positive effect of increased ankle joint stiffness on the stretch-shortening cycle. Furthermore, ankle taping has also been found to increase proprioception and sensorimotor function through the stimulation of cutaneous mechanoreceptors.\textsuperscript{1,3,13} It has been theorized that the activity of these mechanoreceptors are enhanced as a result of the pressure an external ankle support places on the lower leg.\textsuperscript{13} If prime movers such as the plantarflexors are stimulated, these muscles could counteract the effect of the restricted plantarflexor ROM.

A study by Kean et al\textsuperscript{26} implementing six weeks of wobble board training, found an increase in vertical jump height. This study demonstrated that an improvement in stability could positively affect vertical jump height, as enhanced stability helps to direct jump forces in a vertical direction as opposed to slight deviations from vertical. In addition, improved stability can allow for a greater amount of force to be produced.\textsuperscript{17,27} The muscles involved in the movement can be dedicated more to producing motion rather than joint stabilization.\textsuperscript{26,27} As ankle taping improves stability, both of these factors have the potential of counteracting some of the negative effects from a reduction in ankle ROM.

The results of this study also indicated that significant increases occurred in plantarflexion active ROM across all conditions pre- and post-exercise. This finding is in agreement with other studies that attributed the increased ROM to the loosening of the tape as a result of exercise.\textsuperscript{7,15,28} Researchers have reported 40-50% of the tape's initial restrictive support is lost following just 10 minutes of activity.\textsuperscript{7} Despite the loosening of the tape and the increase in ROM, the tape still provides adequate restriction of ROM to aid in injury prevention.\textsuperscript{28} The proprioceptive stimulation provided by the adhesive tape to the lower leg would also be an aid for injury prevention.

Limitations of the present study include the small sample size (n = 11) and the convenience sample. As the sample included only female varsity athletes, the application of the present findings to other populations may be somewhat limited. Further research should examine the effect of other taping methods on performance, inversion/eversion range of motion and more varied samples (males, recreationally active individuals, younger and older individuals, individuals with present or former ankle sprains). More sophisticated analysis could be accomplished if similar research was conducted on a reaction force platform which could monitor changes in three planes, as well as proprioceptive testing.

CONCLUSION

Despite ankle active ROM being restricted by both taping procedures (heel-locks and figure-eights), no effect on vertical jump performance, contact time, or maximal voluntary contraction force occurred. As a result, the personal preference of the clinician, athlete, or coach can be used to determine the taping method without the possibility of decreasing vertical jump height.

REFERENCES


THE EFFECTS OF LOADED VERSUS UNLOADED ACTIVITIES ON FOOT VOLUMETRICS IN OLDER HEALTHY ADULTS

J. Wesley McWhorter, PT, MPT, PhD

ABSTRACT

Background. Health care practitioners, including sports physical therapists, commonly prescribe and recommend aerobic exercise for those patients seeking to improve their cardiovascular fitness across all ages. Current literature demonstrates that weight bearing activities such as walking or running may lead to foot and ankle edema.

Objectives. The purpose of this study is to determine if a significant difference exists between foot volumes (edema) in pre versus post-exercise measurements during a loaded activity (treadmill walking) or an unloaded activity (upright exercise bike) in 31 healthy subjects 50 years of age and older.

Methods. After a rest period, a pre-exercise volumetric measurement of the right leg was obtained by the use of a foot volumeter. The first condition (walking or cycling) was randomly chosen. Each subject completed two 10-minute exercise sessions. Immediately following both exercise sessions, a post-exercise volumetric measurement was completed.

Results. A statistically significant difference in foot volume was found between pre (mean = 742.39ml, 95% CI: 685.23 – 799.55) and post (mean = 753.03ml, 95% CI: 697.51ml – 808.55ml) measurements for the treadmill (weight bearing) protocol. When considering each sex separately, males produced significant increases in foot volume following treadmill walking (pre mean = 871.00ml, 95% CI: 793.95ml – 948.05ml; post mean = 886.20ml, 95% CI: 811.28ml – 961.13ml), while females displayed no significant changes.

Discussion and Conclusion. This study demonstrated a 1.4% increase in foot volume after 10 minutes of treadmill walking. Based on these results, it may be advisable to prescribe non-weight bearing exercise to active older individuals with pre-existing conditions for edema.

Key words: edema, volumetrics, unloaded and loaded activities

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INTRODUCTION

Health care practitioners (including sports physical therapists) commonly prescribe and recommend aerobic exercise for those individuals of all ages seeking to improve their cardiovascular fitness. These aerobic activities often include walking, running, and cycling programs. Current literature demonstrates, however, that weight-bearing activities, such as walking or running, may lead to foot and ankle swelling.1-4 This acute swelling, which is a common complication resulting from weight bearing activities, can lead to more serious conditions such as fibrosis, joint stiffness, pain, and dysfunction.1,2,13

One of the problems that results from aerobic exercise is edema formation in the lower extremities which can lead to peripheral vascular disease or other circulatory insufficiencies.1,2,13 Other research has shown an opposite effect, with aerobic activity resulting in a decrease in lower extremity volume.2,14 This decrease in lower extremity volume may be the result of the muscle-pumping effect of the gastroc-soleus complex.2,13 This increase in swelling, static activities have also been shown to produce edema in the lower leg.1,2,13

Other research has examined the discrepancies involving the effects of loaded dynamic activity on lower extremity volume. Cloughley and Mawdsley3 found a greater increase in foot volume during running as compared to walking. These findings are supported by McWhorter et al13 who found significant increases in foot swelling during walking and running. Other researchers found increases in foot volume during running, but a decrease during walking.1 Evidence also exists demonstrating increases in interstitial and intracellular volume during and after exercise which are directly related to exercise workload.19

During quiet static standing, subjects have been shown to increase lower extremity edema formation as a result of pooling of fluid in the lower extremity.17 Specifically, foot volume during standing has been shown to increase compared to a supine position, possibly the result of a decrease in perfusion of the veins that return to normal when the supine position is resumed.18

Stationary bicycle ergometry is an example of an unloaded dynamic activity. Research by Stick et al14 found that stationary bicycling demonstrated a gradual decrease in foot volume. They also discovered a more significant decrease in foot volume occurred when subjects pedaled against a stronger resistance.

Other studies have examined the effects of differing postures on changes in foot volumes. Seated positioning has been shown to cause an increase in foot volume.14 Another posture, supine lying with or without leg elevation, has demonstrated a significant decrease in foot volume.20,21 All of these studies demonstrate that foot volume can be affected by its gravitational position.

In the young or recreational athlete, the small changes that occur as a result of running or walking may not be a problem. However, in older or geriatric adults, these small increases in foot volume when coupled with chronic resting edema could prove to be harmful.22,23 Peripheral edema is a common finding in the elderly, however, actual figures for prevalence are not known. A survey conducted on peripheral edema in elderly patients admitted to a geriatric ward found that 48% of patients had an overall presence of edema during their admission.24 Compounding the effects of existing edema with co-morbidities will make exercise prescription increasingly more difficult.

The increasing incidence of morbidities involving resting edema, such as coronary heart disease (CHD) and diabetes, showcases the need for further research in this area.8,10,24-26 Arnold et al25 reported the incidence of CHD to be 39.6 per 1,000 persons in men and 22.3 per 1,000 persons in women. Moreover, the incidence of CHD increases 9% with each year of age past 65. Bertoni et al26 reported a high incidence of mortality among older adults with diabetes and heart failure; 32.7 per 100 persons-years compared with 3.7 per 100 person-years among those with diabetes who did not suffer from congestive heart failure (CHF).

The purpose of this study is to determine if a significant difference exists between foot volumes (edema) in pre versus post-exercise measurements during a loaded activity (treadmill walking) or an unloaded activity (upright exercise bike) in the active healthy older population. Based on the findings of McWhorter et al,13 the hypothesis tested was that loaded activities will result in greater edema in the foot and ankle than unloaded activities. Additionally, it is hypothesized that the unloaded position of the bike coupled with the active and passive movement of the ankle may result in a reduction in foot volume secondary to a muscle pumping action moving fluid out of
the area. Results of this study may help health care practitioners prescribe a more appropriate exercise mode when addressing the cardiovascular health of the active geriatric individuals.

METHODS

Subjects
The subjects consisted of 21 female and 10 male volunteers between the ages of 50 to 67 years without a history of musculoskeletal injuries, health problems, or surgery to the lower extremities, and who had no difficulty or discomfort during walking on a treadmill or riding a bicycle ergometer. The mean age of all 31 participants was 56.26 (SD = 4.89) years. For the 21 females, the mean age was 56.1 (SD = 3.97) years and for the males was 56.6 (SD = 6.33) years. All subjects were recruited by using emails sent throughout the university. All participants completed the Physical Activity Readiness Questionnaire (PAR-Q) and signed an informed consent to participate. This research study was approved by the Institutional Review Board at the University of Nevada, Las Vegas. Participants were excluded if they met any of the following conditions: injury to the right lower extremity within the past year, abnormal swelling in the ankles or feet, history of bone or joint disorders that is aggravated by exercise, or any other physical reason provided by a physician that they should not exercise.

Instrumentation
All lower extremity measurements were obtained using a Lucite (Foot Volumeter, P.O. Box 146, Idyllwild, CA, 92349) foot volumeter set (Figure 1) which included the volumeter container, an obturator which was used to calibrate the water levels prior to each measurement, a receiver to catch the water overflow, and a 1000-ml graduated cylinder with 10-ml gradations. All measurements were taken following the manufacturer’s guidelines. Several studies have been performed establishing the reliability and validity of obtaining foot/ankle volume measurements using this equipment.1,3,5,6,13,28

The displaced water was captured in a plastic container and subsequently measured in a graduated cylinder. All data was immediately recorded on a personalized data sheet. As water has a tendency to creep up the sides of the plastic cylinder, measurements were taken from the lowest level at the water line. Each volume measurement was taken by the same observer to ensure proper consistency.

A pilot test was performed previously in order to allow the testers to practice taking foot volumetric measurements. At this time, the researchers performed the volumetric measurements on 10 volunteers. The three researchers involved in data collection were asked to take the measurements from the participants. The data were recorded by an independent observer. Two days later, the researchers, who were blinded to the previous results, took the measurements from the same participants. All measurements were compared for reliability and demonstrated a reliability intra-class correlation coefficient of 0.99 (95% limits of agreement +/− 7.54 ml).29

Procedure
The subjects were given an individual instructional session at which time all aspects of the research study were explained and possible complications as a result of participation were discussed. All subjects were tested at the same time of day. They were informed to not exercise or consume alcoholic beverages on the days prior to being tested and to maintain their present eating habits. Each subject was required to sit in a straight back chair and slowly lower their right leg into the foot volumeter until the foot rested flat against the bottom. They remained in this position until all of the displaced water was collected. All subjects were tested during walking and cycling, thus serving as their own controls.

Prior to each exercise session, all subjects were instructed to bring their athletic footwear. All subjects were required to rest in a supine position for at least 10 minutes prior to testing. The subjects were seated in a chair immediately following their 10-minute rest period. At this time, a pre-exercise volumetric measurement of the right leg was obtained by having the subject slowly lower the right foot into the volumeter.

The activity for the first condition (walking or cycling) was randomly chosen by a flip of a coin. The treadmill (Star Trac Unisen, Inc., 4500 Treadmill, Star Trac, 14410 Myford Rd., Irvine, CA. 92606) speed and cycling (Fitron Cycle, First Fitness

Figure 1: Lucite foot volumeter.
Equipment International, 4750 Bryant Irvine Rd., Ste 808, PMB 229, Ft. Worth, TX 76132-3631) cadence were set at a self-selected comfortable pace for each individual participant. The speed of the treadmill and cadence of the cycle ergometer were recorded on the data sheet. These values were then used for the post-test measure. Due to the fact that walking and cycling speeds vary greatly among individuals, each individual was allowed to determine their own comfortable speed to more closely mimic a real life scenario.30,31

As the exercise session began, each subject performed a 2-minute warm-up session on the treadmill or cycle ergometer at which time they gradually increased their speed until they felt comfortable for the remaining 8 minutes. Subjects were not allowed to grip the handrails on the treadmill during the exercise sessions. The treadmill was kept at a level (zero degrees) elevation for all exercise sessions. During cycling, the seat was adjusted for each participant individually and used for all subsequent sessions. In addition, all cycling sessions used toe straps to minimize foot extraneous movements. The cycle tension was chosen by the participant and used for all subsequent sessions. At least 48 hours of rest was allowed between the two exercise sessions. All procedures were performed in a consistent manner for both sessions.

Data Analysis
Means and standard errors for the fluid volume data were calculated. Given the repeated measures in each exercise protocol, a 2 (exercise) x 2 (time) within factorial ANOVA was utilized to determine if statistical interaction existed in the data. The alpha level was set at 0.05. If statistical interaction was found, simple main effects were calculated using paired t-tests to determine if statistical significance was present.

RESULTS
Factorial results of the 2 x 2 ANOVA revealed a statistical interaction (Figure 2). Because statistical interaction was observed \( \{F(1,30)=5.705, \ p=.023\} \), simple main effects were analyzed. Two paired samples t-tests using a Bonferroni correction \( (p = .025) \) were used to determine the effect of weight-bearing vs. non-weight bearing exercise on foot volume (Table 1). A statistically significant dif-

![Image](image_url)

**Figure 2:** 2 x 2 within factorial ANOVA

<table>
<thead>
<tr>
<th>Mode of Exercise</th>
<th>Mean Volume (ml)</th>
<th>Standard Error</th>
<th>t-values</th>
<th>p-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-walk</td>
<td>742.39</td>
<td>27.99</td>
<td>-2.952</td>
<td>.006*</td>
</tr>
<tr>
<td>Post-walk</td>
<td>753.03</td>
<td>27.19</td>
<td></td>
<td></td>
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<tr>
<td>Pre-bike</td>
<td>743.03</td>
<td>29.22</td>
<td>0.376</td>
<td>.710</td>
</tr>
<tr>
<td>Post-bike</td>
<td>741.23</td>
<td>28.30</td>
<td></td>
<td></td>
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* Significance at \( \alpha = .025 \)

**Table 1:** Comparison of Fluid Volume Changes During Treadmill Walking (Weight Bearing) and Cycle Ergometry (Non-weight Bearing)
ference in foot volume was found between pre (mean=742.39, 95% Confidence Interval: 685.229 – 799.546) and post (mean=753.03, 95% Confidence Interval: 697.511 – 808.553) measurements for the treadmill protocol (weight-bearing), t = -2.952, p = .006 (Figure 3). There was no statistically significant difference between the pre (mean = 743.03, SD = 162.68) and post (mean = 741.23, SD = 155.83), cycle ergometry measurements (non-weight bearing), t = .376, p = .710.

A 2 (exercise) by 2 (time) within factorial ANOVA was also utilized to determine if statistical interaction was present in data sorted by sex. Because statistical interaction was observed for males (F(1,9) = 10.545, p = .010), simple main effects were analyzed. Paired samples t-testing using a Bonferroni correction (p = .0125) found a statistically significant difference in male foot volumes (Figure 4) between pre (mean = 871.00, SD = 107.706) and post (mean = 886.20, SD = 104.739) measurements for the treadmill protocol, t = -5.429, p < .0005. Statistical interaction was not observed for females (F(1,20) = .990, p = .332) and no further statistical analysis was performed.

DISCUSSION

Numerous methods have been used to measure extremity volume. Previous research has demonstrated the water displacement method of volumetry to be valid and reliable, and thus is known to be the gold standard.32-34 Many variables need to be considered when taking volumetric measurements. These include time of day, water temperature, positioning of subject, the temperature of the room, and recent musculoskeletal injuries. However, Moholkar and Fenelon28 showed that time of day does not significantly effect volume measurements of the extremities. Tepid water temperatures between 20 and 35º C did...
not significantly increase or decrease volume measurements, however, extreme hot or cold temperatures have been shown to affect volume. The temperature of the room was not shown to have an effect on the measurements of foot volumes following quiet standing. It also has been shown that individuals with a recent history of musculoskeletal injuries in the lower extremity will have an increase in edema formation. Therefore, it can be safely assumed that the performance of an activity rather than the previously mentioned variables affects foot volumes, except for the conditions of extreme water or room temperatures and recent injuries.

The data from this study showed that, in healthy older subjects, treadmill walking resulted in significant increases in foot and ankle fluid volumes compared to resting measurements. This finding was in agreement with the original hypothesis that weight-bearing exercise will increase foot volume. Additionally, when considering each sex separately, males produced significant increases in foot volume following treadmill walking, while females displayed no significant changes. However, when comparing pre and post-test measurements for biking, no significant changes were observed. This lack of change also held true when considering each sex separately. The results did not support the hypothesis that the biking protocol would cause a significant decrease in foot volume.

The edema in the foot and ankle during walking can be attributed to the increase in blood flow to the exercising muscles. The increase in edema following weight-bearing activity has been shown to increase foot volume by as much as 8%.

Stegall has demonstrated an 80 mmHg drop in venous pressure at the saphenous vein in the ankle during running as compared to quiet standing. As a result, the author suggests that there is an inability of the lower extremities to maintain a steady rate of venous return following vigorous weight-bearing activities.

Prior to this study, the hypothesis was made that the bike protocol would cause a significant decrease in foot volume secondary to a muscle pumping action. However, as previously mentioned, no significant difference was found. After analyzing the data, one possible explanation for these results was that riding an upright exercise bike does not require enough active foot and ankle muscular activity to cause a muscle pumping effect away from the distal lower extremities. Although movement does occur in the foot and ankle during this activity, much of the movement may be passive, thus not adequately activating the muscle pumping mechanism.

Sochart et al examined the relationship between passive and active movement of the foot and ankle related to venous return in the lower extremity. They found that an active “combined” movement (plantarflexion/dorsiflexion and inversion/eversion) produced a significantly larger increase in mean blood velocity than any of the three passive movement patterns. The results found by Sochart et al could help explain why a significant decrease in foot volume for the bike protocol was not observed in this present study.

A difference in fluid volumes after treadmill walking was also found to be significant between sex. In the present study, the participants demonstrated a mean increase in foot volume after a 10 minute walk on the treadmill, but significance between genders was only found in males. The females’ 1.2% increase in foot volume failed to produce significance. A review of the literature failed to identify any studies of post-exercise foot and ankle volume changes based on sex. Chalk et al demonstrated a slight non-significant decrease in foot volume in female inter-collegiate volleyball players after a 2-hour rigorous exercise session. In addition, the benefits of reducing foot volume in females during weight-bearing activities may be offset by the greater benefit of osteoporosis prevention. It should be noted that the sample size for this study is not large enough to draw firm conclusions with regard to sex and foot swelling.

The results of this study provide important clinical implications for physical therapists. This study demonstrated a 1.4% increase in foot volume after 10 minutes of treadmill walking. It is important to note that this statistically significant increase in foot volume occurred only after 10 minutes. Ambulating patients in the acute or rehab settings often takes longer than 10 minutes secondary to their age, medical condition, and other physical limitations. This information is also important for the older recreational athlete who may walk for an extended period of time. Keeping these patients on their feet for longer periods of time could cause further increases in foot volume, resulting in potential further constriction of venous return with possible negative consequences in those with already compromised circulation. Even in cases with mild edema, instability may result due to poorly fitting foot wear as well as the increased weight of the
edematous limb. Patients may experience a decline in walking confidence and become immobile, further aggravating the problem. It may be safer and more effective to prescribe non-weight bearing exercise as a warm-up or treatment alternative to patients with pre-existing peripheral edema or conditions that place them at risk for impaired venous return. Based on the small sample size, no concrete clinical suggestions can be made with regard to sex at this time.

This study had several limitations. For example, the statistical results would be more convincing if the sample had more subjects, particularly when considering statistics sorted by sex. The total sample of 31 provides a fairly strong field to draw conclusions, but when considering each sex separately, the sample size was reduced significantly. Another limitation in this study is the inability to control each subject’s activity level prior to testing. A subject that was active versus sedentary could have a different circulation status upon arrival for exercise testing which could affect foot volume pre and post exercise testing. The non-weight bearing exercise protocol in this study utilized an upright exercise bike. The upright exercise bike caused a considerable flexion angle in the hip that could potentially impair venous return to the heart. A better alternative would be to use a recumbent bike, thus reducing the hip flexion angle.

Future studies should focus on patients with real pre-existing co-morbidities that cause foot edema to determine if these results hold true in such populations. Studies utilizing more subjects with these conditions could help draw firm conclusions regarding sex and foot edema. Although an upright stationary bike was utilized in this study, other forms of non-weight bearing exercise equipment are available. Future studies involving these different exercise modes could help determine the optimal piece of exercise equipment to help minimize foot swelling.

CONCLUSION
The results from this study suggest that treadmill walking (loaded exercise) results in an increase in foot edema when compared to riding an upright stationary exercise bike (unloaded exercise). Although it is difficult to conclude that riding an exercise bike is an effective way to decrease foot edema, these results suggest that stationary biking is a safer mode of exercise than treadmill walking in controlling foot edema, especially in older men. Therefore, unloaded activities may be the most appropriate exercise to prescribe when an increase in foot volume is unwanted. Further investigations into the injured (ankle sprains) and chronically ill (congestive heart failure, peripheral vascular disease, diabetes) patients are necessary to ascertain whether similar findings would result. This knowledge would be very applicable for clinical use of the cycle ergometer as a modality to positively influence venous stasis and decrease the problems associated with ankle and foot edema.

REFERENCES
ABSTRACT

Background. Stretching has long been an integral component of pre-performance activities for a multitude of athletic endeavors. Previous research has demonstrated that stretching may have detrimental effects on performance. Specific knowledge of the precise effects of stretching may influence the decision to appropriately apply stretching techniques in the sport and therapeutic settings.

Objective. The purpose of this pilot study was to examine the effects of static stretching, proprioceptive neuromuscular facilitation (contract-relax) stretching, and no stretching of the quadriceps muscle group on agility performance.

Methods. Twelve healthy, female, collegiate soccer players aged 18 – 25 performed one of the three stretching protocols (static, contract-relax, no stretch) and the agility test (T-test) on three non-consecutive days. Agility times were recorded and compared based on stretching technique and day that each test was performed.

Results. No significant difference was found among the means of the different stretching techniques. The t-test agility performance times were as follows: control, =9.7 seconds; static stretch, =9.73 seconds; and contract-relax, =9.62 seconds.

Conclusion. The results of this study suggest that agility performance may be independent of stretching technique of the quadriceps performed in female collegiate soccer athletes. It is recommended that female soccer athletes about to engage in agility activity may perform either no stretch, static stretch, or contract-relax stretching according to individual preference.

Key words: agility performance, contract-relax stretching, static-stretching, female athletes.
INTRODUCTION

Stretching is a common component of pre-performance activities for many athletic events. As such, the literature is rich with evidence supporting the effects of stretching on flexibility, with mounting evidence as to the effects of stretching on performance. However, limited research exists concerning the acute affects of different stretching techniques on athletic performance variables, specifically, agility.

Several types of stretching techniques are currently incorporated by athletes for pre-event activities. Static stretching and proprioceptive neuromuscular facilitation (PNF) are common techniques used by therapists, athletic trainers, strength and conditioning professionals, and athletes to enhance flexibility. In most cases, these stretching activities are integrated as part of a warm-up session.

Some researchers studying the effects of stretching on performance have reported significant deficits in performance-related variables, while others found little or no difference. Church et al. examined the effects of warm-up and flexibility treatments on vertical jump performance in females. Results demonstrated a decrease in vertical jump height for the PNF treatment group, leading researchers to speculate that performing PNF stretching techniques before a vertical jump test may be detrimental to performance. Wallmann et al. investigated the effects of static stretching of the gastrocnemius on vertical jump performance in healthy adults. Researchers concluded that, since vertical jump height decreased by 5.6%, static stretching of the gastrocnemius had an immediate adverse effect on maximal jumping performance.

In contrast to the aforementioned findings, Unick et al. examined the acute effects of stretching on vertical jump performance in female collegiate basketball players and concluded that vertical jump performance was not affected by stretching. They measured the effects of static and ballistic stretching, as well as power output at 15 and 30 minutes post-stretch. They reported no significant difference between power output and vertical jump values pre and post-stretch. Likewise, Behm et al. reported that static stretching showed a 6.9% decrease in maximal voluntary contraction of the quadriceps while a control group experienced a 5.6% decrease in maximal voluntary control of the quadriceps from pre-test to post-test.

A major component of sport performance that has been poorly researched in the stretching literature is agility. The American College of Sports Medicine describes agility as the “ability to rapidly change the position of the entire body in space with speed and accuracy.” Agility can be thought of as a systemic integration of neuromuscular coordination, reaction time, speed, strength, balance. This complex nature of agility performance has lead many researchers to conduct studies that involve a breakdown of its component parts.

Cochrane et al. additionally noted the complexity of factors that interact to produce agility performance and the difficulty in actually identifying and measuring those components. McMillian et al. examined the effects of static versus dynamic warm-up protocols on agility performance, utilizing a common standardized agility test called the T-test. Results revealed a difference between the dynamic warm-up and both the static warm-up and no warm-up groups. Researchers concluded that a dynamic warm-up protocol may provide performance benefits that are superior to static or no warm-up protocols.

Given the paucity of literature regarding the effects of stretching on agility, the purpose of this pilot study was to examine the effects of three different stretching techniques (static, contract-relax stretching, and no stretch) on the quadriceps muscle group with regards to agility performance. The quadriceps muscle group was chosen primarily because females have been shown to be quadriceps dominant and it was thought that this dominance may be affected by stretching. The hypothesis to be tested is that agility performance would decrease in association with bouts of static stretching and PNF.

METHODS

Subjects

Twelve female Division I collegiate soccer players ages 18 – 25 (mean = 19.17; SD =0.94) participated in this study. The following criteria were used to select the subjects: a member of the women’s soccer team, age 18-25, not currently pregnant, and no lower extremity orthopaedic injuries sustained within the last six months that would hinder the ability to give maximal effort during the T-test. Before initiating the study, the Biomedical Institutional
Review Board of the University of Nevada, Las Vegas approved the study. Each subject gave both written and oral consent before engaging in the research protocol.

**Equipment**

The T-test (Figure 1) is a common test used to measure 4-directional agility, and evaluates the ability of the subject to rapidly change direction while maintaining balance without loss of speed. The subject starts with both feet behind a line and sprints 10 yards forward, then shuffles 5 yards to the left, followed by 10 yards to the right, then 5 yards to the left, and finally, 10 yards backward to the original starting point. Pauole et al. demonstrated that the T-test is a reliable and valid measure of leg speed, leg power, and agility.

Four cones were placed on the floor using the standard parameters for the T-test as described by Pauole et al. Additionally, two timing photocells (Lafayette Instrument Co., Lafayette, IN) were placed 6 ft apart at the start/finish position to record the time it took each subject to complete the T-test. One plinth was used for the PNF stretching station and one stool was used for the stretching subject to hold on to for balance during the static stretching station. One stopwatch was utilized to measure the duration of stretch at each station, and one stop-watch was used to time the 5-minute self-selected jog warm-up.

**Procedure**

A repeated-measures design was used to determine the effectiveness of different stretching techniques on agility performance in female college soccer players over a one week period. The dependent variable was the time it took each athlete to complete the T-test. The independent variable consisted of three stretching techniques: contract-relax, static stretching, and a control group.

A pre-study information session was conducted in which subjects were instructed on the testing protocol as well as the proper method for each technique. A demonstration of the T-test was given and all subjects were asked to perform the T-test one time to allow for familiarity with the test. Subjects were also instructed not to participate in excessive physical activity prior to the testing sessions, but to continue with their normal workout routines.

Data was collected on three non-consecutive days over the course of one week. Using a balanced Latin square to reduce test order bias, subjects were randomly assigned into one of three different test orders as follows:

a) Group A performed no stretching on Monday, static stretching on Wednesday, and contract-relax stretching on Friday.

b) Group B performed contract-relax stretching on Monday, no stretching on Wednesday, and static stretching on Friday.

c) Group C performed static stretching on Monday, contract-relax stretching on Wednesday, and no stretching on Friday.

Prior to engaging in the stretching protocols, each subject completed a 5-minute warm-up jog at a self-selected speed. The purpose of this jog was to provide a general warm-up to minimize the risk of straining the quadriceps muscles during a maximal agility effort. Subjects then completed the assigned stretch protocol for that day. Immediately after completing the protocol, subjects performed the T-test one time. The three stretching protocols were as follows:

a. **Static stretching.** This activity consisted of actively stretching the quadriceps muscles of each leg alternately three times each for 30 seconds each (3 minutes total) for both legs. The knee of the leg being stretched was flexed and held by the same upper extremity as the lower extremity being stretched. In order to maintain consistency with this technique and enhance the feeling of inducing a stretch, the subjects were instructed to push their hips forward during the stretch to facilitate a posterior pelvic tilt. An investigator stood with each subject and called out the 30-second increments with the use of a stopwatch so that the
subject could maintain the appropriate time frame for each stretch (Figure 2).

b. Contract-relax. This activity consisted of interactive stretching between the subject and the tester. The tester provided resistance to active contraction of the quadriceps for 6 seconds with a 4 second relaxation phase for a total of 30 seconds alternately three times each (3 minutes total) for both legs. The subject was placed supine on a plinth with the leg to be stretched hanging off of the table. The other leg was held in a knee to chest position in which the knee and hip were both flexed. The tester asked the subject to push the stretching leg into the tester’s hand giving approximately 30% of maximal effort. The subjects were then asked to relax the stretching leg and the tester then pushed the leg into its new available range of motion (Figure 3).

c. No stretching. No stretching was performed; the subject sat on the ground for 3 minutes. This group served as the control group.

Statistical Analyses
A one-way repeated measures analysis of variance (ANOVA) was used to analyze the differences among the three different stretching protocols. Statistical significance was set at $p = 0.05$ and all analyses were carried out using the Statistical Package for the Social Sciences version 13.0 (SPSS, Inc, Chicago, IL).

RESULTS
A repeated measures ANOVA revealed no statistically significant difference among the means, $F(2,22) = 0.759$, $p = 0.480$, power = 0.162 for the control (no stretch), static stretching, and contract-relax stretching techniques in T-test agility performance times. The mean T-test performance times and standard deviations for control, static stretching, and contract-relax stretching as well as 95% confidence intervals are displayed in Table 1.

DISCUSSION
The purpose of this pilot study was to examine the differences among three different stretching techniques on agility performance in female collegiate soccer athletes. The results of this study revealed no differences among the three treatment groups on agility performance times.

An accurate comparison of this study to other studies is difficult secondary to a lack of published literature about the topic. However, results of this study are consistent with a similar study conducted by Faigenbaum et al5, in which researchers examined the acute effects of pre-event static stretching, dynamic exercise, and static stretching and

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<th>Table 1. Means (± standard deviation) and confidence intervals for T-test agility performance times (seconds)</th>
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<td><strong>Technique</strong></td>
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dynamic exercise combined on vertical jump, medicine ball toss, 10-yard sprint, and pro-agility shuttle run in teenage athletes. Prior to testing, participants performed 5 minutes of walking/jogging followed by one of the warm-up protocols. Results revealed that performance on the vertical jump, medicine ball toss, and 10-yard sprint were significantly improved after dynamic exercise, and dynamic exercise and static stretching combined, as compared to static stretching alone. No significant difference was noted in the agility performance after the three different warm-up protocols. These results led researchers to believe that pre-event dynamic exercise or static stretching followed by dynamic exercise may be more beneficial than pre-event static stretching alone in teenage athletes participating in power activities.

Little and Williams18 examined the effects of different stretching protocols during warm-ups on high-speed motor capacities in 18 professional soccer players. Their design was similar, in that they examined the effects of no stretching and static stretching on agility performance. However, their design differed as they incorporated a dynamic stretch, rather than a PNF stretching technique. In addition, the agility task was performed on a zigzag course, versus the T-test used in the current study. These authors concluded that there was no difference between the control and static stretching groups. This result is consistent with the results revealed in the present study; however, the authors did report that the dynamic stretch protocol produced significantly faster agility performance than did both the control and static stretch groups.

Although a paucity of literature exists regarding the effects of stretching on agility performance, other components of agility have been researched, namely, speed and strength. The evidence on the effect of stretching on sprint performance provides conflicting results with questionable research quality making definitive conclusions difficult.24 However, work by other researchers4,17 supports the hypothesis that static stretching has a detrimental effect on sprint performance.

The evidence regarding the effects of stretching on force, torque, and jump performance also appears to provide inconclusive results.5,10,13,25 Whereas Wallmann et al10 and Church et al9 reported significant decreases in vertical jump height after bouts of static stretching and PNF stretching, respectively, Unick et al11 reported no difference in vertical jump scores as a result of static or ballistic stretching. The Unick et al11 study included 16 actively trained women who performed a series of vertical jumps at 4 minutes, 15 minutes, and 30 minutes after stretching the hamstrings, quadriceps, and gastrocnemius/soleus muscle complex. The protocol required the stretch to be held for a period of 15 seconds. This short time period may not have been long enough to induce a tissue extensibility change within the muscle. Research has shown that at least 30 seconds is needed to be effective in bringing about a change in flexibility.2,28 In addition, the vertical jumps were performed after 4 minutes of walking; which may have allowed the muscle to return to its pre-stretched length, thereby, affecting the results.

Power et al25 found that no difference existed in vertical jump scores after a static stretching routine. However, decreases in isometric maximal voluntary contraction and an increase of inactivation of the quadriceps were found to be statistically significant. Maximal voluntary contraction force of the quadriceps muscle showed a 9.5% decrease over the course of the 120 minute measurement period, while a 5.4% increase of inactivation of the quadriceps muscle was revealed, suggesting that static stretching may adversely affect these variables. Behm et al13 reported similar results in regard to maximal voluntary contraction of the quadriceps muscle. In their study, the static stretching group showed a 6.9% decrease in maximal voluntary contraction of the quadriceps muscles while the control group experienced a 5.6% decrease in maximal voluntary contraction of the quadriceps muscle from pre-test to post-test.

Although these previous studies revealed decreases in both speed and strength, which are components of agility, the studies do not appear to be consistent with the present results, which showed no differences in agility T-test performance scores. This may be because much of the current literature involves examining the effects of stretching on performance utilizing the hamstrings and triceps surae musculature.

In the present study, the authors chose to isolate the quadriceps muscle group, primarily because females have been shown to be quadriceps dominant and it was thought that this dominance27-29 may be affected by stretching. Additionally, there is very little, if any, literature investi-
gating the effects of stretching on performance of only the quadriceps muscles. However, the results of this study reveal that the quadriceps muscle group may only play a small role in the variance of agility performance. Consequently, agility performance does not appear to be immediately affected by stretching only the quadriceps muscle group.

Strengthening other muscle groups may have varied the results. But it would be difficult to determine effects of stretching several muscle groups at once as this stretching may allow the muscles to return to their pre-stretched length prior to athletic performance due to the length of time between stretches.

Limitations
Other limitations in this study include varying of testing times, activity level of the subjects prior to our testing time, and a small testing sample. There were some variations regarding data collection times due to time constraints on the part of the soccer team. For example, on Monday and Wednesday, data were collected at 2:00 p.m., while on Friday, data collection occurred at 9:00 a.m. Concerning activity level, the subjects were in a pre-season conditioning program, so we could not control the activity level of each subject prior to data collection, although we did ask the participants to maintain their current level of physical activity during the testing week. This variance in activity level may have affected the effort given by each subject while performing the T-test. The number of subjects participating in this study was small; a larger sample size would be more desirable and may have increased the power of the study. As such, the power was very low for the study. Consequently, the chance of making a type 2 error was high. However, as this was a feasibility study, we believe that the results from this study offer evidence for investigating the effects of stretching using the quadriceps and other muscle groups on agility performance using a more rigorous design.

Research Importance
This study holds relevance to the field of sport research in that current literature has demonstrated both the positive and adverse effects of stretching on flexibility, running, jumping, muscle strength, and power output; however, despite the availability of such literature, little research exists that investigates the acute effects of stretching on agility performance. Agility is a major component of many popular sports. Scientific knowledge regarding the effects of stretching on agility may be beneficial in the development of a training regimen designed to enhance athletic performance.

CONCLUSION
In conclusion, the results of the present study suggest that static stretching, contract-relax stretching, and no stretching of the quadriceps muscle group have no immediate adverse effect on agility performance in female collegiate soccer players. Further controlled-randomized trials are needed to fully examine and understand the complex nature of this topic. Also, a follow-up study with a larger sample size is needed. In addition, future research should also examine other muscle groups, motivational factors involved in stretching and performance, and athlete preferences and beliefs towards the effects of stretching and performance. It is recommended that female soccer athletes about to engage in agility activity may perform either no stretch, static stretch, or contract-relax stretching according to individual preference with no adverse effects on performance.

REFERENCES
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