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Third World Congress of Sports Physical Therapy Abstracts
S1 The International Journal of Sports Physical Therapy is pleased to publish abstracts of the 3rd World Congress of Sports Physical Therapy which took place in Vancouver BC October 4-5, 2019. The theme of the Congress was “High Performance to Clinical Practice.” The variety of presentations during this congress are examples of the contemporary sports physical therapy research activities taking place around the world. It should be noted that abstracts have not been reviewed by the Editorial Board, Associate Editors or Editor-in-Chief of the International Journal of Sports Physical Therapy.
ABSTRACT

Background: Knowledge of the body's response to and recovery from exercise is rapidly increasing. State-of-the-art equipment and facilities allow recreationally active adults to seek innovations to enhance performance and shorten recovery time. Myofascial rolling (MR) is a relatively new practice, providing acute benefits for muscle pain and range of motion (ROM). However, there is no consensus on optimal MR duration.

Purpose: The purpose of this systematic review is to determine the optimal MR duration using a foam roller or a roller massager for muscle pain, ROM, and athletic performance via qualitative review.

Study Design: Systematic Review of the Literature

Methods: A systematic search was conducted using PubMed, EMBASE, EBSCOHost and PEDro (July 2018). Twenty-two studies met the inclusion criteria and were appraised using the PEDro scale. Studies were grouped by outcome measure, with a total number of subjects of n=328 for pain/soreness, n=398 for ROM, and n=241 for performance. Heterogeneity of data prohibited a formal meta-analysis: studies were manually reviewed and classified as providing evidence for benefit of MR (i.e., significant positive effect) or not (i.e., null or negative effect) for each of the studied outcomes.

Results: The most evidence-based benefit of MR is the alleviation of muscle soreness; seven of eight studies assessing pain/soreness resulted in a short-term reduction, and a minimum dose of 90 seconds per muscle appeared beneficial. While ten of 17 studies involving ROM showed acute improvements, the results were inconsistent and highly variable. No significant effects on performance were detected.

Conclusion: Available data indicate that MR for 90 seconds per muscle group may be the minimal duration to achieve a short-term reduction in pain/soreness, with no upper limit found. Results do not support increases in chronic ROM or performance, and data are insufficient to provide a conclusive recommendation for impacting acute ROM. The heterogeneity of the literature highlights the need for additional research to determine optimal dose of MR.

Level of evidence: 2a- (Systematic Review with heterogeneity).

Keywords: Athletic performance; dose; movement system; myofascial rolling; pain; range of motion
INTRODUCTION

Performance among high-level athletes is undeniably improving. While there are many factors involved, advancements in technology and understanding of anatomy and physiology are the largest contributors. These advancements in high-level athletics have downstream effects on the wider population: recreationally active people at all ages and levels seek new information to improve their personal training regimens, whether it is based on clinical recommendation or athlete/celebrity endorsement. When a new training system or recovery tool is introduced and promoted, it is rapidly and widely adopted by people anxious to improve their performance or shorten their subsequent recovery. Importantly, clinicians rely on these therapeutic advancements to expedite their patients’ return to function and improved quality of life.

Myofascial rolling (MR) using a foam roller (FR) or a roller massager (RM) is a relatively new treatment method, accompanied by a recent surge in new literature. MR with a FR involves rolling along the length of the targeted muscle belly on the device, using one’s body weight in a laying or seated position to determine the desired treatment pressure. The same concept is applied to MR with a RM, except the individual handles the device and rolls it along the targeted muscle belly, dictating the applied pressure using their upper limbs. A typical FR and a typical RM are shown in Figure 1. Despite the widespread use of MR, there is currently no agreement on the physiological effects of FR or RM-assisted MR, though it has been postulated that applying deep pressure can reduce fascial adhesions, improve fascial viscosity and mobility, and alter mechano-receptor response in the myofascial unit.

Research examining the clinical effects of MR has increased considerably over the past decade; however, a true consensus on the benefits and potential risks of MR has not been established. Some available data suggest that MR acutely increases range of motion (ROM) and/or reduces pain or soreness while simultaneously limiting decrements to athletic performance. However, the existing data are highly heterogeneous, making a true quantitative review challenging. Therefore, a qualitative review of quantitative data is needed to determine true effects.

METHODS

Systematic literature review

This review was conducted in accordance with PRISMA guidelines. In July 2018, a systematic search of PubMed, EMBASE, and EBSCOHost was conducted, using the following search terms: foam roll; roller massager; time; duration; pressure; pain; myalgia; delayed-onset muscle soreness; range of motion; pain; myalgia; delayed-onset muscle soreness; range of motion;
athletic performance; acute pain; chronic pain; musculoskeletal pain. The terms were then combined with the appropriate Boolean connectors according to a PICO search table: each term under “population”, “intervention”, “comparison”, and “outcome” (PICO) were combined within groups with “OR”, while each term between groups were combined with “AND”. The search strategy did not target a specific population; however, only apparently healthy populations (i.e., no special populations) were included. A manual search of the Physiotherapy Evidence Database (PEDro) was also conducted using the same strategy. No date or language restrictions were implemented when searching the databases.

Exclusion criteria
One reviewer screened titles and abstracts. Studies were excluded if they did not satisfy the following: i) Were published in an English language, peer-reviewed journal; ii) Incorporated FR or RM (or both) as the primary intervention(s); iii) Directly compared the intervention to an independent control group; iv) Considered at least one of the following primary outcome measures: acute pain, chronic pain, muscle soreness, range of motion, athletic/muscular performance; v) Specified the duration of treatment in the Methods; and vi) Studied healthy participants or those with no existing chronic conditions that might influence results of an athletic test (e.g. arthritis or cardiovascular disease). Articles that passed the screening then underwent a full-text review by two reviewers to be further examined for eligibility.

The systematic and manual searches identified 113 articles. From there, 69 studies were removed due to being duplicates (n = 57), reviews (n = 8) or abstracts (n = 4). The remaining 44 studies were considered for full review; after applying the inclusion criteria, 16 studies were removed after abstract review, and six additional studies were removed after full-text review. The flow chart summarizing the systematic review can be found in Figure 2.

Data Quality and Analysis
The quality of included studies was assessed by two independent reviewers according to the Physiotherapy Evidence Database (PEDro) scale, developed to rate the quality of RCTs evaluating physical therapist interventions based on their methodological quality and reliability (Table 1).14-16 Among the available data, the population demographics, intervention type and protocol, outcome measures, and results were extracted for analysis. Studies were grouped by outcome measure for analysis of their interventions’ effect on the study population. Upon grouping, each study’s intervention duration and their general study conclusion (positive, negative, or null result) were combined to construct a linear plot illustrating dose-response indications in the literature.

RESULTS
The results of the 22 qualifying studies were grouped according to outcome measure (i.e., ROM, pain/soreness, and performance). Including studies analyzing multiple outcomes, there were eight studies examining pain/soreness, 17 measuring ROM, and 12 that assessed some aspect of athletic performance. In total, 16 studies involved a FR as their main intervention, while the remaining six used a RM. Areas treated by either a FR or a RM and used for subsequent test/retest in the qualifying studies included the gluteals (n = 4), the hip flexors (n = 1), the quadriceps (n = 12), the hamstrings (n = 10), the iliotibial band (n = 4), the adductors (n = 4), and the plantar flexors (n = 8). Similar to previous reviews on this topic, 4, 10, 12 even with separated outcome measures the heterogeneity of studies made data consolidation and meta-analysis invalid.

Population Characteristics
The combined population of participants in the 22 studies was n = 644. One study17 did not disclose the sex of their subjects (n = 40) and was therefore not included in analysis of sexual distribution. Of the remaining 604 subjects, 62.9% were male (n = 380) and 37.1% were female (n = 224). Separated by outcome measure, there were n = 328 subjects (63.4% male, n = 208 and 36.6% female, n = 120) in studies relating to pain/soreness,8,19,21,23,24,26,28-30,32,34,37 and n = 241 (60.2% male, n = 145 and 39.8% female, n = 96) for athletic performance.6,19,21,23,24,26,28-30,32,34,37 The typical study participant across all outcomes was a recreationally active adult (e.g. moderately active two to three times per week), aged between 18 to 47 years (mean +/- standard deviation [SD] = 25.0 +/- 5.54 years).
One study18 did not disclose the ages of their participants (n=150) beyond describing them as university-aged; they were therefore omitted from the age distribution analysis. For pain/soreness, ages ranged from 19 to 47 years (26.0 +/- 5.34 years), with 93% of the participants (n=306) being at least recreationally active on a regular basis. ROM participant ages ranged from 18 to 47 years (24.9 +/- 5.98 years), the large majority (93.0%, n=370) of which were also at least recreationally active on a regular basis. Finally, subjects in studies relating to athletic performance had no age range available (24.0 +/- 4.05 years), with 97.5% of the participants (n=235) being at least recreationally active on a regular basis.

Dose-Response Analysis
Appendices 1-3 describe the design and results of the 22 included studies relating to (1) pain/soreness, (2) ROM, and (3) athletic performance. The results column includes only the results that are pertinent to the selected outcomes of this review; they are not an exhaustive list of all the outcome measures assessed by the original study authors. Figures 3 and
non-significant result²¹ can be considered an outlier. However, when separated by total time treating a single muscle group (Figure 4), the data points shift slightly and a minimum dose can be observed. Foam rolling a single muscle group for under 45 seconds may indeed be insufficient for adequate recovery from muscle pain or acute/chronic muscle soreness. Further, the positive result seen at 45 seconds per muscle group²⁴ draws conclusions based upon magnitude-based inferences³⁸ (% likelihood) as opposed to including effect sizes (Cohen’s d) or tests of significance (p-value) like many of the other experiments. More robust results were seen in studies that intervened for durations between 90 and 600 seconds per muscle group,¹⁸–²⁰,²²,²³,²⁵ suggesting that a minimum dose of 90 seconds is most reliable and is best suited for recovery of muscle pain/soreness.

Pain/Soreness

Overall, results for the recovery from muscle pain/soreness indicated that the use of MR for any duration would improve a subject’s outcome. When analyzed by total time spent treating the subject (Figure 3), no dose-response is present and the single non-significant result²¹ can be considered an outlier. However, when separated by total time treating a single muscle group (Figure 4), the data points shift slightly and a minimum dose can be observed. Foam rolling a single muscle group for under 45 seconds may indeed be insufficient for adequate recovery from muscle pain or acute/chronic muscle soreness. Further, the positive result seen at 45 seconds per muscle group²⁴ draws conclusions based upon magnitude-based inferences³⁸ (% likelihood) as opposed to including effect sizes (Cohen’s d) or tests of significance (p-value) like many of the other experiments. More robust results were seen in studies that intervened for durations between 90 and 600 seconds per muscle group,¹⁸–²⁰,²²,²³,²⁵ suggesting that a minimum dose of 90 seconds is most reliable and is best suited for recovery of muscle pain/soreness.
In terms of a true dose-response trend (i.e. longer MR sessions leading to more lasting effects), the heterogeneity of studies made this difficult to discern. For example, the study with the longest single-muscle MR duration (hamstrings for one set of 600 seconds) measured the effects up to 60 minutes post-MR. While they achieved a statistically significant reduction in muscle soreness versus both their control and within-subject control groups, another study intervened with only 120 seconds per muscle (five hip and thigh muscles, bilaterally) and observed a decrease in muscle soreness lasting 72 hours post-MR. However, these studies differed in many areas, including the SMR tool they used (FR versus RM), fitness level of their study population, muscle groups that they treated, muscle soreness data collection method (algometer versus rating scale), and statistics that they.

Figure 3. Effect of total Self-Myofascial Release (SMR) duration using a foam roller or a roller massager, in seconds, on each of the three indicated outcome measures. Each green circle or red X denotes a unique study result. Some studies appear in multiple outcomes, and some studies have multiple SMR durations per outcome.

Figure 4. Effect of Self-Myofascial Release (SMR) duration per muscle group using a foam roller or a roller massager in seconds on each of the three indicated outcome measures. Each green circle or red X denotes a unique study result. Some studies appear in multiple outcomes, and some studies have multiple SMR durations per outcome.
analyzed (p-value versus Cohen’s d). It is worth noting, meanwhile, that when considering the total duration of a single MR session (Figure 3), the study with the longest total MR duration (1200 seconds) also resulted in the longest lasting significant effect (72 hours). Otherwise, most studies assessing muscle pain and soreness noted the acute and transient nature of their results, suggesting that MR is an effective option only for short-term relief.

Range of Motion

The results for MR’s effect on ROM are much less clear. In total, 10 of 17 studies reported statistically significant ROM improvements of some kind, with no ideal MR duration apparent. Similarly, when split by studies that tested ROM by active versus passive means, five of nine studies measuring active ROM showed significant improvements while five of eight studies measuring passive ROM noted the same. Among the methods used to assess ROM, the kneeling lunge test (for the hip flexors) was the most common with five studies opting for that technique; however, the fact that a total of ten different methods were used in 17 different studies to assess ROM about various joints demonstrates that the variation is too large to directly compare results. In terms of MR duration, the results were spread evenly across all time points. There was also a near equal split of positive and negative trials appearing on both sides of the MR duration line when considering both the total MR session duration and the total time spent on one muscle (Figures 3 & 4). From this, it is not possible to provide conclusive support of an optimal MR duration, and further trials are needed to rigorously test and retest (using similar testing protocols) the effect of MR on ROM.

Athletic Performance

Athletic performance was minimally affected by MR. While ROM was difficult to interpret due to its wide array of testing techniques, assessing MR’s effect on performance is challenging as there are multiple operational definitions of “athletic performance” and many ways to measure it. Included among the outcome measures are dynamic tests like the vertical jump test or an 800-meter run test. Likewise, tests of maximal voluntary contraction (MVC) and sub-maximal electromyography (EMG) were also used as measures of athletic performance, exacerbating the challenge of combining data. Assessing results as either a significant positive result, a non-significant result, or a significant negative result (as in Figures 3 & 4), demonstrates that MR using either a FR or a RM does not typically provide an individual with a performance increase. Both positive and negative results are spread out along the duration line, so it is not possible to discern a recommended MR duration time for optimal athletic performance. Three of the four studies that reported a performance increase post-MR noted that the effects lasted up to 72 hours post treatment (the fourth did not perform follow-up testing). Conversely, the results of another study directly contradicted this finding, showing no effect on performance versus control at any time point for 72 hours. One study, however, analyzed the effects of two different FR durations of the hamstring (60 or 120 seconds) on the maximum number of subsequent consecutive knee extension repetitions. While both FR durations resulted in a decrease in repetitions versus control, they noted a dose-response: the longer the FR duration, the fewer repetitions their subjects were able to perform.

DISCUSSION

This systematic review sought to determine a consensus on MR duration for optimal muscle pain/soreness recovery, ROM, and athletic performance. The results of this review suggest that MR using a FR or a RM for at least 90 seconds per muscle will acutely alleviate muscle soreness; the current literature also suggests that a longer treatment duration extends the duration of analgesic effects, although this effect is non-linear. Nonetheless, more robust data are needed to confirm these findings, as the data studied here are highly heterogeneous. While many studies did report an acute positive effect at varying intervention durations, the long-term effectiveness of MR for ROM remains inconclusive. As the underlying physiological effect of MR is still uncertain, improving subject ROM via MR may vary across individuals, and whether ROM is restricted by pain or by true myofascial stiffness (discussed later in the Nociceptor Involvement section). Finally,
the literature indicates that MR has little effect on improving or enhancing athletic performance at any duration, and actually suggests that performance may begin to suffer progressively with longer treatment. Although the effects of MR are inconclusive for acute and chronic ROM, and MR may be detrimental to athletic performance, the authors suggest that MR for approximately 90 seconds per unilateral muscle group may be the most efficient duration to achieve a reduction in muscle pain/soreness.

With the rise in MR popularity over the past decade, research on the topic is recent but remains limited in scope: all 22 studies included in this review were published between 2013 and 2018. Recent reviews examining measurable effects of FR and RM’s have come to similar conclusions,\textsuperscript{4,9,10,12} however, a common theme was the emphasis on determining the optimal duration of MR. Therefore, this review analyzed the topic by separating the literature into three main outcome measures: muscle pain/soreness recovery, ROM, and athletic performance.

The current consensus in the literature regarding MR is that it reduces soreness and improves ROM with limited decrements in performance.\textsuperscript{4,9-11} The available data indicate that MR is a recovery tool rather than a performance enhancer; consequently, negative plot points (those indicating no effect, not those indicating a negative effect) on Figures 3 and 4 can be considered a positive result assuming the main goal is a reduction in soreness or an increase in ROM. Since data from one study indicate a negative MR dose-response for performance\textsuperscript{37} and the available evidence indicates that muscle pain and soreness can decrease after approximately 90 seconds of MR, the authors believe an MR duration of roughly 90 seconds per muscle is ideal to maximize the positive benefit of pain/soreness recovery while minimizing the decrement to performance.

\textbf{Nociceptor Involvement}

The mechanism(s) underlying the analgesic effects of MR are ill-defined. Recent findings have identified nociceptors within multi-layered fascia in rats, with researchers postulating that these nociceptors may play a role in chronic muscle pain.\textsuperscript{39} As is well established, pain is often associated with limited ROM, while non-neurological tension signs in addition to pain further limit ROM.\textsuperscript{40,41} When considering this in the context of recent data on MR, a persistent question emerges: does MR truly mobilize the myofascial unit, or does it simply dampen the nociceptive response, allowing those with limited ROM due to pain to move beyond their baseline measurements?

The study by Young et al\textsuperscript{25} (included within the pain/soreness section, Appendix 1) examined this phenomenon, assessing whether or not using a RM on the plantar flexors would reduce spinal excitability, thus increasing a subject's pain-pressure threshold (PPT). They determined that spinal excitability decreased post-RM, with a pressure-dependent response observed (i.e., more pressure led to more neurological inhibition). This response suggested a fast-adaptation: spinal excitability quickly recovered from its response-dampened state in under three minutes. This result appeared as a consistent trend in the majority of studies that observed a significant increase in ROM post-MR; although flexibility improves, the results were transient and only remained significant for a short period of time after MR. One possible interpretation of these findings is that restricted ROM derived from pain/soreness is amenable to improvement via MR, while ROM that is truly restricted by myofascial tightness is non-responsive. Clearly, further research is required to test this hypothesis.

Additionally, studies by both Aboodarda et al\textsuperscript{18} and Cavanaugh et al\textsuperscript{42} have found evidence of a global pain modulatory system through their observed effects of roller massaging. Both author's results noted that with three, 30-second RM treatments on the same muscle, there was a significantly smaller increase in pain experienced post-RM intervention in both the ipsilateral and contralateral limb, even though the contralateral limb had not been touched by the intervention. As this directly contradicts early ideas of purported MR mechanisms (i.e., reduced fascial adhesions, improved fascial viscosity and mobility, and altered mechanoreceptor response in the myofascial unit), this further supports the notion that the effects of MR are grounded in cross-over effects of neurological basis. If, conversely, the effects of MR were due to alterations in the mechanical properties of the tissue, one would expect to see ipsilateral effects, local only to the tissue treated. However, as...
evidence has shown transient, non-local effects in the reduction of pain/soreness, it suggests that MR acts on a neurological basis, with recent evidence suggesting the presence of a global pain modulatory system likely within the central nervous system.

Limitations
Several factors limit the conclusiveness of these findings. As demonstrated above, the heterogeneity of MR research is the overarching issue in the relevant literature. When searching for a consensus on the optimal MR duration, no significant number of studies were similar enough for direct comparison; as testing protocols contained too much variation. Studies often analyzed different muscle groups and utilized different muscle soreness/ROM/performance measurements (e.g., testing active versus passive ROM, or measuring pain on a subjective rating scale versus using an algometer). Similarly, there was minimal statistical consistency: not all studies included the same statistics to permit data pooling. This did not allow for true quantitative data analysis, which restricted this review to a qualitative investigation. Another uncertainty among MR research is in regard to the potential lasting effects. Unfortunately, most studies did not assess their subjects with long-term follow-ups to determine if the effects were retained, but rather conducted a same-day test/retest protocol and collected data solely in the acute setting.

CONCLUSION
Available data indicate that MR for 90 seconds per unilateral muscle group may be the minimal duration to achieve a reduction in pain/soreness, with no upper limit found. While the analgesic effects were transient in nature, the longer time spent on MR, the longer the effects seemed to last; however, these results are non-linear and require further investigation to arrive at a consensus. Results do not support increases in chronic ROM or performance, and data are insufficient to provide a conclusive recommendation regarding acute ROM. The heterogeneity of the literature highlights the need for additional research to determine optimal dose of MR.

REFERENCES


## Appendix 1. Description of Included Studies: Outcomes Relating to Pain/Soreness.

<table>
<thead>
<tr>
<th>Author</th>
<th>Tool</th>
<th>Study Population</th>
<th>Muscle(s) Treated</th>
<th>Duration of FR/RM²</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aboodarda et al</td>
<td>RM</td>
<td>n=150 (80 males, 70 females)</td>
<td>Plantar flexors</td>
<td>3 sets of 30s,</td>
<td>Increase in PPT in ipsilateral and contralateral RM group at 30s post (p&lt;0.03) and 15m post (p&lt;0.05) vs control and sham</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Recreationally active adults</td>
<td>with 30s rest between sets</td>
<td>90s total</td>
<td>• Acute, transient, and non-localized effect</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Exhibited point tenderness on plantar flexors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Casanova et al</td>
<td>RM</td>
<td>n=20 (18 males, 2 females)</td>
<td>Plantar flexors</td>
<td>6 sets of 45s,</td>
<td>Increase in PPT (p=0.032) immediately after exercise-induced muscle damage stimulus vs no RM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Adult athletes with occasional resistance training experience and no recent ankle injuries</td>
<td>with 20s rest between sets</td>
<td>270s total</td>
<td>• Acute, transient effect</td>
</tr>
<tr>
<td>Cheatham et al</td>
<td>FR</td>
<td>n=45 (27 males, 18 females)</td>
<td>Quadriceps</td>
<td>1 set of 120s,</td>
<td>Increase in PPT (p&lt;0.001) immediately post-FR in non-vibrating FR group vs control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Recreationally active adults</td>
<td></td>
<td>120s total</td>
<td>• No analysis of chronic effects</td>
</tr>
<tr>
<td>Fleckenstein et al</td>
<td>FR</td>
<td>n=45 (23 males, 22 females)</td>
<td>Quadriceps, hamstrings, adductors, plantar flexors, and iliotibial band</td>
<td>1 set of 30s on each muscle group, bilaterally</td>
<td>No significant difference of FR on pain sensation in the preventative nor the regenerative groups vs control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Regularly active adults</td>
<td></td>
<td>300s total</td>
<td></td>
</tr>
<tr>
<td>Jay et al</td>
<td>RM</td>
<td>n=22 (all male)</td>
<td>Hamstrings</td>
<td>1 set of 600s,</td>
<td>Decrease in muscle soreness for RM group at 0, 10, 30, and 60 (all p&lt;0.0001) minutes vs control, and for RM group at 0 (p&lt;0.0001),</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Untrained adults with no prior history of knee, low back, or neck pain</td>
<td></td>
<td>600s total</td>
<td>10 (p&lt;0.0001), 30 (p&lt;0.0003), and 60 (p&lt;0.0001) minutes vs within-subject control</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Increase in PPT for RM group at 0 (p&lt;0.0002), 10 (p&lt;0.0001), and 30 (p&lt;0.0001) minutes vs control, and for RM group at 0 (p&lt;0.0001),</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>10 (p=0.0002), 30 (p=0.0005), and 60 (p=0.002) minutes vs within-subject control</td>
</tr>
<tr>
<td>MacDonald et al (2014)</td>
<td>FR</td>
<td>n=20 (all male)</td>
<td>Quadriceps, hamstrings, adductors, iliotibial band, and gluteals</td>
<td>2 sets of 60s per region, bilaterally</td>
<td>Decrease in muscle soreness for FR group at 24 (Cohen’s d=0.66), 48 (d=1.03), and 72 (d=1.01) hours vs control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• All regularly resistance trained 3 or more days/week</td>
<td></td>
<td>1200s total</td>
<td></td>
</tr>
<tr>
<td>Pearson et al</td>
<td>FR</td>
<td>n=8 (all male)</td>
<td>Quadriceps, hamstrings, adductors, iliotibial band, and gluteals</td>
<td>1 set of 45s</td>
<td>Moderate effect of FR on decreasing quadriceps soreness at 24h (74% likely) and large effect on decreasing quadriceps soreness at 48h (94% likely) post-exercise</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Recreational resistance-training adults, classified as moderately to very physically active</td>
<td>per region, bilaterally, with 15s rest in between</td>
<td>450s total</td>
<td>• Acute, transient effect</td>
</tr>
<tr>
<td>Young et al</td>
<td>RM</td>
<td>n=18 (10 males, 8 females)</td>
<td>Plantar flexors</td>
<td>3 sets of 30s,</td>
<td>Decrease in H-reflex amplitude in RM groups (p&lt;0.001, d=0.87) vs sham, implying significantly reduced muscle pain sensation and increased PPT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Recreationally active adults</td>
<td>with 30s of rest in between</td>
<td>90s total</td>
<td>• Acute, transient effect</td>
</tr>
</tbody>
</table>

* - Statistically significant positive conclusion
FR - Foam Roller
RM - Roller Massager
PPT - Pain-Pressure Threshold
# reported as s/m/h - Denotes the indicated number of seconds (s), minutes (m), or hours (h)
Appendix 2. Description of Included Studies: Outcomes Relating to Range of Motion (ROM).

<table>
<thead>
<tr>
<th>Author</th>
<th>Tool</th>
<th>Study Population</th>
<th>Muscle(s) Treated</th>
<th>Duration of FR/RMa</th>
<th>Results</th>
</tr>
</thead>
</table>
| *Bradbury-Squires et al* | RM   | n=10 (all male)  • Recreationally active adults                                   | Quadriceps                         | 5 sets of 20s or 5 sets of 60s with 60s rest between sets 100s or 300s total | Increase in ROM in both the 20 and 60s conditions (both p<0.05) vs control  
  • No analysis of chronic effects                                     |
| Bushell et al           | FR   | n=31 (19 males, 12 females)  • Adults who were physically active at least 1.5 hours per week who hadn’t recently foam rolled | Quadriceps                         | 3 sets of 60s with 30s rest in between sets 180s total 1 FR session during each of sessions 1 & 2, and 5x in 7 days between 1 & 2 | No significant difference in ROM for the FR group vs control across all 6 lunges performed at each of the 3 sessions |
| Casanova et al          | RM   | p=20 (18 males, 2 females)  • Adult athletes with occasional resistance training experience and no recent ankle injuries | Plantar flexors                    | 6 sets of 45s with 20s rest between sets 270s total | No significant difference in ROM for the RM group vs control at all time points (up to 72h) |
| *Cheatham et al*        | FR   | n=45 (27 males, 18 females)  • Recreationally active adults                      | Quadriceps                         | 1 set of 120s 120s total | Increase in ROM (p<0.001) immediately post-FR in non-vibrating FR group vs control  
  • No analysis of chronic effects                                     |
| D’Amico & Paolone       | FR   | n=16 (all male)  • Trained adults, able to complete an 800 metre run in under 160s | Gluteals, hip flexors, quadriceps, iliotibial band, adductors, and calves 1 set of 30s per region, bilaterally 360s total | | No significant difference in ROM for the FR group vs control |
| *Jay et al*             | RM   | n=22 (all male)  • Untrained adults with no prior history of knee, low back, or neck pain | Hamstrings                         | 1 set of 60s 600s total | Increase in ROM at 10m (p=0.03) post-RM in RM group vs control  
  • Increase in ROM immediately (p=0.03) post-RM in RM group vs within-subject control (contralateral leg)  
  • Acute, transient effect: no other statistically significant data on ROM post-FR in FR group vs control  
  • No significant difference in ROM between FR group and PNF stretching group  
  • No analysis of chronic effects                                     |
| *Junker & Stogb*        | FR   | n=40 (all male)  • Recreationally active adults who perform sport-like activity 2-3 times per week | Hamstrings                         | 3 sets of 30-40s, bilaterally 180-240s total (mean=210s) 3 FR sessions per week for 4 weeks | No significant difference in ROM for the FR group vs control |
| Kelly & Beardsley       | FR   | n=26 (16 males, 10 females)  • Recreationally active adults performing exercise 2-3 times per week on average | Plantar flexors                    | 3 sets of 30s with 10s rest between sets 90s total | No significant difference in ROM in the FR group vs control |
| *MacDonald et al (2014)* | FR   | n=20 (all male)  • All regularly resistance trained 3 or more days/week         | Quadriceps, hamstrings, adductors, iliotibial band, and gluteals 2 sets of 60s per region, bilaterally 1200s total | Moderate effect on increasing quadriceps passive ROM at 48 (d=0.77) and 72h (d=0.56) post FR, hamstring passive ROM at 72h (d=0.62) post FR, and hamstring dynamic ROM at 24h (d=0.57) post FR | |
| *MacDonald et al (2013)* | FR   | n=11 (all male)  • Recreational resistance training adults, classified as moderately to very physically active | Quadriceps                         | 2 sets of 60s, with 30s rest between sets 120s total | Increase in ROM at both time points of 2 and 10m (both p<0.001) post-FR vs control |
| Macgregor et al         | FR   | n=16 (all male)  • Recreationally active adults                                  | Quadriceps                         | 1 set of 120s 120s total 1 FR session per day for 3 consecutive days | No significant difference in ROM in the FR group vs control |
### Appendix 2. Continued.

<table>
<thead>
<tr>
<th>Author</th>
<th>Tool</th>
<th>Study Population</th>
<th>Muscle(s) Treated</th>
<th>Duration of FR/RM</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Mohr et al</em>&lt;sup&gt;14&lt;/sup&gt;</td>
<td>FR</td>
<td>n=40, Recreationally active adults, engaging in physical activity 1-5 hours per week</td>
<td>Hamstrings</td>
<td>3 sets of 60s, with 30s rest between sets; 180s total</td>
<td>Increase in ROM regardless of treatment group (p&lt;0.001)</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td>FR + static stretching (SS) group's ROM increased significantly more than SS (p=0.04), FR (p=0.06), or control (p=0.001)</td>
</tr>
<tr>
<td>Morales-Arriacho et al*&lt;sup&gt;14&lt;/sup&gt;</td>
<td>FR</td>
<td>n=14 (all male), Physically active adults, performing 3-4 hours of sport per week</td>
<td>Hamstrings</td>
<td>1 set of 60s bilateral FR, followed by 5 sets of 60s unilateral FR, bilaterally; 660s total</td>
<td>No significant difference in ROM in the FR group vs control</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>Cycling + FR as a warm-up significantly increased ROM at 5 (p&lt;0.001) and 30m (p=0.046) vs control, but was no better than the cycling group vs control alone</td>
</tr>
<tr>
<td><em>Phillips et al</em>&lt;sup&gt;15&lt;/sup&gt;</td>
<td>FR</td>
<td>n=24 (8 males, 16 females), Physically active adults, exercising at least 3 times per week</td>
<td>Quadriceps and plantar flexors</td>
<td>1 set of either 60s or 30s per region, bilaterally; 240/1200s total</td>
<td>Increase in kneeling lunge knee ROM in both FR groups (p&lt;0.01) vs control</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Effects of both FR groups were statistically similar, however FR60 had a moderate effect (d=0.58), while FR300 had a large effect (d=0.85)</td>
</tr>
<tr>
<td><em>Smith et al</em>&lt;sup&gt;16&lt;/sup&gt;</td>
<td>FR</td>
<td>n=29 (8 males, 21 females) Physically active (n=23) or sedentary (n=6) adults</td>
<td>Gluteals, hamstrings, quadriceps, and plantar flexors</td>
<td>3 sets of 30s per bilateral region, with 30s rest between sets; 360s total</td>
<td>Increase in sit-and-reach scores immediately (p=0.003) post-FR vs control, but at no further time points</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Acute, transient effect</td>
</tr>
<tr>
<td><em>Sullivan et al</em>&lt;sup&gt;17&lt;/sup&gt;</td>
<td>RM</td>
<td>n=17 (7 males, 10 females), Recreationally active adults participating in physical activity roughly 3 times per week</td>
<td>Hamstrings</td>
<td>1 or 2 sets of 5 or 10s; 5, 10, or 20s total</td>
<td>Increase in ROM regardless of treatment group (p=0.0001) vs control</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Non-significant trend toward increase in ROM in the 10s groups (p=0.069) vs 5s groups, regardless of set number</td>
</tr>
<tr>
<td>Wilke et al*&lt;sup&gt;18&lt;/sup&gt;</td>
<td>FR</td>
<td>n=17 (7 males, 10 females), Physically active adults</td>
<td>Quadriceps</td>
<td>4 sets of 45s, with 30s rest between sets; 180s total</td>
<td>No significant difference in ROM in either FR group vs control</td>
</tr>
</tbody>
</table>

* - Statistically significant positive conclusion  
FR - Foam Roller  
RM - Roller Massager  
PNF - Proprioceptive Neuromuscular Facilitation  
# reported as s/min/h - Denotes the indicated number of seconds (s), minutes (m), or hours (h)
### Appendix 3. Description of Included Studies: Outcomes Relating to Performance.

<table>
<thead>
<tr>
<th>Author</th>
<th>Tool</th>
<th>Study Population</th>
<th>Muscle(s) Treated</th>
<th>Duration of FR/RM</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Bradbury-Squires et al</em></td>
<td>RM</td>
<td>n=10 (all male)</td>
<td>Quadriceps</td>
<td>5 sets of 20s or 5 sets of 60s with 60s rest between sets</td>
<td>Decreased vastus lateralis RMS EMG during active lunge in both the 20 and 60s conditions (both p&lt;0.05) vs control, and dose response indicating 60s decreases lunge EMG more than 20s (p&lt;0.05)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recreationally active adults</td>
<td></td>
<td>100s or 300s total</td>
<td>Results imply greater muscular efficiency post RM</td>
</tr>
<tr>
<td>Casanova et al*</td>
<td>RM</td>
<td>n=20 (18 males, 2 females)</td>
<td>Plantar flexors</td>
<td>6 sets of 45s with 20s rest between sets</td>
<td>No significant difference in maximal voluntary isometric contraction (MVIC) for the RM group vs control at all time points (up to 72s)</td>
</tr>
<tr>
<td>D’Amico &amp; Paolone*</td>
<td>FR</td>
<td>n=16 (all male)</td>
<td>Gluteals, hip flexors, quadriceps, iliotibial band, adductors, and calves</td>
<td>1 set of 30s per region, bilaterally</td>
<td>No significant difference in any performance parameters for the FR group vs control</td>
</tr>
<tr>
<td>Fleckenstein et al*</td>
<td>FR</td>
<td>n=45 (23 males, 22 females)</td>
<td>Quadriceps, hamstring, adductors, plantar flexors, and iliotibial band</td>
<td>1 set of 30s on each muscle group, bilaterally</td>
<td>No significant difference in jump height in the preventative or the regenerative FR groups vs control</td>
</tr>
<tr>
<td><em>MacDonald et al (2014)</em></td>
<td>FR</td>
<td>n=20 (all male)</td>
<td>Quadriceps, hamstring, adductors, plantar flexors, and iliotibial band</td>
<td>2 sets of 60s per region, bilaterally</td>
<td>Increased vertical jump height with a large effect at 48h (d=0.81) post FR vs control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All regularly resistance trained 3 or more days/week</td>
<td></td>
<td>1200s total</td>
<td>Increased voluntary muscle activation with a moderate effect at 24h (d=0.71) post FR, a large effect at 48h (d=1) post FR, and a moderate effect at 72h (d=0.57) post FR vs control</td>
</tr>
<tr>
<td>MacDonald et al (2013)*</td>
<td>FR</td>
<td>n=11 (all male)</td>
<td>Quadriceps</td>
<td>2 sets of 60s, with 30s rest between sets</td>
<td>No significant difference in any neuromuscular performance parameters in FR group vs control</td>
</tr>
<tr>
<td><em>Macgregor et al</em></td>
<td>FR</td>
<td>n=16 (all male)</td>
<td>Quadriceps</td>
<td>1 set of 120s, 120s total</td>
<td>Maintenance of MVC across 3-day span (p=0.002) in FR group while MVC decreased in the control group</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recreationally active adults</td>
<td></td>
<td>1 FR session per day for 3 consecutive days</td>
<td>Decreased EMG RMS for a submaximal task at 0 (p=0.006), 15 (p=0.003), and 30m (p=0.002) post-FR vs control, implying greater muscular efficiency</td>
</tr>
<tr>
<td>Monteiro et al*</td>
<td>FR</td>
<td>n=25 (all female)</td>
<td>Hamstrings</td>
<td>1 set of either 60s or 120s, 60/120s total</td>
<td>Decreased average knee extension repetitions performed in the FR60 group (d=1.2) as well as the FR120 group (d=2.0) vs control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recreationally active adults</td>
<td></td>
<td>1 FR session during each of the 2 inter-set rest periods</td>
<td>Knee response was noted: the longer the duration of FR, the fewer total knee repetitions were able to be done</td>
</tr>
<tr>
<td><em>Pearcey et al</em></td>
<td>FR</td>
<td>n=8 (all male)</td>
<td>Quadriceps, hamstring, adductors, iliotibial band, and gluteals</td>
<td>1 set of 45s per region, bilaterally, with 15s rest in between</td>
<td>Increased recovery for sprint performance with a moderate effect at 24 (77% likely) and 72h (81% likely) post-exercise</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recreational resistance training adults, classified as moderately to very physically active</td>
<td></td>
<td>450s total</td>
<td>Increased recovery for broad jump performance with a small effect at 24h (72% likely) post-exercise, and a large effect at 72h (86% likely) post-exercise vs control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Physical activity adults, exercising at least 3 times per week</td>
<td></td>
<td></td>
<td>Increased squat performance with a moderate effect at 48h (79% likely) post-exercise vs control</td>
</tr>
<tr>
<td>Phillips et al*</td>
<td>FR</td>
<td>n=24 (8 males, 16 females)</td>
<td>Quadriceps and plantar flexors</td>
<td>1 set of either 60s or 300s per region, bilaterally, 240/1200s total</td>
<td>Decrease in vertical jump height in all conditions (p&lt;0.001), however significantly more decreased in FR300 than in both FR60 and control (p&lt;0.001)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Increase in agility performance after FR60 (p&lt;0.05) vs FR300 and control, but small effect sizes for each (d=0.06-0.15)</td>
</tr>
</tbody>
</table>
### Appendix 3. Continued.

<table>
<thead>
<tr>
<th>Author</th>
<th>Tool</th>
<th>Study Population</th>
<th>Muscle(s) Treated</th>
<th>Duration of FR/RM²</th>
<th>Results</th>
</tr>
</thead>
</table>
| Smith et al²⁵ | FR   | • n=29 (8 males, 21 females)                                                      | • Gluteals, hamstrings, quadriceps, and plantar flexors                           | • 3 sets of 30s per bilateral region, with 30s rest between sets • 360s total  | • No significant difference in vertical jump height in FR group vs control  
|               |      | • Physically active (n=23) or sedentary (n=6) adults                              |                                                                                   |                                                                                  | • Increase in vertical jump height in dynamic stretch + FR group at 0 and 5m (both p<0.001) post-dynamic stretch + FR vs control, but was not significantly different from dynamic stretching group alone |
| Sullivan et al²⁷ | RM   | • n=17 (7 males, 10 females)                                                      | • Hamstrings                                                                      | • 1 or 2 sets of 5 or 10s • 5, 10, or 20s total                                  | • No significant differences in MVC force or EMG activity in any condition vs control                                                                                                                |
|               |      | • Recreationally active adults participating in physical activity roughly 3 times per week |                                                                                   |                                                                                  |                                                                                  |

* - Statistically significant positive conclusion  
FR - Foam Roller  
RM - Roller Massager  
RMS - Root Mean Square  
EMG - Electromyogram  
MVC - Maximal Voluntary Contraction  
# reported as s/m/h - Denotes the indicated number of seconds (s), minutes (m), or hours (h)
ABSTRACT

Background: Running cadence, or step rate, is often measured in running gait analysis and manipulated in gait retraining. A lower body positive pressure treadmill, or anti-gravity treadmill, allows users to walk/run in a reduced gravity environment.

Purpose: The primary purpose of this study was to determine how natural running cadence is affected by running on an anti-gravity treadmill compared to a standard treadmill in a healthy, active population. The secondary purpose was to determine if natural and increased cadence is affected by amount of body weight support.

Study Design: Cross-sectional study (convenience sample).

Methods: Thirty participants were recruited to run on an anti-gravity treadmill (AlterG Anti-Gravity Treadmill™ M320) at their pre-determined, self-selected, comfortable treadmill speed. Cadence was recorded at nine randomized bodyweight conditions, ranging from 100% of body weight to 20% of body weight, in 10% increments. An additional nine participants were recruited to try to replicate their natural, standard treadmill cadence, as well as increase it by 5% and 10%, while on an anti-gravity treadmill with the same randomized bodyweight conditions.

Results: Thirty participants, 19 females and 11 males, mean age 27.3 years (range, 22-45), completed Part 1 of the study protocol, while nine additional participants (2 females and 7 males) with a mean age of 29.6 years old (range, 25-40 years) completed Part 2 of the protocol. There was a significant effect of natural running cadence on the anti-gravity treadmill at reduced body weight percentages (p<.01). Post-hoc t-tests revealed that every 10% bodyweight interval was significantly lower than the previous 10% interval (p<.01) on the anti-gravity treadmill, with cadence decreases ranging from 1.5%-3.5% between intervals. Seven of the nine (77.8%) participants in Part 2 were able to replicate and increase their cadence at all body weight levels on the anti-gravity treadmill.

Conclusions: Decreasing bodyweight level on an anti-gravity treadmill yields a significant and linear decrease in running cadence when performed at a self-selected, moderate intensity pace. Further, the vast majority of participants were able to successfully replicate and increase cadence at all levels of bodyweight percentage.

Key Words: Anti-gravity treadmill, Cadence, Running

THE EFFECT OF AN ANTI-GRAVITY TREADMILL ON RUNNING CADENCE

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The protocol for this study was approved by the Institutional Review Board of the University of Minnesota.

The authors report no conflicts of interest.
INTRODUCTION
The recreational sport of running is associated with a high risk of overuse injury.1-12 The reported lower extremity injury rate ranges from 18% to 94%, with the greatest percentage of injuries being related to the knee.13-15 During a period of injury rehabilitation and potential reduction in running tolerance, runners often utilize cross-training modalities such as elliptical training or pool-related activities to supplement for or replace the aerobic benefits of running.

Running step rate, or cadence, is routinely assessed in running gait analysis. Previous research supports the use of step rate manipulation through increased cadence to alter running kinetics and kinematics. Heiderscheit et al. demonstrated that an increase of 5% above natural running cadence reduces hip and knee joint loading, which may correlate with injury prevention and treatment of overuse injuries.16 Allen et al. found a step rate 10% above natural cadence was effective in transitioning those with a heel strike running pattern at initial contact to a non-heel strike or less severe heel strike pattern, altering ground reaction forces.17

An anti-gravity treadmill allows users to walk or run in a reduced body weight environment. The user walks or runs on a treadmill belt surrounded by an enclosed, air-filled chamber. When air pressure increases, an upward force offloads the weight of the runner and decreases the percentage of body weight (BW%) experienced upon foot impact. Anti-gravity treadmills provide a mode of aerobic exercise that impart reduced ground reaction forces and are utilized in the rehabilitation community as well as in the healthy population.18

Differences have been documented in both level of exertion and running mechanics between standard treadmill and anti-gravity treadmill running. Figueroa et al. determined that, in healthy subjects, the metabolic cost of running was less on an anti-gravity treadmill with body weight support as compared to a standard treadmill.19 Kline et al. published metabolic conversions for standard treadmill speeds compared to anti-gravity treadmill at 50% to 100% body weight support.20

Two studies have investigated the effect of anti-gravity treadmill on running cadence. Raffalt et al. measured step length and frequency at five standardized speeds and at four BW% conditions on the anti-gravity treadmill in elite or sub-elite male runners.18 Across all speed intervals, as body weight support increased, step frequency decreased and step length increased. Neal et al. studied lower body kinematics in healthy male runners at three conditions equivalent to 60%, 70%, and 80% VO2 peak capacity.21 On the anti-gravity treadmill, ankle and knee kinematics were significantly altered during stance phase as compared to standard treadmill, and stance time significantly decreased when body weight was less than 80%. Spatiotemporal data collection in the previously mentioned studies was completed with in-shoe plantar pressure sensors. To the authors’ knowledge, no previous studies have investigated the effect of anti-gravity treadmill in a non-runner population or while allowing participants to use a self-selected pace.

The primary purpose of this study was to determine how natural running cadence is affected by running on an anti-gravity treadmill compared to a standard treadmill in a healthy, active population. The secondary purpose was to determine if natural and increased cadence is affected by amount of body weight support. The authors hypothesized that: a) natural cadence would decrease on an anti-gravity treadmill compared to a standard treadmill, b) natural cadence would decrease with increasing body weight support on the anti-gravity treadmill, and c) over ground running cadence would be maintained through 50% of bodyweight, after which time it would no longer be feasible to maintain, and a 10% increase in step rate would be maintained through 60% of body weight.

METHODS
A sample of convenience participated in this study at a private, outpatient, physical therapy clinic. Participants were recruited through word of mouth via colleagues within a single institution. Inclusion criteria for participation included being between the ages of 18-49 being self-described as physically active (engaged in a regular activity regimen of >150 minutes of moderate intensity exercise causing perspiration or heavy breathing for sessions of 30 consecutive minutes or greater per week).22 Participants were also novice runners, performing less
than 15 miles of running per week. Participants were excluded if they had sustained a lower extremity injury in the prior three months, had a history of lower extremity surgery, had a current back or lower extremity pain with running, had cardiovascular or neurological compromise, or were unable to provide voluntary consent.

**PROCEDURES**

Part 1: Participants performed a five-minute warm up on the standard treadmill; they were blinded to speed and instructed to increase the belt speed to a “moderate-intensity pace that you would run three miles or five kilometers at.” After the warm up, the treadmill speed was recorded and the natural running step rate of each participant was measured by a researcher visually counting the number of foot contacts in a thirty second period (with the participant running on the treadmill) and recording this as “steps per minute”. Participants next entered the anti-gravity treadmill (AlterG Anti-Gravity Treadmill™ M320, AlterG, Inc., Fremont, CA) set to the self-selected pace. After a sixty second familiarization period running at 100% of bodyweight, participants ran at nine randomized bodyweight intervals for sixty seconds each, ranging from 100% of BW to 20% of BW in 10% increments. Cadence was recorded for the final thirty seconds of each period.

Part 2: The participant’s self-selected pace and natural running cadence was determined on the standard treadmill in the same manner described above. A cell phone metronome was used to audibly cue 100%, 105%, and 110% of natural cadence, and the participant performed the step rate for a sixty second period. Participants then entered the anti-gravity treadmill and ran at each of the nine randomized BW% conditions as described above. For each interval, participants again attempted to perform natural (100%) step rate, 5% increased, and 10% increased step rate, as cued by a metronome. If a participant was unable to sustain natural cadence at a given BW% interval, the increased step rate condition was not attempted for that body weight interval, and the tester instead transitioned the anti-gravity treadmill to the next randomized body weight condition. Similarly, if unsuccessful at a 5% cadence increase, a 10% cadence increase was not attempted.

All participants gave their informed consent to participate, and the study was approved by the University of Minnesota Institutional Review Board.

In order to statistically determine differences across body weight trials, a repeated measures ANOVA was used, as well as post-hoc t-tests. Statistical analysis was performed using IBM SPSS Statistics for Windows, v23 (IBM Corp., Armonk, NY). Significance was set at p<0.05.

**RESULTS**

There were 30 participants (19 females and 11 males) with a mean age of 27.3 years old (range, 22-45 years old) in Part 1, and nine participants (2 females and 7 males) with a mean age of 29.6 years old (range, 25-40 years old) in Part 2.

For Part 1, a repeated measures ANOVA showed a significant effect of natural running cadence on the anti-gravity treadmill at reduced body weight percentages (p<.01). Post-hoc t-tests revealed that every 10% bodyweight interval was significantly lower than the previous 10% interval (p<.01) on the anti-gravity treadmill, with cadence decreases ranging from 1.5%-3.5% between intervals (Figure 1).

In relation to baseline cadence, the first 10% decrease in cadence occurred at roughly 50% of body weight, followed by a 20% decrease in cadence occurring at roughly 20% of body weight (Figure 1).

For Part 2, seven of the nine participants were able to successfully perform baseline, 5% increase, and 10% increase in running cadence on both the standard treadmill and the anti-gravity treadmill. Participants were excluded if they had sustained a lower extremity injury in the prior three months, had a history of lower extremity surgery, had a current back or lower extremity pain with running, had cardiovascular or neurological compromise, or were unable to provide voluntary consent.

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treadmill and for all nine body weight conditions on the anti-gravity treadmill. One participant was unable to sustain a 5% cadence increase at 60% of body weight, and was also unable to sustain a 10% cadence increase at 20% of body weight (which were the first two randomized BW conditions). However, this participant successfully completed the 5% and 10% increase in cadence conditions at all other body weight percentages. Another participant failed to perform 5% or 10% cadence increases at 20%, 30%, 50%, and 70% of body weight conditions, which were the final four randomized body weight levels, respectively.

DISCUSSION
The results of Part 1 indicate that natural step rate at any decreased BW% on an anti-gravity treadmill will be less than natural cadence on a standard treadmill at a self-selected, 5k pace. This is consistent with findings from previous studies performed at set speeds. While cadence data points were significantly different between each BW% levels, the values ranged from 1.5-3.5% between intervals, which may not be clinically relevant as previous literature has shown a significant change in muscle activation with a minimum cadence change of 5%. However, expecting a 10% decrease in cadence at 50% of body weight and a 20% decrease in cadence at 20% of body weight may be helpful for clinicians in prospectively estimating standard treadmill cadence based on anti-gravity treadmill performance. Additionally, these findings may assist clinicians in selecting a desirable bodyweight support level to minimize change in running cadence and to minimize the natural decrease in cadence with BW support for runners who aim to maintain a set cadence. Of note, this study was performed on a healthy population, and, if repeated on an injured population, a trend of anti-gravity treadmill natural step rate may need to be ascertained for a specific rehab population.

Step rate manipulation of natural standard treadmill running cadence and 5% and 10% increases were successfully performed by 77.8% of participants. Two participants were unable to complete all cadence conditions. One of the two participants failed during the early-randomized BW% levels, yet successfully completed each condition at all other BW% intervals, suggesting a delayed learning effect of either an anti-gravity treadmill environment or with matching the metronome cue. For the second participant, the failed attempts all appeared towards the end of data collection, perhaps due to a potential fatigue effect for this particular participant.

The results of Part 2 provide evidence that, in a healthy, active population, cadence can be reproduced at natural step rate and up to 10% increased step rate on an anti-gravity treadmill, regardless of the body weight percentage experienced while running. The authors are currently unaware of any previously reported literature that either confirms or refutes these findings. This information may benefit runners who utilize the anti-gravity treadmill as a training modality and are attempting cadence manipulation.

These results indicate that running cadence at any body weight level on an anti-gravity treadmill can be expected to be less than over-ground cadence. Compared to natural cadence on a standard treadmill, one can expect a 10% decrease in cadence at 50% body weight and a 20% decrease in cadence at 20% body weight. These values may be helpful for clinicians in forming expectations for over-ground running cadence based on anti-gravity treadmill performance.

Furthermore, this study lays a foundation for future investigations on injured runners, a population that may benefit from gait retraining in the early stages of the rehabilitation process. The anti-gravity treadmill offers potential for earlier initiation of cadence retraining, fostering neuromuscular adaptations prior to returning an injured athlete to over-ground running. Utilizing an anti-gravity treadmill may also be desirable as a method of estimating over-ground running cadence in injured runners training on an antigravity treadmill at their current level of function. Knowing the expected reduction in cadence that naturally occurs as body weight support increases can allow clinicians to gauge the progress of their patient in reaching their natural cadence based upon the level of body weight support is being utilized.

There are several limitations of this study. First, it was performed on a healthy population, with the understanding that if repeated on an injured population, a different trend of anti-gravity treadmill cadence may be realized. Second, having novice
runners self-select their speed may alter the ability to manipulate cadence, as faster speeds may put more demand on running mechanics as well as the cardiovascular system as a whole. A further limitation of the study is potential for error in data collection due to the researcher visually counting foot strikes as compared to objective data collection with pressure sensors used in past studies. However, the results of this current study are consistent with the past studies, which supports visual tracking of cadence as a convenient alternative to more costly methods.

**CONCLUSION**

Running at decreased BW% on an anti-gravity treadmill yields a significant and linear decrease in cadence when performed at a self-selected, moderate intensity pace, as compared to cadence on a standard treadmill. On an anti-gravity treadmill, each 10% decrease in body weight resulted in a significant decrease in natural running cadence. Further, the vast majority of healthy individuals are able to maintain and increase their natural cadence at varying body weight percentages, which supports the possibility of cadence training taking place prior to injured individuals commencing full body weight running. The appropriate cadence manipulation candidate may benefit from earlier initiation of cadence retraining, and this may be possible in the reduced bodyweight environment that the anti-gravity treadmill provides.

**REFERENCES**


ORIGINAL RESEARCH

THE INFLUENCE OF HEEL HEIGHT ON MUSCLE ELECTROMYOGRAPHY OF THE LOWER EXTREMITY DURING LANDING TASKS IN RECREATIONALLY ACTIVE FEMALES: A WITHIN SUBJECTS RANDOMIZED TRIAL

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ABSTRACT

Background: An increased risk of ACL injury has been shown in female athletes who land from jumping maneuvers with knee angles close to extension and in those who demonstrate a hamstring-to-quadriceps muscle recruitment imbalance.

Hypothesis/Purpose: The purpose of this study was to determine if added heel lift height would alter electromyography (EMG) magnitude and timing of the quadriceps (vastus medialis, vastus lateralis), hamstrings (semitendinosus, biceps femoris) and gastroc (medial gastroc, lateral gastroc) musculature during forward jump and drop-rebound jump landing tasks in females. The authors hypothesized increased heel lift height would promote recruitment of the hamstring and gastrocnemius muscles and increase the time to peak muscle activity in the quadriceps muscles.

Study Design: Prospective randomized trial

Methods: 60 recreationally active females participated. Participants performed five repetitions of forward jump and drop-rebound jump landing tasks while wearing different heel lifts heights (0, 12, 18, 24 mm) placed on the under-side of an athletic shoe. Task order and heel lift height were randomized. Dependent measures were average magnitude of muscle recruitment (AMR), peak magnitude of muscle recruitment (PMR), and time to reach PMR for six lower extremity muscle groups as measured by surface EMG.

Results: Repeated measures ANOVAs were used to determine the influence of heel lift height on the dependent measures. There were no significant differences in the AMR, PMR, or time to reach PMR with the four different heel heights during the landing maneuvers, with one exception. A significant difference was found in the time to achieve PMR in the semitendinosis muscle during a forward jump landing (p=.024). Post hoc analysis found significant differences with both the 18mm and 24mm heel lift height compared to 0mm.

Conclusions: Utilization of larger heel lifts (18mm and 24mm) to influence landing biomechanics may be of potential benefit; however, only when performing forward jump landing tasks. Further investigation into the protective effects of a quicker onset of semitendinosis peak magnitude is warranted.

Level of Evidence: 2

Key Words: ACL, electromyography, heel lift, kinematics, landing

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INTRODUCTION
Researchers have consistently demonstrated that anterior cruciate ligament (ACL) injuries occur more frequently in female compared to male athletes.1,2,3,4,5 However, the basis of this gender disparity remains poorly understood. Although many theories have been proposed,6,7,8,9 no evidence exists that supports a single cause for the female’s propensity towards ACL injury. Furthermore, researchers have struggled to find proven methods to limit or prevent these injuries.10

Risk factors for sustaining ACL injuries have been divided into four general categories: environmental, anatomical, hormonal, or biomechanical.6 Many of these risk factors cannot feasibly be altered. However, given the ability to change joint kinematics and muscle activity, many researchers have focused on the biomechanical risk factors utilized by female athletes during sports maneuvers.7,8,9,11,12,13,14,15,16 Researchers have demonstrated that females repeatedly utilize an extension-biased knee landing pattern in a variety of sport maneuvers.11,13,14,17,18 The ramifications of landing with the knee closer to extension include increased EMG activity of the quadriceps,10,13,20,21 increased anterior tibio-femoral shear,21,22,23 increased vertical ground reaction forces,14,24 and a decrease in EMG activity of the hamstrings.13,22 Each of these characteristics are thought to increase ACL injury risk.23,25,26

ACL injury prevention programs have been used to favorably influence kinematic patterns during varied landing tasks in female athletes.27,28,29,30,31,32,33 However, many of these programs require a substantial time investment of 90-minutes or more several times per week,14,27,28,29,35,36 often requiring greater than six-weeks of consistent training.27,28,29,34,35,37,38 This time component is apt to have negative effects on compliance, which has been demonstrated to be a substantial factor in the overall success of a program.33,35 Furthermore, the duration of the protective effects of these training programs after cessation of participation is unknown. Conversely, some challenge these prevention programs, refuting the proposed benefits and arguing a lack of effect with reduction of non-contact female athlete ACL injury.10 Vescovi et al suggests these programs do not readily improve athletic performance, perhaps further hindering compliance from the perspective of coaching staff with dense team training schedules.38

A prevention strategy that requires minimal time and effort yet can still favorably alter knee biomechanics would be of substantial benefit to female athletes. To this end, evidence exists that increased heel height alters lower extremity biomechanics and muscle activity during gait,40,41,42,43,44,45,46 and muscle activity during sit to stand and jump-landing tasks.47,48 Both static-standing and dynamic gait analyses have demonstrated increased knee flexion angles with increased heel height.39,40,41,42,43,44,45,46,47,48 Lindenberg et al demonstrated that a 24 mm heel lift significantly increased knee flexion angles at initial contact and maximal excursion, as well as slowed the rate of excursion during a single forward jump landing maneuver. Further research demonstrated that a 24 mm heel lift significantly decreased peak vertical ground reaction force when landing from a forward jump landing maneuver.48 These kinematic changes associated with added heel lift height suggest that the incorporation of a heel lift may offer an alternative strategy for altering knee kinematics during sporting activities. However, no research has been performed to explore the effect of added heel lift height on muscle recruitment patterns during landing maneuvers.

Therefore, the purpose of this study was to determine if added heel lift height would alter electromyography (EMG) magnitude and timing of the quadriceps (vastus medialis, vastus lateralis), hamstrings (semitendinosus, biceps femoris) and gastrocnemius (medial gastroc, lateral gastroc) musculature during forward jump and drop-rebound jump landing tasks in females. The authors hypothesize that added heel lift height will significantly slow the onset of quadriceps recruitment and increase the magnitude of hamstring and gastrocnemius recruitment.

METHODS
A convenience sample of 60 recreationally active females between 18 and 25 years of age was recruited for this study. Recreationally active was defined as engaging in aerobic and/or anaerobic exercise for an average of four to five hours per week. To be included in the study, all participants declared the ability to perform a forward jump and drop-rebound jump landing onto the dominant lower extremity. However,
subjects were not asked to perform these activities until after informed consent had been obtained. Individuals who had previous surgery to their lower extremities or who had an acute lower extremity injury within the six months prior to the study were excluded. For the purposes of this study, “acute” was defined as suffering an injury to the lower extremity that required the use of an assistive device for more than one day. Furthermore, individuals who wore foot orthotics were excluded from the study. Data from a previously conducted pilot study was used to calculate the required sample size for this current study. G* Power software (G*Power 3.1.10, Dusseldorf, Germany) was used to determine that the sample size needed to achieve statistical power was 60 subjects. This study was approved by the Institutional Review Board at Slippery Rock University.

The study utilized a randomized block design. All data collection was performed in one session. Testing took place in a motion analysis laboratory at the university. After the collection of demographic information and maximum voluntary isometric contraction (MVIC) data, all subjects completed two landing tasks: landing from a 40 cm platform and a forward jump at a distance of 45% the subject’s body height. The subject completed these tasks under four different heel lift height conditions: 0mm, 12mm, 18mm, and 24 mm. Prior to beginning the two landing tasks, the investigator randomly determined the order of heel lift application in order to diminish bias. Randomization was performed by drawing the four different heel lift conditions, which were written on slips of paper and placed in a hat. Previous studies\(^{47,48}\) utilized similar landing tasks to those presented here to analyze lower extremity kinematics in athletes. This allowed for direct comparison to previous work.

**Dependent Variables**

Six lower extremity muscle groups were examined through the use of surface EMG including the vastus medialis obliquus (VMO), vastus lateralis (VL), biceps femoris (BF), semitendinosis (ST), medial gastrocnemius (MG) and lateral gastrocnemius (LG) regarding the following variables:

1. Magnitude of muscle activity at initial contact with landing (expressed as a percentage of the MVIC)
2. Magnitude of peak muscle activity (expressed as a percentage of the MVIC)
3. Time to achieve peak muscle activity with landing

**Independent Variable**

Heel lift height with four levels: 0mm, 12mm, 18mm, 24mm.

**Instrumentation**

Four footswitch triggers (Noraxon DTS Footswitch probe with four FSR sensors, Scottsdale, AZ) were utilized to mark initial contact during landing to assist with data reduction procedures.

Surface electrodes and wireless telemetric electromyography (EMG) system (Telemyo DTS desktop receiver; Noraxon, Scottsdale, AZ) were used to capture EMG data, from which muscle recruitment and timing were later extracted.

A System 4 Pro Dynamometer (Biodex Medical Systems, Shirley, NY) was utilized to standardize position and stabilization while measuring MVIC of each muscle group.

Heel lifts (G&W Heel Lift Incorporated; Cuba, MO) were injection-molded PVC vinyl lifts 6mm and 12mm in height. Two heel lifts were combined with double-sided tape provided by the manufacturer to achieve the 18 and 24mm height. The investigator affixed the appropriate heel lift to the under-surface of the subject’s shoe with one inch wide carpet tape (Ace Hardware Corp.; Oak Brook, IL).

**Collection of data**

Data collection was completed in one session. Each subject reported to the motion analysis laboratory for testing. Subjects were oriented to the instrumentation and all procedures were thoroughly explained. Informed consent procedures were completed, and demographic information was recorded.

All data were collected from the subject’s dominant lower extremity. Lower extremity dominance was determined using a self-selection strategy. Specifically, subjects were asked to perform a single leg landing from a 20 cm box. The leg the subject landed on for two out of three trials was defined as their dominant lower extremity.
Subjects were asked to demonstrate the ability to perform both the forward jump and drop-rebound jump landing tasks without restrictions. If an individual was unable to do so, then he or she was excused from participation in the study.

Subjects were fitted with four foot switches on the plantar surface of the dominant lower extremity. The foot switch consisted of sensors that were secured to the foot plantar surface via double sided tape. Sensors were located on the heel, first metatarsal head, fifth metatarsal head, and pad of great toe per manufacturer recommendations.

Subjects donned a standardized athletic shoe (New Balance, Boston, MA). Throughout the data collection session, the various heel lift heights were affixed to the outside/bottom of the subject’s shoes. The manufacturer established the use of two adjoined heel lifts as an acceptable use of the product. Specialized adhesive for this purpose was provided with the purchase of the heel lifts. Subjects were not made aware of the order of the heel lift heights that were applied for each jump.

Next, surface electrodes were placed on the skin of the subject at standard positions for each of the six muscles to be recorded. The skin was prepared prior to electrode application by cleaning the area with an alcohol swab and allowing time for the area to dry. The participant was then seated and the dominant lower extremity secured in the appropriate limb attachment on the Biodex Dynamometer. For both quadriceps and hamstring MVIC measurements, the knee attachment was used. The subject was positioned with 75° knee flexion, the backrest of the dynamometer seat was inclined to promote a hip joint angle of 100°. The mechanical axis of the dynamometer was aligned with the lateral femoral condyle. For gastrocnemius MVIC measurements, the combination ankle plate attachment with footrest adapter and limb support pad were utilized. The backrest was positioned as stated above. The subject’s knee was supported via the limb support pad promoting a knee angle of 20° flexion. The ankle attachment was set at 0° tilt with subject’s ankle positioned at 10° of plantarflexion. The mechanical axis of the dynamometer was aligned with the talus. Stabilization straps were used to secure the chest and thigh. The subject was asked to perform a series of three five-second MVICs with one-minute rest periods between each set for all the muscle groups. The muscle activity was captured via EMG recording and averaged for a net output of isometric torque.

Next, the subject performed two landing tasks. The order in which these tasks were performed was counterbalanced between the subjects. The first subject’s order was determined by coin flip and subsequent subjects performed the tasks in alternating order. The drop-rebound jump landing task required the subject to stand with her feet shoulder width apart and toes aligned with the edge of the 40 cm high platform. The subject then jumped forward landing on both lower extremities and immediately rebounded into a vertical jump. Subjects were asked to jump “as high as they could” on the rebound and “land softly” on both lower extremities to complete the task. The other landing task involved a forward jump from a distance of 45% of subject’s height from the landing marker. A 10 cm high by 15 cm wide box was placed halfway between the subject and the landing marker. The box size was not difficult to maneuver over; however, it encouraged a more vertical component to the task. Subjects jumped over the box, traveled a distance of 45% her height, and landed on both lower extremities on a tile marked with an ‘X’.

To ensure safety for the subject, a padded table (secured to the floor) was placed in front of or beside the subject so that they could “catch” themselves should they have felt the need to do so. This was found to be adequate in ensuring balance recovery during previous studies. Each subject had three practice trials for each landing task to become acquainted and comfortable with the technique.

For testing, subjects completed five trials of each landing task for each of the four heel lift heights (40 trials total). To prevent fatigue subjects rested 30 seconds between trials and five minutes between heel lift height conditions (during the time it took to change the heel lift on the shoe). No subjects reported or showed signs of fatigue or soreness during or after performance of these tasks. Furthermore, no specific risks or benefits to individual subjects were noted throughout the study process.

During the landing tasks, EMG data were collected via the surface electrodes on the six muscle groups
and recorded using MyoResearch XP data acquisition software (Noraxon, Scottsdale, AZ). The pressure-sensitive footswitches were integrated with this software. When initial contact occurred during the landing tasks, the footswitches registered an event that provided a standardized marker to be used when analyzing the EMG data.

**DATA REDUCTION AND STATISTICAL METHODS**
The EMG data were reduced within the acquisition/analysis software. Event markers were created in the program based on the initial contact registered by the footswitches to identify the start of each trial. The five trials for each task were averaged and custom buffers created, thereby allowing the investigator to identify the dependent variables. Signal smoothing using a root mean square algorithm at 50ms and full-wave rectification were used to process the data. Average and peak muscle activation and time to achieve peak muscle activation data were then analyzed within the software. These data were downloaded and organized into a spreadsheet (Microsoft Excel (2015), Redmond, WA). EMG data were then normalized to a percent of the MVIC. After data reduction, statistical analyses were completed with a commercially available statistical software package (SPSS 18.0; Chicago, IL). Separate repeated measures (randomized block) analysis of variances (ANOVA) were utilized to determine the influence of additional heel lift on the magnitude of muscle contraction at initial contact and peak activity and time to achieve peak muscle activity for each muscle for each landing task. When appropriate, post hoc testing using one-tailed paired t-tests were performed to identify any significant differences in the dependent variables between the heel lift conditions. Alpha levels were set a-priori at $p < 0.05$.

**RESULTS**
Sixty recreationally active females participated. Five subjects’ data were not able to be used due to poor EMG or footswitch recordings. Table 1 presents demographic information. There were no significant differences in the average magnitude of muscle activity, peak magnitude, or time to achieve peak magnitude with the four different heel lift heights during the forward jump (Table 2, 3, and 4 respectively) and drop-rebound jump (Table 5, 6, and 7 respectively) maneuvers with one exception. A significant difference was found in the time to achieve peak magnitude of muscle activity in the semitendinosus muscle during a forward jump landing ($p = .024$). Post hoc analysis determined that significant differences existed between both the 18mm and 24mm heel lift height when compared to 0mm (Figure 1).

**Table 1. Subject demographic data (n = 60).**

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**Table 2. Average EMG activity per muscle during forward jump.**

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<th>Ave mag p-values</th>
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$^1$ - means represent the normalized EMG data
SD-standard deviation; Ave-average; mag-magnitude; VMO-vastus medialis; VL-vastus lateralis; ST-semitendinosus, BF-biceps femoris, MG-medial gastrocnemius, LG-lateral gastrocnemius
DISCUSSION
The purpose of this study was to investigate the influence of heel lift height on muscle activity during forward jump and drop-rebound landing tasks. The semitendinosus was found to achieve a faster time to peak muscle activation during the forward jump landing task with the addition of a 18mm or 24mm heel lift compared to the control condition of 0mm. A trend was identified demonstrating increased hamstring peak magnitude (normalized EMG output for semitendinosus increased from 1.0716 at 0mm to 1.3142 at 24mm and biceps femoris from 1.9562 at 0mm to 2.3631 at 24mm) and a slower time to achieve peak magnitude for the quadriceps musculature (vastus lateralis time to peak increased from 0.0776 ms to 0.0898 ms); however, these results were not statistically significant.

Investigation of the utilization of heel lifts to influence landing maneuvers continues to remain novel research. Thus, there is a paucity of literature to directly compare the results of this study. One study found that the addition of a 24 mm heel lift significantly increased knee flexion at initial contact and peak knee flexion as well as slowed the rate of joint excursion when landing from a forward jump.47 In a follow up publication, it was further demonstrated that utilization of a 24mm heel lift caused a decrease in vertical ground reaction force (vGRF) with a forward jump, but not during a drop-rebound jumping

| Table 3. Peak EMG activity per muscle during forward jump. |
|---|---|---|---|---|
| Muscle | Lift (mm) | Means¹ | SD | Peak mag p-values |
| VMO | 0 | 4.1506 | 8.1211 | 0.324 |
| 12 | 3.0929 | 1.6322 |
| 18 | 3.0544 | 1.9353 |
| 24 | 3.1937 | 1.9076 |
| VL | 0 | 2.5690 | 1.2916 | 0.291 |
| 12 | 2.6652 | 1.3435 |
| 18 | 2.7918 | 1.8140 |
| 24 | 2.7709 | 1.4365 |
| ST | 0 | 1.0716 | 0.9476 | 0.355 |
| 12 | 1.0210 | 0.8029 |
| 18 | 1.0924 | 1.1114 |
| 24 | 1.3142 | 2.1312 |
| BF | 0 | 1.9562 | 2.9291 | 0.162 |
| 12 | 2.0578 | 3.3342 |
| 18 | 1.9444 | 2.9331 |
| 24 | 2.3631 | 4.0588 |
| MG | 0 | 2.1194 | 1.1991 | 0.102 |
| 12 | 2.4853 | 2.0865 |
| 18 | 2.3638 | 1.6378 |
| 24 | 2.4793 | 1.8056 |
| LG | 0 | 3.2240 | 3.0276 | 0.529 |
| 12 | 3.1979 | 2.8806 |
| 18 | 3.3873 | 3.2605 |
| 24 | 3.5134 | 3.1249 |

† - means represent the normalized EMG data
SD-standard deviation; mag-magnitude;
VMO-vastus medialis; VL-vastus lateralis;
ST-semitendinosus,
BF-biceps femoris, MG-medial gastrocnemius,
LG-lateral gastrocnemius

| Table 4. Time to achieve peak EMG activity per muscle during forward jump. |
|---|---|---|---|---|
| Muscle | Lift (mm) | Means¹ | SD | TTP p-values |
| VMO | 0 | 0.0675 | 0.035 | 0.192 |
| 12 | 0.0767 | 0.044 |
| 18 | 0.0725 | 0.042 |
| 24 | 0.0771 | 0.053 |
| VL | 0 | 0.0776 | 0.038 | 0.283 |
| 12 | 0.0797 | 0.04 |
| 18 | 0.0779 | 0.042 |
| 24 | 0.0898 | 0.076 |
| ST | 0 | 0.0725 | 0.061 | 0.024* |
| 12 | 0.063 | 0.058 |
| 18 | 0.0524 | 0.05 |
| 24 | 0.0506 | 0.055 |
| BF | 0 | 0.0861 | 0.044 | 0.336 |
| 12 | 0.1015 | 0.098 |
| 18 | 0.083 | 0.039 |
| 24 | 0.0843 | 0.088 |
| MG | 0 | 0.0358 | 0.036 | 0.06 |
| 12 | 0.0405 | 0.041 |
| 18 | 0.0397 | 0.039 |
| 24 | 0.0642 | 0.12 |
| LG | 0 | 0.0643 | 0.053 | 0.454 |
| 12 | 0.0541 | 0.044 |
| 18 | 0.0508 | 0.038 |
| 24 | 0.0543 | 0.074 |

† - means represent time in milliseconds
* - significant difference at p<0.05 (with ANOVA)
SD-standard deviation; TTP-time to achieve peak EMG activity;
VMO-vastus medialis; VL-vastus lateralis;
ST-semitendinosus, BF-biceps femoris, MG-medial gastrocnemius, LG-lateral gastrocnemius
These results collectively suggest that the addition of heel lifts favorably alters lower extremity biomechanics during a forward jump landing task. However, the role of muscle activity in these biomechanical responses remains unclear. It is generally accepted that an imbalanced hamstring to quadriceps ratio and a delayed onset of hamstring time to peak torque are both ACL risk factors. Huston and colleagues found that Division I female athletes took significantly longer to produce hamstring peak torque and relied on more of their quadriceps musculature in response to anterior tibial translation when compared to their male counterparts. As such, a faster time to peak magnitude of the semitendinosus through the utilization of a heel lift has been speculated to be ideal when attempting to maximize protection of the ACL. Although not found to be statistically significant, trends were identified in this current study for slower time to peak magnitude in the quadriceps musculature and increased magnitude of hamstring activity during landing tasks.

Hong and colleagues investigated the effects of footwear with differing heel heights (0cm, 3.8cm, and 7.6cm) on EMG responses throughout the lower extremity while walking. They found that elevated heel heights reduced load of the quadriceps musculature, supporting the trends of the authors’ current research that the quadriceps musculature may be influenced through the utilization of added heel lift height. However, the reduction of quadriceps activation with elevated heel heights is inconsistent

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<th>Ave mag p-values</th>
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+ means represent time in milliseconds
SD-standard deviation; Ave-average; mag-magnitude; VMO-vastus medialis; VL-vastus lateralis; ST-semitendinosus, BF-biceps femoris, MG-medial gastrocnemius, LG-lateral gastrocnemius

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+ means represent time in milliseconds
SD-standard deviation; mag-magnitude; VMO-vastus medialis; VL-vastus lateralis; ST-semitendinosus, BF-biceps femoris, MG-medial gastrocnemius, LG-lateral gastrocnemius
throughout the literature, with reports of increased quadriceps muscle EMG while utilizing a heel lift during gait.\textsuperscript{51,52,53} These publications utilized larger heel lift heights (range of 4-10 cm) compared to the highest heel lift height used in the present study of 24mm (2.4 cm). However, it is possible that extreme heel lift heights would be deleterious from a biomechanical perspective, possibly even increasing the likelihood of injury. Determination of an optimal heel lift height has yet to be determined and requires further research.

As demonstrated in the current study and previous publications, there were no statistically significant differences in joint kinematics or EMG activity observed during drop-rebound jump landing tasks with the utilization of heel height lifts.\textsuperscript{47,48} This could be attributed to a more forefoot-based landing strategy during the rebound jump. It has been demonstrated in other research that subjects landing from a more vertically oriented jump demonstrate a larger degree of ankle plantarflexion and utilize a forefoot landing strategy.\textsuperscript{56,57,58} Thus, the subjects in this study may not have had enough heel contact with the ground to utilize the effects of the increased heel lift height. The current findings suggest that the only possible protective benefit of heel lift utilization occurs only with forward jump tasks, and with greater heel lift heights (18mm and 24mm). It is unknown whether these effects would apply to other dynamic, sport specific maneuvers that have yet to be studied.

One limitation of this study was that a limited number of lower extremity muscles were assessed during the landing procedures. For example, gluteus medius has been investigated in other studies for its role in knee kinematics during landing.\textsuperscript{59,60} The current project did not identify significant alterations in the activation of six muscles under different heel lift conditions. However, it is possible that other muscles could play a role in promoting the kinematic changes seen in past research using the same conditions.

No data were gathered on ankle kinematics or other musculature of the ankle. Therefore, the influence of added heel lift height on the ankle during the selected landing tasks is unknown. Researchers investigating muscle response to heel lifts during gait have reported decreased amplitude of

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\textsuperscript{†} - means represent time in milliseconds
SD-standard deviation; TTP-time to peak; VMO-vastus medialis; VL-vastus lateralis; ST-semitendinosus, BF-biceps femoris, MG-medial gastrocnemius, LG-lateral gastrocnemius

Figure 1. Post hoc results for Time to Achievement of Peak EMG activity (TTP) in semitendinosus during forward hop
*Significant difference from 0mm heel lift FH-forward hop; TTP-time to peak EMG magnitude; ST-semitendinosus
the gastrocnemius muscle EMG response\textsuperscript{42,61} and increased plantarflexion.\textsuperscript{44,47} The current study found no significant changes in gastrocnemius activity during either landing maneuver. More research is warranted to further investigate these relationships.

At this time, the authors of this study are unable to predict any potential negative effects from using elevated heel lift heights in athletic shoe wear. There is very little information on the use of heel lifts in landing activities and, thus, there is no data suggesting whether an elevated heel could have a negative impact on performance, joint integrity, or the overall safety of the individual. Additionally, it is not possible to comment on how elevated heel lift height might alter other athletic activities, such as running or cutting. Again, future research and longitudinal studies would be necessary to discover if any problems would arise from the use of heel lifts.

Future research on the effect of heel lift height on landing mechanics is warranted. Positive knee kinematic changes and ground reaction force values have been identified when using heel lifts during forward jump maneuvers.\textsuperscript{47,48} Future research should investigate other biomechanical factors such as recruitment order and onset timing of key muscle groups. Sports maneuvers such as pivoting and cutting have also been associated with non-contact ACL injury risk.\textsuperscript{11,12,17} It would be beneficial to determine if the use of heel lifts would show similar kinematic effects as those seen with forward jump maneuvers. It would also be prudent to identify the impact that heel lifts would have at the ankle, hip, and trunk during sports maneuvers. Research could continue to investigate ACL injury risk reduction while also identifying any potentially adverse responses generated by the additional heel lift height.

**CONCLUSION**

ACL injuries remain one of the most frequent knee injuries in physically active individuals, especially in the female population.\textsuperscript{1-3,4,5} Previous studies have suggested that the utilization of heel lifts to positively influence biomechanics may be of potential benefit.\textsuperscript{47,48} In the current study, there were no significant differences found in the muscle recruitment under the various heel lift conditions with the exception of the semitendinosus time to achieve peak magnitude. By influencing the semitendinosus to achieve peak magnitude more quickly, an athlete may reap protective benefits and decrease ACL injury risk. The clinical relevance of these findings remains unknown. Further research is warranted.

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ABSTRACT

**Background:** Poor flexibility is considered a risk factor for the hamstring strain injury, and the active straight leg raise (ASLR) test proposed as a part of the Functional Movement Screen™ (FMS™) has been used to assess athletes hamstring flexibility. However, the accuracy of this screening test remains undescribed.

**Purpose:** To examine the accuracy of the FMS™ ASLR test for assessment of hamstring flexibility in soccer players.

**Study design:** Cross-sectional study.

**Methods:** One-hundred and one male soccer players (age, 21±3 years; height, 179±7 cm; weight, 75±9 kg) were bilaterally evaluated. All players performed a gold standard test for hamstring flexibility evaluation: the passive straight leg raise (PSLR) test measured using a gravitational inclinometer. All players also performed the ASLR test and were scored using the criteria proposed by the FMS™.

**Results:** Of the 202 lower limbs evaluated, 17.82% scored a 1 on the ASLR [mean passive flexibility: 80.44±14.69° (55°-110°)], 50.99% scored a 2 on the ASLR [mean passive flexibility=84.60±10.59° (56°-115°)], and 31.18% scored a 3 on the ASLR [mean passive flexibility=92.32±11.53° (70°-120°)]. Limbs with FMS™ score of 3 presented significantly higher values for passive flexibility than limbs with scores of 1 and 2 (p <0.05), but there was no significant difference between limbs with scores of 1 and 2 (p > 0.05).

**Conclusion:** The score obtained in the FMS™ ASLR test does not satisfactorily stratify the level of hamstring flexibility in soccer players.

**Level of evidence:** 3a

**Key words:** Hamstring, injury prevention, posterior thigh, range of motion, soccer

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**Original Research**

ACCURACY OF THE FUNCTIONAL MOVEMENT SCREEN (FMS™) ACTIVE STRAIGHT LEG RAISE TEST TO EVALUATE HAMSTRING FLEXIBILITY IN SOCCER PLAYERS

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**Conflict of interest:** The authors declare no conflicts of interest.
INTRODUCTION
The hamstring muscle group (biceps femoris, semitendinosus, and semimembranosus) is particularly prone to injury in sports involving high-speed movements such as rugby,1 basketball,2 American football,3 track and field,4 and soccer.5 Hamstring strain injury (HSI) is a major concern in professional soccer, since it is the most common non-contact injury comprising 12% to 16% of all injuries.6,7 Furthermore, the reinjury rate of HSI is relatively high (13%),6 and more than half of the injuries lead to 8 to 28 lay-off days.8 Consequently, HSI results in significant financial loss and performance deficits for the club involved.9,10

Age and previous muscle injuries are well described non-modifiable HSI risk factors,11,12 while modifiable risk factors include deficits in hamstring eccentric strength,13–16 hamstring-quadriceps strength ratio,16–18 core muscle activation,19 biceps femoris fascicle length,15 and hamstring flexibility.20,21 Poor flexibility is one of the earliest risk factors for HSI described in the literature,22 and it is still considered an important risk factor for injuries by professionals working in premier league soccer clubs.23,24 Therefore, soccer teams commonly include assessments of hamstring flexibility in the pre-season tests to identify players potentially more susceptible to HSI.23,24

There are several ways to evaluate hamstring flexibility.25 Among them, the Straight Leg Raise (SLR) is the most commonly used test,25 which can be carried out either passively or actively. During the passive SLR (PSLR), the athlete lays supine while one tester moves the lower limb to be tested in hip flexion with the knee fully extended and the ankle relaxed. A second tester measures hamstring flexibility with either a goniometer or an inclinometer, and a third tester might be needed to stabilize the pelvis and the non-tested limb. This test is reliable in assessing hamstring flexibility,26 but it might not be practical in evaluating dozens of athletes in a short period during regular pre-season screenings.

In an attempt to solve that problem, some medical staff have evaluated hamstring flexibility through the active SLR (ASLR) test as included in the Functional Movement Screen™ (FMS™).27,28 The FMS™ is a battery of screening tests based on competence during active movement that aims to provide a clinically interpretable measure of "quality of movement" and that has been highly valued in high-performance soccer.23,24 In the ASLR test, the athlete is requested to actively flex the hip of tested limb while keeping the non-tested limb fully extended and the torso stabilized without any external support. The FMS™ ASLR test is fast, and it does not require more than one tester or any special equipment, which makes this test a viable option to assess hamstring flexibility. During the test, the tester scores the athlete’s performance categorically, according to criteria defined by creators of FMS™27,28 (details provided in the Methods section). However, the fact that the results of FMS™ ASLR test are presented in a categorical way (scores from 0 to 3) might limit its use in pre-season screens that have the goal of identifying potential risk factors for injury. It remains unknown whether FMS™ ASLR test provides sufficiently accurate information about the amount of hamstring flexibility in order to allow for identifying those athletes with a relevant lack of hamstring flexibility. Hence, the purpose of the current study was to examine the accuracy of the FMS™ ASLR test for assessment of hamstring flexibility in soccer players.

METHODS
Study design
In this cross-sectional study, male soccer players were evaluated in a single visit to the laboratory. All volunteers performed a gold standard test for hamstring flexibility evaluation: the PSLR test assessed using a gravitational inclinometer, followed by the full FMS™ sequence of screening tests, including the ASLR. The study was approved by the institutional ethics committee, and all participants signed an informed consent before engaging in the study.

Participants
Two soccer clubs agreed to participate in this study. Both clubs competed in a first state division, and all soccer players had professional employment contracts with their clubs. One hundred and one male soccer players were assessed (age, 21 ± 3 years; height, 179 ± 7 cm; weight, 75 ± 9 kg): 52 from professionals team (18 to 33 years old) and 49 from under-20 team (18 to 20 years old). Both teams followed a similar training routine, which generally covered...
two daily training sessions, three to five days per week, according to each team’s weekly schedule. All evaluations were performed during the first two weeks of preseason (before the start of the championships).

Participants with the following conditions were excluded from the study: (1) players currently undergoing rehabilitation of any musculoskeletal injury in either the lower or the upper limbs; or (2) players who had been away from the team’s training routine for >30 days within the six-month period prior to the study due to musculoskeletal injuries or any other health conditions.

**Procedures**

Participants were previously informed about the day and time they would be evaluated, and received the following recommendations: (1) not to perform high-intensity physical activities in the 24 hours prior to the tests; (2) not to drink alcohol within 48 hours prior to testing; (3) not to take any kind of analgesic and/or anti-inflammatory drugs within 48 hours prior to testing; (4) not to consume stimulant substances (e.g., caffeine) within 12 hours prior to testing; and (5) wear adequate clothing to perform the tests (shorts, t-shirt and sneakers).

The PSLR test was performed by two testers using a gravitational inclinometer (Fleximetro, FL6010, Sanny, Brazil), following a previously described protocol. The athletes did not perform any type of warm-up or stretching exercises prior to the tests. Participants were positioned supine. One tester held the non-tested lower limb in full extension and kept the hip stabilized to avoid lumbopelvic compensations, a second tester passively flexed the hip with the knee extended and the ankle relaxed until the maximally tolerated (feeling of resistance) range of motion (ROM) was reached (Figure 1). Three trials were performed on each limb, and the highest value was used in the analyses.

The ASLR test was performed in accordance with the recommendations of the FMS™ creators. Participants were positioned supine, with the knees over the FMS™ platform. The tester placed a stick perpendicular to the ground in the medium point between the anterior-superior iliac spine and the patella of the opposite limb. Once positioned, the participant was asked to slowly raise his limb with the knee fully extended and the ankle in maximal dorsiflexion. During the test, the non-tested limb was kept on the platform, with the ankle in maximum dorsiflexion and the head on the ground (Figure 2). When the maximum ROM was reached, the evaluator checked the position of the lateral malleolus of the tested limb in relation to the stick. The screening test can receive four scores (0, 1, 2 and 3), depending on the position of the lower extremity in relation to the stick. The test was scored according to the FMS™ directions with a score 3 operationally defined as satisfactory ROM with adequate movement pattern, score
2 defined as the existence of moderate limitations/movement dysfunction, and score 1 defined as severe limitation/movement dysfunction. Athletes scored zero if they described pain during the test.

**Statistical Analyses**

The normality of data was verified by the Shapiro-Wilk test. The effect of the lower limb laterality (dominant vs. non-dominant) on the flexibility results was evaluated using independent t-test. Chi-square test was performed to verify the scores distribution 1, 2, or 3 on both dominant and non-dominant lower limbs (no volunteer referred pain/discomfort during tests, thus there was no score zero). A one-way ANOVA followed by a Bonferroni test was performed to compare the passive flexibility results of the limbs that scored 1, 2, or 3 in the FMS™ ASLR test. The level of significance for all tests was set at \( p < 0.05 \). The clinical relevance was assessed through the calculation of effect size (Cohen’s \( d \)) among the passive flexibility values presented by the lower limbs with 1, 2, or 3 FMS™ scores. Effect sizes were considered trivial (\( d < 0.2 \)), small (\( d > 0.2 \)), moderate (\( d > 0.5 \)), and large (\( d > 0.8 \)).

**RESULTS**

There were no significant differences in either the flexibility or in the FMS™ scores distributions between dominant and non-dominant limbs of the 101 soccer players included in the present study (Table 1), which enabled analysis using both of the athletes’ limbs.

Of the 202 limbs assessed, 36 (17.82%) scored a 1 [passive flexibility: \( 80.44 \pm 14.69° \) (55°-110°)], 103 (50.99% scored a 2 [passive flexibility = 84.60±10.59° (56°-115°)], and 63 (31.18%) scored a 3 [passive flexibility = 92.32±11.53° (70°-120°)] on the FMS™ ASLR.

The limbs that scored a 3 presented passive flexibility values significantly higher than the limbs that scored either a 1 or a 2 on the FMS™ ASLR. However, there was no significant difference in passive flexibility values between the limbs that scored 1 and 2 on the FMS™. The effect sizes observed between the passive flexibility values of the players with different scores on FMS™ were: 1 vs. 2, small effect size (\( d = 0.36 \)); 2 vs. 3, moderate effect size (\( d = 0.71 \)); 1 vs. 3, large effect size (\( d = 0.94 \)) (Figure 3).

![Figure 3. Individual (gray circles) and grouped results (horizontal bars; mean ± SD) of passive straight leg raise (PSLR) test classified according to the active straight leg raise (ASLR) test proposed by the Functional Movement Screen (FMS™).](image)

**Table 1.** Passive Straight Leg Raise (PSLR) test values and percent distribution on each score of the Functional Movement Screen (FMS™) Active Straight Leg Raise (ASLR) test.

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<td>- Score 2 (%)</td>
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<td>- Score 3 (%)</td>
<td>30.09</td>
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DISCUSSION

The present study aimed to evaluate whether the FMS™ ASLR test was able to accurately assess hamstring flexibility in soccer players. The main finding was that the FMS™ ASLR does not adequately identify differences in hamstring flexibility level when a score of 1 or 2 is achieved, and even some athletes with the maximum performance who scored a 3 on the FMS™ ASLR may present poor hamstring passive flexibility when assessed with the PSLR test.

Flexibility can be defined as the capacity of a muscle (or a muscle group) to elongate, and it is influenced by muscular, connective and neural tissue. Stretching exercise programs are an effective strategy to increase flexibility level in soccer players, and top-tier teams usually include stretching exercises in their training routines. A recent review concluded that increasing hamstring flexibility through static stretching training might be effective to improve performance in certain functional tasks. In soccer players, García-Pinillos et al. suggested that lack of hamstring flexibility may impair performance during sprint, jumping, and kicking. On the other hand, Rey et al. did not find any evidence that hamstring flexibility limitation decreases either jumping or sprinting performances in soccer players. Even though the literature is not conclusive whether poor hamstring flexibility impairs athletes' performance, there is also no evidence that satisfactory levels of flexibility may be detrimental in soccer or other team sports.

Hamstring flexibility levels are widely used as criteria for both treatment progression and return to sport decisions after HSI. Another important issue is the role of decreased hamstring flexibility as a risk factor for muscle injury. Henderson et al. verified that soccer players with lack of hip flexion ROM had a significantly higher risk of injuring the hamstring muscle group. In contrast, Van Dyk evaluated 438 professional soccer players and found that lack of hamstring flexibility did not adequately predict HSI. These conflicting results may be related to the multifactorial nature of sports injuries, which do not result from a linear interaction between isolated predictive factors, but from the complex interaction between a web of determinants. Even in the face of uncertainties about the relationship between flexibility and hamstring injury, the assessment of the flexibility of the hamstrings is commonly conducted during both pre-season and in-season screenings. Therefore, it seems important to have a reproducible test to be performed in such evaluations.

The passive flexibility values found in the current study ranged from 55° to 120°, which means that there were players that presented with less than half of the flexibility values when compared with some of their peers. Previous investigations found mean PSLR values ranging between 75° and 88°, which is similar to the results of the present study (average value ~86°). Similarly, Marques et al. evaluated 103 young soccer players using the ASLR and found that 16% scored a 1, 57% scored a 2, and 26% scored a 3; a distribution close to the present study (18%, 51%, and 31% for the scores of 1, 2, and 3, respectively). Therefore, the soccer players included in the current study seem to be representative of this population with respect to levels of flexibility as measured via both during PSLR test and the FMS™ ASLR test.

According to the FMS™ conceptual bases, each test can receive four scores, ranging from 0 to 3. However, the findings of the present study suggest that establishing athletes’ flexibility level as high, acceptable or low based solely on the FMS™ ASLR test outcome (score) is not appropriate. The FMS™ ASLR presents acceptable levels of inter-rater and intra-rater reliability, thus reliability of the screening test and its ability to be scored does not seem to be a cause for the results found in the current study. The results of the present study suggest that the categorical scoring construct of the FMS™ ASLR does not represent equal “difference” between categorical scores. The difference between a 1 and a 2 could be very different than the difference between a 2 and a 3. The difference between categories is likely to not capture the subtle flexibility differences that are captured by continuous measures (e.g. PSLR in degrees). Although the FMS™ ASLR may be an important component of functional analysis, the use of this test alone should not be encouraged in the assessment of hamstring flexibility.

An important reason why the FMS™ ASLR test may not be the most accurate way to assess hamstring flexibility might be related to the influence structures
other than the hamstrings that may limit the ability to perform the movement. The FMS™ ASLR requires the ankle of the limb being tested to remain in full dorsiflexion, and this contributes to the global resistance developed by the neuromusculoskeletal complex (e.g. muscles, tendons, ligaments, fasciae, nerves, and joint capsule), which may vary among athletes and influence the results. In addition, a proper ASLR requires several other muscular synergic responses, such as contralateral hip extension moment, activation of the abdominal muscles, sagittal plane lateral stabilization, and activity of the contralateral transverse plane rotators. Therefore, the FMS™ ASLR test is a more complex task than PSLR test and poor scores do not necessarily indicate only a hamstring flexibility deficit.

The capacity of FMS™ in predicting injuries remains uncertain. To date, there are no cohort studies associating specifically the FMS™ ASLR test with HSI risk. However, it would seem plausible to assume that a subject with maximum score (i.e. score 3) in the FMS™ ASLR test shows a good level of hamstring flexibility and, consequently, would not be in the group of athletes with higher susceptibility to HSI due to this factor. However, the results presented in Figure 3 show that there are lower limbs with less than 90° of hip flexion ROM in all three groups, including subjects with up to 70° who scored a 3 on the FMS™ ASLR. Hip flexion passive ROM inferior to 90° is commonly considered a risk factor for HSI in soccer players. Witvrouw et al. have shown that only 6.5° in hip flexion passive ROM separates a group of soccer players who sustained HSI versus those who did not throughout a season, while Henderson et al. found that the odds of sustaining an HSI increased by 1.29 times for every 1° decrease in PSLR test. These findings suggest that a few degrees of ROM have impact on the HSI susceptibility of soccer players. Hence, according results provided by this study, would be reasonable to assume that the FMS™ ASLR test alone is not capable to capture those few degrees and determine the athletes' susceptibility to suffer an HSI. Consequently, it is recommended a more accurate test to assess hamstring flexibility such as the PSLR to be carried out during pre-season in order to identify an HSI risk factor and prepare adequate preventive programs.

CONCLUSION

The findings of the present study suggest that the scores on the FMS™ ASLR test do not adequately stratify the hamstring flexibility in soccer players when compared to a passive measure of hamstring flexibility. Practitioners should reconsider the use of FMS™ ASLR as the sole assessment of hamstring flexibility.

REFERENCES


ABSTRACT

Background and Purpose: Hamstring injuries (HSI) occur more commonly in baseball than are often appreciated and can impact the potential career of a player. Little is known about the historical incidence of these injuries in summer league players preparing for their upcoming collegiate season or being drafted by major league team(s). Summer league baseball players have a high historical incidence of HSI which are often unknown at the start of their summer league play. The purpose of this study was to administer a validated questionnaire to assess various factors regarding the prevalence of prior hamstring injuries, current symptoms of posterior thigh pain or hamstring injuries in amateur summer league baseball players, and to provide details on the injury history, time lost from injury, injury reoccurrence, position, individual player physical characteristics and physical activities that might be associated with those injuries.

Study Design: Cross-sectional Observational Study

Method: A self-reported, validated questionnaire regarding the history, prevalence, reoccurrence and functional impact of HSI and posterior thigh pain was administered to and completed by 201 out of 251 summer league baseball players associated with the Cape Cod League and the Northwoods League at the start of the 2013-2015 seasons. The questionnaire was administered by certified athletic trainers associated with each team. Participation was voluntary and informed consent was obtained from all players.

Results: Forty seven out of 201 players surveyed reported a HSI history. Sixty-six percent of these players (N=31) reported unilateral injuries and 34% (N=16) reported bilateral injuries. Reoccurrence rate was 27.7% across all players. Approximately 1/3rd of all position players (catchers 33.3%, infielders 32.6% and outfielders 31.6%) reported a HSI history compared to 12.9% of all pitchers. Significant differences (p<.05) existed between the HSI and Non-HSI groups for self-reported symptoms, soreness, and pain, as well as function and quality of life. Within the HSI history group, players who batted left and threw right reported the most injuries.

Conclusion: A large number of position players and pitchers who report for summer league baseball have a history of posterior thigh pain and HSI. Those with prior injuries have a high reoccurrence rate. Position players have a higher incidence of injury than do pitchers.

Level of Evidence: 3

Key Words: Baseball, hamstring injuries, Hamstring Outcome Score, incidence, movement system, posterior thigh pain

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INTRODUCTION
Various epidemiologic studies have described the incidence, frequency, characteristics and types of injuries that commonly occur in interscholastic,1,2 intercollegiate,3,4 and professional baseball.5 As expected, injuries that involve the upper extremity, specifically the shoulder, elbow, hand and wrist, are the most common in this upper extremity dominant sport. However, other types of injuries can occur and can have an adverse impact on the players' ability to train and participate in games. The impact of these non-throwing, non-upper extremity injuries are often underestimated and unappreciated, until significant time is lost on the playing field. Injuries to the hamstring complex are one such injury.

The literature discussing the incidence of hamstring injury for other sports is much more robust overall than the existing literature for baseball. Authors who have studied other sports report up to 29% of all injuries involve the hamstring complex6-16 which may be serious enough that prolonged time is lost from practice or play,8,17-22 and may be recurrent.17,21,23-26 However, only a few studies on hamstring injuries in baseball are available in the literature.1,3,5,25,27,28 These studies have mostly centered around high school and NCAA athletes, not those participating in summer league baseball. During the summer, leagues such as the Cape Cod League and the Northern League, operate in order to allow players to try to improve their skills and showcase their abilities in preparation for returning to college baseball or preparing for possible draft to the minor leagues.

Studies of athletes of other sports have detailed injury history, personal demographic and physical characteristics of the athlete and sport specific characteristics (position, type of activity, personal characteristics such as height, weight, side dominance) that may contribute to the knowledge of what type of player is more likely to incur a hamstring injury, and the sport specific factors that might contribute to or cause a hamstring injury in that particular sport.14,29,30 Information such as this is critical for the development of targeted conditioning and injury prevention programs, especially in developing players in order to try to prevent the occurrence and/or minimize the reoccurrence of hamstring injuries. These sport specific factor studies have stimulated the development of Hamstring Injury Prevention programs (HIP) which have been shown to be effective in decreasing the rate of acute and chronic hamstring injury in athletes in several sports.7,30-36 Recently, a study utilizing eccentric hamstring training in Major and Minor League baseball demonstrated a significant decrease in acute hamstring strains in addition to a decrease in time loss due to injury.27 However, adherence and compliance to such prevention programs has been inconsistent, therefore diminishing the ability to effectively decrease the hamstring injury rate.37

The purpose of this study was to administer a validated questionnaire to assess various factors regarding the prevalence of prior hamstring injuries, current symptoms of posterior thigh pain or hamstring injuries in amateur summer league baseball players, and to provide details on the injury history, time lost from injury, injury reoccurrence, position, individual player physical characteristics and physical activities that might be associated with those injuries.

METHODS
Summer league athletes completed a previously validated Hamstring Outcome Score (HaOS – Appendix 1) questionnaire created by the Oslo Sports Trauma Research Center (OSTRC).38 This self-reported questionnaire provides information regarding time lost from injury, frequency of injury and reoccurrence, and symptoms associated with these injuries for general physical activities associated with athletics (running, jogging, accelerating, walking up two steps at a time, etc). This questionnaire was specifically modified for baseball related activities to improve the contextuality for the sport of baseball with written permission from OSTRC. To maintain validity of the questionnaire, only slight adaptations were made to the questionnaire that increased its' relevance to the sport of baseball (including characteristics regarding position, batting, throwing and activities associated within baseball such as “running to first base,” stopping after and sprinting to first base in the wording of the questions).

All questions were associated with general physical/athletic activities and the adapted vernacular was used to make sure the player understood the
question, and to clarify how the question(s) related to the sport of baseball. This questionnaire consists of five subscales whose scores are reported as percentages, with 100% indicating no hamstring complaints or symptoms; each item/question within the subscale is scored on a scale of zero to four when analyzed by the researcher. Players were unaware of the value assigned to each response. Lower scores/ totals are expected for players with a history of HSI or current problems, indicating more disability related to HSI. The HaOS total score is the mean value of the five subscales.

• **Part A: Previous Injury** - Inquires about the number of previous injuries, time since their most recent injury, how long they were fully unable to practice/play for, whether or not they missed practice/play as a result of the injury and whether or not they had symptoms over the prior week.

• **Part B: Soreness** - Acquires information regarding discomfort or soreness in the area of the “back of your thigh” during or after practice or play, symptom variation during the day and symptoms with sitting. The question seeks information on discomfort or soreness compared to pain associated with specifically described physical activities related to daily living or sport specific activities (as worded in Part C).

• **Part C: Pain** - Provides information regarding the frequency of pain in the “back of the thigh/hamstrings” and how quickly symptoms may have resolved and whether or not they are symptomatic with general athletic activities such as stretching, walking up steps, jogging and baseball specific activities such as base running.

• **Part D: Function** - Asks general questions regarding difficulty or posterior thigh pain in the prior week with general running, jumping, accelerating or decelerating after sprinting.

• **Part E: Quality of Life** - Asks how much the athlete trusts their hamstring(s) during physical activity and whether they are able to perform at 100% due to any concerns about injuring/re-injuring their hamstring(s).

The questionnaire was administered to eight different summer league teams in the Cape Cod and Northwood’s Leagues over a three-year period between 2013 and 2015. The questionnaire was confidentially administered to the athlete by a certified athletic trainer (ATC) associated with each team. A total 251 players on the teams’ rosters at the start of their summer league season were asked to complete the questionnaire. Completion of the questionnaire was voluntary on the part of each player, and no player completed the questionnaire more than once during the course of the study. Informed consent was obtained by all players who completed the questionnaire. The study was reviewed and granted approval by the Johns Hopkins Medicine Institutional Review Board.

**STATISTICS**

Results from the questionnaire were analyzed to assess the differences between players who reported a history of HSI and posterior thigh pain associated with physical activites to those players without a history of HSI and posterior thigh pain. Chi-square tests and t-tests were used to analyze player physical characteristics (age, height, weight, position, and batting and throwing handedness) and to make comparisons by position. HaOS outcome score comparisons were made using a Mixed Model, nesting players within teams. All assumptions for all models were assessed. Statistically significant differences were assessed using the alpha level set at p < 0.05.

**RESULTS**

Out of the 251 players who were asked to complete the questionnaire, a total of 201 questionnaires were completed and analyzed, for a response rate of 80.1%. There was no significant difference in player age (p = 0.82) or weight (p = 0.097), but injured athletes were on average one inch shorter compared to their uninjured counterparts (p = 0.010). (Table 1). Over the course of the three-season study period, 47 (23.8%) of the 201 athletes who completed the survey reported having a HSI history. A total of 81 different hamstring injuries were reported by the 47 players. Forty-three injuries involved the left leg (53.1%) and 38 injuries involved the right leg (43.9%); there was no significant side difference (p = 0.490). However, there was a significant relationship between injuries and primary position played. Pitchers (12.2%) were significantly less likely (p = .015) to have had an
previous injury. The time lost to injury (an injury which prevented an athlete from participating in a subsequent training session or game) and severity (number of days away from practice or play) were defined using the definitions developed in the Union of European Football Associations (UEFA) Consensus Statement. Specific ranges and percentages of time lost are detailed in Table 4. Overall, 44% of injuries resulted in greater than one-week loss from baseball, while 56% lost less than one week. Ten out of 16 players (62.5%) with bilateral injuries lost more than one week from play while fifteen of the 31 (48.4%) players who had unilateral injury lost more than one week from play. Seven of thirteen players with recurrent injuries (53.8%) lost more than one week from play, and six of these seven players also had bilateral injuries.

Self reported data was also collected from the players regarding time lost from practice or play due to previous injury. The time lost to injury (an injury which prevented an athlete from participating in a subsequent training session or game) and severity (number of days away from practice or play) were defined using the definitions developed in the Union of European Football Associations (UEFA) Consensus Statement. Specific ranges and percentages of time lost are detailed in Table 4. Overall, 44% of injuries resulted in greater than one-week loss from baseball, while 56% lost less than one week. Ten out of 16 players (62.5%) with bilateral injuries lost more than one week from play while fifteen of the 31 (48.4%) players who had unilateral injury lost more than one week from play. Seven of thirteen players with recurrent injuries (53.8%) lost more than one week from play, and six of these seven players also had bilateral injuries.

Data stratified by handedness for batting and throwing is presented in Table 5. Athletes with HSI history

<table>
<thead>
<tr>
<th>Table 1. Physical Characteristics Injured vs. Uninjured Players.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Uninjured Players</strong></td>
</tr>
<tr>
<td>-----------------------</td>
</tr>
<tr>
<td><strong>Number (%)</strong></td>
</tr>
<tr>
<td>Total Athletes N = 201</td>
</tr>
<tr>
<td>Age (Years)</td>
</tr>
<tr>
<td>Height (Inches)</td>
</tr>
<tr>
<td>Weight (Pounds)</td>
</tr>
<tr>
<td>*p&lt;.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2. Injury History by Position.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Player Position</strong></td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>Catcher</td>
</tr>
<tr>
<td>Infield</td>
</tr>
<tr>
<td>Outfield</td>
</tr>
<tr>
<td>Pitcher</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3. Injury History: Reoccurrence, Unilateral and Bilateral Injuries.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Player Position</strong></td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>Catcher</td>
</tr>
<tr>
<td>Infield</td>
</tr>
<tr>
<td>Outfield</td>
</tr>
<tr>
<td>Pitcher</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4. Self Reported Time Lost from Injury.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time Lost from Injury</strong></td>
</tr>
<tr>
<td>---------------------------</td>
</tr>
<tr>
<td>1-3 Days</td>
</tr>
<tr>
<td>4-7 Days</td>
</tr>
<tr>
<td>1-4 Weeks</td>
</tr>
<tr>
<td>4+ Weeks</td>
</tr>
</tbody>
</table>

HSI = Hamstring injury

HSI injury compared to position players: Catchers (33.3%), Infielders (32.6%), and Outfielders (31.6%).

(Table 2)
more often batted right handed (n = 25) versus left handed (n = 19). Of the six players who identified as switch hitters, only one had an HSI history, and he threw right handed. A total of 37 different players with HSI history threw right handed and eight threw left handed. There was no significant relationship between history of injury with handedness as examined by batting (p = .410) or throwing (p = .607) in this group of 201 players.

Interestingly, when examining HSI with batting preference and throwing dominance simultaneously, a difference is noted between players with and without a HSI history. While not statistically significant, 32% percent (12/37) of all players who batted left handed and threw right handed had an HSI history, while the percent of players with other combinations for batting and throwing who also had a HSI history ranged from 14-22% (χ² = 3.05; p = .550).

The Hamstring Outcome Score (HaOS) was used to provide detail and information on the number of previous hamstring injuries suffered by the players, including side of injury and the impact of posterior thigh pain and hamstring injury on the player’s physical function. A Mixed Model was used to analyze HaOS total and subscale scores, nesting athletes within teams. This analytic method helps to account for any correlation that might be seen because athletes who played for the same teams may be more likely to have similar scores than two players from different teams since these “teammates” are subjected to similar training methodologies, acute and chronic loading and conditioning programs. In addition, this accommodates for the variation in number of responses per team, ranging from 8 to 31. There were significant differences found between players with and without HSI history for total HaOS score, with uninjured players scoring significantly higher on all the subscales (p < .05) (Table 6, Figure 1).

Table 7 presents the results of the percentage of players who stated that they had symptoms of posterior thigh pain or soreness the week prior to the administration of the questionnaire. Differences are demonstrated between the groups regarding their responses to specific questions about symptoms and soreness relative to workouts. The higher value responses for athletes with a HSI history would be expected. As would be expected, the HSI group also responded that they had more soreness with the variety of activities asked about on the survey.

<table>
<thead>
<tr>
<th>Total N (% within combination)</th>
<th>BAT LEFT THROW RIGHT</th>
<th>BAT LEFT THROW LEFT</th>
<th>BAT RIGHT THROW RIGHT</th>
<th>BAT RIGHT THROW LEFT</th>
<th>SWITCH HITTERS</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Injury History</td>
<td>25 (68%)</td>
<td>24 (77%)</td>
<td>96 (80%)</td>
<td>6 (86%)</td>
<td>5 (83%)</td>
<td>156</td>
</tr>
<tr>
<td>Injury History</td>
<td>12 (32%)</td>
<td>7 (22%)</td>
<td>24 (20%)</td>
<td>1 (14%)</td>
<td>1 (17%)</td>
<td>45</td>
</tr>
<tr>
<td>Total</td>
<td>37 (100%)</td>
<td>31 (100%)</td>
<td>120 (100%)</td>
<td>7 (100%)</td>
<td>4 (100%)</td>
<td>201 (100%)</td>
</tr>
</tbody>
</table>

Table 6. Means and Standard Errors from Mixed Model comparison of HaOS for HSI and non-HSI athletes.

<table>
<thead>
<tr>
<th>HaOS Section and Total Scores</th>
<th>Mixed Model Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Injury History</td>
</tr>
<tr>
<td>Mean</td>
<td>SE</td>
</tr>
<tr>
<td>Previous Injury and Symptoms</td>
<td>82.67</td>
</tr>
<tr>
<td>Soreness</td>
<td>86.97</td>
</tr>
<tr>
<td>Pain</td>
<td>94.76</td>
</tr>
<tr>
<td>Function</td>
<td>96.63</td>
</tr>
<tr>
<td>Quality of Life</td>
<td>94.32</td>
</tr>
<tr>
<td>Total Score</td>
<td>90.94</td>
</tr>
</tbody>
</table>

HaOS – Hamstring Outcome Score
HSI – Hamstring Injury
* = p<.05
DISCUSSION

This study has attempted to identify some specific characteristics regarding hamstring injuries that are incurred among summer league baseball players, identify athletes who have a history of HSI or recurrence, and factors that are associated with these injuries.

While a statistically significant one-inch difference in height was demonstrated for players in this study with a history of HSI (Table 1) it should not be considered clinically significant as, based on the age range of these players, many may have been actively growing and changing.

Table 8 provides details on the frequency of posterior thigh pain and whether or not pain was present with baseball related activities such as stretching, base running, sprinting to first base, decelerating after reaching first base or rounding the bases. Again, as would be expected, players without HSI never or rarely had symptoms with these activities. Players with HSI had more frequent pain, more pain with stretching and symptoms took longer to resolve. However, their results regarding pain with running activities were very similar to those players without HSI.

Baseball studies in the current literature tend to discuss and focus on the incidence of injury per athletic exposure (AE), the overall injury rate (IR) during practice and games, and the number or percent each type of injury accounts for, with some discussion of recurrence. Injuries to the area described as “upper leg/thigh” account for between 8.2% to 14.5% of these high school baseball injuries and are most commonly labeled as “muscle strains”. Dalton et al. reported the epidemiology of hamstring strains for 25 different NCAA sports using data gathered between 2009-2014. Overall, baseball

Table 7. Self Reported Symptoms and Soreness Responses Reported as % of Athletes who responded.

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Uninjured Athletes</th>
<th>Hamstring Injury Athletes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Never</td>
<td>0</td>
<td>51.3%</td>
</tr>
<tr>
<td>Rarely/A Little</td>
<td>1</td>
<td>32.5%</td>
</tr>
<tr>
<td>Sometimes/Moderate</td>
<td>2</td>
<td>15.6%</td>
</tr>
<tr>
<td>Often/A lot</td>
<td>3</td>
<td>0.6%</td>
</tr>
<tr>
<td>Always/Significant</td>
<td>4</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Figure 1. Hamstring Outcome Score (HaOS). Graph depicting HaOS Outcome Scores for the five subsections and total score for injured and uninjured players. A score of 100% reflects full function and no impairment.
accounted for 4.8% of all hamstring strain injuries reported during this period.\(^4\) Further stratification by body part revealed that “upper leg muscle tendon strains” accounted for 8.3% of practice injuries and 11% of all game related injuries.\(^3\) NCAA data has demonstrated that lower extremity injury accounted for over 50% of all injuries in NCAA athletes,\(^4\) and that for baseball, the lower extremity is the second most common area injured during practice or games, accounting for 35% of all collegiate baseball injuries. None of these studies however provide insight into HSI history by position.

This study provides detail regarding baseball related HSI by player position (Table 2). Twenty four percent of players who completed the questionnaire reported a history of HSI. While the percentage of position players who report a history of HSI is similar (31.6 to 33.3%) pitchers reports significantly fewer injuries (12.9%, \(p=0.015\)). This difference may be due to the activity profiles of these different positions (i.e. the amount of running, base running, changes in direction and start and stop activities associated with the specific positions). Compared to position players, pitchers may not be as involved in the type of activities that may cause HSI (base running type activities).\(^3\)

This study also provides insight into whether these injuries tend to be unilateral or bilateral, and the rate of recurrence (Table 3), although no statistically significant differences were seen between players of varied positions. Recurrence was not uncommon in this population of players with a history of HSI. The recurrence rate in this group of elite players (27.7%) was higher than that reported by Dalton et al (16%) across all NCAA baseball teams.\(^4\) The difference in the rate of recurrence in this study may be related to the quality of the players associated in these elite summer leagues compared to non-elite level players who may make up the majority of collegiate teams. The higher recurrence rate could be related to the amount of practice or game play time by these elite summer league players during their collegiate seasons, although this was not monitored during this study. The athlete exposure rate (AE) and injury rate (IR) may have been higher in this group as one would expect elite players to see more practice and play time than none elite, general collegiate population players.\(^1,2,3,4\) Summer leagues, such as the Cape Cod League and Northwoods League are showcase leagues whose teams accept only the best college baseball players in the country, who may eventually be drafted by major league baseball teams. Many more players, while talented enough for collegiate ball, may not see the same practice and play time as elite players. The higher incidence of recurrence reported in this study might also be due to stopping play and “resting” at the end of the players’ college seasons and then quickly starting up again at the start of summer league. The adherence of these athletes to conditioning programs for strength, endurance and flexibility may decrease during this “rest” period between seasons, although this was not monitored in the current study. These elite players may

### Table 8. Self Reported Pain with Baseball Related Activities (reported as % of athletes who responded)

<table>
<thead>
<tr>
<th>Pain Frequency</th>
<th>Frequency of “Small Injuries”</th>
<th>Pain with Stretch</th>
<th>Pain with Double Steps</th>
<th>Pain with Jogging</th>
<th>Pain with Rounding Base</th>
<th>Pain with Sprinting to 1st</th>
<th>Pain with Hitting After 1st</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uninjured Athletes</td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>Never</td>
<td>0</td>
<td>69.5%</td>
<td>66.9%</td>
<td>72.7%</td>
<td>72.7%</td>
<td>Never</td>
<td>68.8%</td>
</tr>
<tr>
<td>Rarely</td>
<td>1</td>
<td>26.0%</td>
<td>27.3%</td>
<td>22.7%</td>
<td>22.1%</td>
<td>A Little</td>
<td>23.4%</td>
</tr>
<tr>
<td>Sometimes</td>
<td>2</td>
<td>3.9%</td>
<td>5.2%</td>
<td>2.6%</td>
<td>3.9%</td>
<td>Moderate</td>
<td>6.5%</td>
</tr>
<tr>
<td>Often</td>
<td>3</td>
<td>0.6%</td>
<td>0.6%</td>
<td>1.9%</td>
<td>1.3%</td>
<td>A Lot</td>
<td>1.5%</td>
</tr>
<tr>
<td>Always</td>
<td>4</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>Significant</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

| Hamstring Injury Athletes | Left | Right | Left | Right | Left | Right | Left | Right | Left | Right | Left | Right | Left | Right | Left | Right | Left | Right | Left | Right |
|-----------------------------|-----------------------------|-------------------|-----------------------|-----------------|------------------------|------------------------|---------------------------|
| Never | 0 | 51.1% | 57.4% | 48.9% | 53.2% | Never | 57.4% | 57.4% | 89.4% | 91.5% | 80.9% | 85.0% | 78.7% | 76.6% | 74.5% | 74.5% | 72.3% | 78.7% |
| Rarely | 1 | 34.0% | 27.7% | 34.0% | 31.9% | A Little | 27.7% | 23.4% | 8.5% | 6.4% | 14.9% | 10.6% | 21.3% | 19.1% | 23.4% | 19.1% | 19.1% | 14.9% |
| Sometimes | 2 | 12.8% | 10.6% | 17.0% | 14.9% | Moderate | 12.8% | 17.0% | 21.3% | 21.3% | 4.3% | 6.4% | 0.0% | 4.3% | 2.1% | 2.1% | 8.4% | 2.1% |
| Often | 3 | 2.1% | 4.3% | 0.0% | 0.0% | A Lot | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 4.3% | 2.1% |
| Always | 4 | 0.0% | 0.0% | 0.0% | 0.0% | Significant | 2.1% | 2.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
The amount of time lost from practice or competitive play can be significant and may have negative ramifications for both the individual’s and the team’s overall performance.10-44 Lower extremity injury for the purpose of this manuscript was defined to specifically encompass injury to the hamstring or the posterior thigh. The total number of days missed due to injury was quantified and each athlete’s injuries were categorized by severity defined by the UEFA Consensus Statement.39

Historically, Powel et al report that 31% of injured high school baseball players missed more than seven days,2 while 25% of NCAA injuries were considered severe and players missed >10 days.3 The amount of time missed due to injury that was reported by the athletes who completed this survey (Table 4) is similar to other reports.1-3,5,27,45 Data from those publications are based on injury data bases and documentation from athletic trainers, physicians or other members of the sports medicine team. Given that data from the current study was based on retrospective recall of the HSI by the athlete, the ultimate accuracy of the data (under or over estimation of time missed) could be subject to question and recall accuracy or bias. However, the amount of time missed is still significant from a season participation perspective, and is aligned with other published reports.1-4 In this study 35% of all players who reported HSI reported that they lost between one and four weeks of play due to injury, and approximately 10% stated they lost more than four weeks. Efforts to prevent or reduce primary injury, or certainly the recurrence of injury would appear to be worth strong consideration.

Fifty six percent of players lost less than seven days of practice or play in this study with 40% reporting only one to three days lost from HSI. While this brief time loss (one to three days) might be attributable simply to “muscle soreness” from an alteration or change in their conditioning program once reporting to a summer league team, the report from any player of any time lost from practice or play must be carefully considered given the history of recurrence of HSI in an athletic population.14 This study could not relate the type or amount of time lost due to injury to be typically associated with delayed onset muscle soreness (DOMS) that might be associated with the onset, change or increase of training load associated with being part of an elite summer league team as mentioned above. For this reason, the study attempted to have the players promptly fill out the questionnaire upon reporting to the team and prior to the commencement of summer league training if possible to minimize the impact of a change in their program.

A statistically significant difference between all sub-scale scores and the total score of the HaOS was demonstrated between the two groups (Table 6). This type of finding is in agreement with investigations of athletes from other sports, such as elite level soccer, that used the HaOS.38 The HaOS is a good tool that may be used to identify players with prior HSI and potential risk for recurrent injury. This survey could help teams identify those players who need specific rehabilitation, training and conditioning programs to mitigate chance of injury recurrence or further injury.
As expected, there was a higher percentage of players with no history of HSI reporting symptoms “never or rarely” compared to players with a history of HSI (Table 7 and Table 8). Players with HSI reported “sometimes having symptoms or moderate symptoms” on a more frequent basis than non-HSI players. The higher percentage of injured HSI players reporting “sometimes or having moderate” symptoms with baseball-related running activity is in agreement with the findings of other studies that demonstrated that up to 76% of HSI occur with base running.3

As demonstrated by other reports, base running is considered to be a primary mechanism of HSI in baseball players.3,5,28 While the current study did not assess the mechanism of injury or when the injury occurred, athletes with HSI responded that they had more pain during baseball-related activities such as rounding the bases, sprinting to first base or braking after first compared to those who did not have a history of HSI (Table 8). These baseball running activities are similar to those reported in other sports (sprinting, stopping/starting, change of direction) that are related to HSI. It should be noted that of the athletes who reported no HSI, 14% reported that they had had pain sprinting to first base, and one third of this group responded that they had pain with stretching. Responses such as these may need to be considered in the design, incorporation and compliance with general stretching and conditioning programs, not only for baseball athletes with HSI, but also for those baseball players with no history of HSI, especially if the goal of these programs is injury prevention.

Each player was allowed to determine what “sore” meant or what “small injuries” meant when they filled out the HaOS questionnaire. “Soreness” and “small Injuries” may be interpreted differently by individuals. Given that this was a self-reported questionnaire the authors felt that it was best to let each athlete determine what this meant for themselves, rather forcing an operational definition that may not make sense to them.

While one might expect those players with HSI to report symptoms, a large percentage of athletes without a history of HSI also reported hamstring soreness in the week prior to the survey, were sore after their workout or had discomfort/pain with stretching (Table 7). However, they did not report time lost from practice or play. This report of soreness may have been associated with DOMS from transitioning between seasons or diversification of training programs associated with their summer league teams. The percentage of athletes answering “never or rarely/a little” was similar between the groups regarding soreness after a workout. However, the HSI group reported soreness “sometimes/moderate” more frequently than the non-HSI group. Soreness during a workout or that lingers may be something for sports medicine personnel to consider in helping to identify athletes at risk. Similar response percentages were demonstrated when athletes with and without a history of HSI answered a question on their perception of the “frequency of small injuries” they experience in their posterior thigh/hamstring area (Table 8). This should also be considered when attempting to identify the baseball player at risk.

The limitations of this study include that this survey is based on a retrospective self-report of injury rather than on objective data collected during the season by members of the sports medicine staff, hence being subject to inherent recall bias. However, the data is consistent with the current HSI rates reported in the baseball literature. In addition, the posterior thigh and hamstring injuries that were reported were not verified by any type of imaging study nor by a physician. However, these athletes were NCAA athletes (largely Division I) and had access to physicians and certified Athletic Trainers (ATC) which may have been instrumental in diagnosis and treatment of previous injuries. In addition, both the Cape Cod League and the Northwoods League each have at least one ATC on staff. Since the summer league is a continuation of a competitive spring season, the notion of overload (training, innings played, etc.) and fatigue from continued play is a consideration. The athletes in this study were coming out of highly competitive programs, so ostensibly, their NCAA seasons could extend into late May and early June (including conference tournaments and potentially the College World Series).

CLINICAL RELEVANCE AND CONCLUSIONS

Understanding the prevalence of posterior thigh pain and HSI history in summer league baseball
players will assist sports medicine staff in designing and implementing effective injury reduction and rehabilitation programs. The results of this study demonstrate that approximately one third of all position players and almost 13% of pitchers who report to summer league baseball, in hope of and preparation for being drafted by Major League Baseball, report a history of hamstring injury. Approximately one third of these injuries are bilateral. The reported reoccurrence rate of injury is greater than 25%. Reviewing the HSI history of summer league players would be useful at the start of the season. Consideration should then be given to developing appropriate injury reduction and optimal conditioning programs.

REFERENCES


APPENDIX 1

History of Hamstring Injuries

<table>
<thead>
<tr>
<th>Left Side</th>
<th>Right Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of previous hamstring strains/injuries:</td>
<td>Number of previous hamstring strains/injuries:</td>
</tr>
<tr>
<td>☐ 0</td>
<td>☐ 0</td>
</tr>
<tr>
<td>☐ 1</td>
<td>☐ 1</td>
</tr>
<tr>
<td>☐ 2</td>
<td>☐ 2</td>
</tr>
<tr>
<td>☐ 3</td>
<td>☐ 3</td>
</tr>
<tr>
<td>☐ 4</td>
<td>☐ 4</td>
</tr>
<tr>
<td>☐ 5</td>
<td>☐ 5</td>
</tr>
</tbody>
</table>

If you answered "0" to the question above skip the next three questions regarding the left hamstring and continue at the next section

If you answered "0" to the question above skip the next three questions regarding the right hamstring and continue at the next section

How long were you fully unable to play/practice?
| 0-6 mos. | 0-6 mos. |
| 6-12 mos. | 6-12 mos. |
| 1-2 yrs. | 1-2 yrs. |
| 2-3 yrs. | 2-3 yrs. |
| ☐ 4-6 wks. | ☐ 4-6 wks. |
| ☐ 4-7 wks. | ☐ 4-7 wks. |
| ☐ 4-8 wks. | ☐ 4-8 wks. |
| ☐ 1-2 months | ☐ 1-2 months |

How much did you miss a practice/game during the previous season due to symptoms/pain from your left hamstring?
| ☐ No/Fewer | ☐ No/Fewer |
| ☐ Rarely | ☐ Rarely |
| ☐ Sometimes | ☐ Sometimes |
| ☐ Often | ☐ Often |

How much did you miss a practice/game during the previous season due to symptoms/pain from your right hamstring?
| ☐ No/Fewer | ☐ No/Fewer |
| ☐ Rarely | ☐ Rarely |
| ☐ Sometimes | ☐ Sometimes |
| ☐ Often | ☐ Often |

Pain

How often do you experience pain from the back of your thigh/hamstrings?

<table>
<thead>
<tr>
<th>Left Leg</th>
<th>Right Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never</td>
<td>Never</td>
</tr>
<tr>
<td>Rarely</td>
<td>Rarely</td>
</tr>
<tr>
<td>Sometimes</td>
<td>Sometimes</td>
</tr>
<tr>
<td>Often</td>
<td>Often</td>
</tr>
</tbody>
</table>

Do you often have small strains/injuries in the back of your thigh/hamstrings that resolve quickly?

<table>
<thead>
<tr>
<th>Left Leg</th>
<th>Right Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never</td>
<td>Never</td>
</tr>
<tr>
<td>Rarely</td>
<td>Rarely</td>
</tr>
<tr>
<td>Sometimes</td>
<td>Sometimes</td>
</tr>
<tr>
<td>Often</td>
<td>Often</td>
</tr>
</tbody>
</table>

Please tell us the degree of pain that you have felt from the back of your thigh/hamstrings during the last week when performing the following activities.

Stretching the back of your thigh/hamstrings?

<table>
<thead>
<tr>
<th>Left Leg</th>
<th>Right Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Pain</td>
<td>No Pain</td>
</tr>
<tr>
<td>A little Pain</td>
<td>A little Pain</td>
</tr>
<tr>
<td>Moderate Pain</td>
<td>Moderate Pain</td>
</tr>
<tr>
<td>A Lot Very Painful</td>
<td>A Lot Very Painful</td>
</tr>
</tbody>
</table>

Walking up a ladder/stairs (double steps)

<table>
<thead>
<tr>
<th>Left Leg</th>
<th>Right Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Pain</td>
<td>No Pain</td>
</tr>
<tr>
<td>A little Pain</td>
<td>A little Pain</td>
</tr>
<tr>
<td>Moderate Pain</td>
<td>Moderate Pain</td>
</tr>
<tr>
<td>A Lot Very Painful</td>
<td>A Lot Very Painful</td>
</tr>
</tbody>
</table>

Jogging?

<table>
<thead>
<tr>
<th>Left Leg</th>
<th>Right Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Pain</td>
<td>No Pain</td>
</tr>
<tr>
<td>A little Pain</td>
<td>A little Pain</td>
</tr>
<tr>
<td>Moderate Pain</td>
<td>Moderate Pain</td>
</tr>
<tr>
<td>A Lot Very Painful</td>
<td>A Lot Very Painful</td>
</tr>
</tbody>
</table>

Symptoms

Please respond to every question by checking the appropriate box, only one box per question.

Have you experienced soreness/stiffness/had pain from the back of your thigh/hamstrings during the last week?

<table>
<thead>
<tr>
<th>Left Leg</th>
<th>Right Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never</td>
<td>Never</td>
</tr>
<tr>
<td>Rarely</td>
<td>Rarely</td>
</tr>
<tr>
<td>Sometimes</td>
<td>Sometimes</td>
</tr>
<tr>
<td>Often</td>
<td>Often</td>
</tr>
<tr>
<td>Always</td>
<td>Always</td>
</tr>
</tbody>
</table>

Soreness - The following questions relate to soreness in the back of your thigh. Report on the degree of soreness you experience from the back of your thigh/hamstrings during a typical week.

How sore is the back of your leg/hamstring after a workout, practice or playing a game?

<table>
<thead>
<tr>
<th>Left Leg</th>
<th>Right Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never</td>
<td>Never</td>
</tr>
<tr>
<td>A little</td>
<td>A little</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>A Lot</td>
<td>A Lot</td>
</tr>
<tr>
<td>Significant</td>
<td>Significant</td>
</tr>
</tbody>
</table>

How sore is the back of your leg/hamstring during a workout, practice or playing a game?

<table>
<thead>
<tr>
<th>Left Leg</th>
<th>Right Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never</td>
<td>Never</td>
</tr>
<tr>
<td>A little</td>
<td>A little</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>A Lot</td>
<td>A Lot</td>
</tr>
<tr>
<td>Significant</td>
<td>Significant</td>
</tr>
</tbody>
</table>

How sore is the back of your leg/hamstring when you wake up in the morning?

<table>
<thead>
<tr>
<th>Left Leg</th>
<th>Right Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never</td>
<td>Never</td>
</tr>
<tr>
<td>A little</td>
<td>A little</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>A Lot</td>
<td>A Lot</td>
</tr>
<tr>
<td>Significant</td>
<td>Significant</td>
</tr>
</tbody>
</table>

How sore is the back of your leg/hamstring if you have been sitting still for a while during the day?

<table>
<thead>
<tr>
<th>Left Leg</th>
<th>Right Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never</td>
<td>Never</td>
</tr>
<tr>
<td>A little</td>
<td>A little</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>A Lot</td>
<td>A Lot</td>
</tr>
<tr>
<td>Significant</td>
<td>Significant</td>
</tr>
</tbody>
</table>

Adapted with Permission from: Ohio Sports Trauma Research Center, Oslo, Norway
Function, daily living activities and sports
The following questions concern your physical function. For each of the following activities, please indicate the degree of difficulty you have experienced in the last week due to the back of your thigh/hamstrings.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Left Leg</th>
<th>Right Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Running?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pain</td>
<td>No</td>
<td>Moderate</td>
</tr>
<tr>
<td>A little</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A Lot</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very painful</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jumping?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pain</td>
<td>No</td>
<td>Moderate</td>
</tr>
<tr>
<td>A little</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A Lot</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very painful</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accelerating?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pain</td>
<td>No</td>
<td>Moderate</td>
</tr>
<tr>
<td>A little</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A Lot</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very painful</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Braking after sprinting?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pain</td>
<td>No</td>
<td>Moderate</td>
</tr>
<tr>
<td>A little</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A Lot</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very painful</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Quality of Life
The following questions concern how problems from your hamstrings restrain you during physical activity. Tell us the amount of difficulty you have had during the last week due to the back of your thigh/hamstrings?

<table>
<thead>
<tr>
<th>Activity</th>
<th>Left Leg</th>
<th>Right Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>How much do you trust the back of your thigh/hamstrings during physical activity?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pain</td>
<td>No</td>
<td>Moderate</td>
</tr>
<tr>
<td>A little</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A Lot</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very painful</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Do you sometimes keep from performing 100% due to concerns about injuring the back of your thigh/hamstrings?

<table>
<thead>
<tr>
<th>Activity</th>
<th>Left Leg</th>
<th>Right Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not at all</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Somewhat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A Lot</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totally</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Adapted with Permission from: Ohio Sports Trauma Research Center, Oslo, Norway
ABSTRACT

**Background:** Reductions in hip range of motion (ROM) correlate with lower extremity injury and alterations in shoulder mechanics in overhead athletes. Such shifts in kinetic-chain dynamics may lead to additional stresses at common injury sites of the upper and lower extremities. Researchers have suggested that Total Motion Release® (TMR®) increases shoulder ROM more effectively than traditional warm-up methods. It is plausible that similar methods may produce increases in ROM at the hip.

**Purpose:** To explore the effects of a TMR® based intervention on active hip rotational ROM in overhead athletes compared to a traditional athletic warm-up.

**Study Design:** Randomized Control Trial.

**Methods:** Twenty-two secondary school, NCAA Division I, III, and Club student-athlete participants (sex: 13 females, 9 males; sport: 9 javelin, 7 volleyball, 7 baseball; age = 19.3 ± 1.1 years; height = 178 ± 11.4 cm; weight = 76.4 ± 11.2 kg.) were randomly assigned to TMR® (TMRG; n=11) and traditional warm-up (TWG; n=11) groups. The TMRG performed three sets of forward flexed trunk twist and seated straight leg raise held for 20 seconds each to the side of ease with a 30-second rest interval. Active hip internal and external rotation was measured using the Clinometer smartphone application immediately before and after intervention.

**Results:** The TMRG experienced significant immediate increases in active dominant hip ER, active nondominant hip ER, active dominant total hip rotational ROM, and active nondominant total hip rotational ROM (mean change = +6.27°, +12.2°, 4.8°, and +11.9°), compared to the TWG (mean change = +0°, +1.9°, -1°, and 1°) respectively.

**Conclusion:** Using TMR® motions and principles as a warm-up produced meaningful changes in active hip rotational ROM bilaterally in overhead athletes.

**Level of Evidence:** IIb

**Key words:** Contralateral exercise, hip range of motion, overhead athletes, movement system, warm up

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E-mail: rdexter@centerfoundation.org
INTRODUCTION:
The importance of trunk stability prior to coordinated movement of the extremities has been well established in the literature, as have the dynamic kinetic-chain links between the lower and upper extremities in overhead athletes. The interdependent nature of the upper and lower extremities in overhead athletics is crucial when considering injury risk and athletic performance. Due to kinetic-chain relationships in overhead athletics, the hip becomes a joint of primary interest when evaluating performance metrics and injury risk. For example, previous researchers have suggested that decreases in kinetic energy at the hip and trunk may result in reduced shoulder stability and increased rotational velocity demands at the shoulder in order to produce distal force.

Increased hip range of motion (ROM) may have positive effects on performance and injury prevention in a variety of overhead athlete populations. For example, world class javelin throwers have been found to possess significantly greater hip axis rotation at release when compared to national class javelin throwers. Others have suggested that alterations in hip ROM may correlate with changes in shoulder external rotation (ER) ROM in baseball position players and pitchers with a history of injury at the shoulder. Decreased hip extension has also been correlated with risk of shoulder injury while decreased total hip arc ROM has been found to predispose baseball players to lower extremity injury. Reduced active and passive hip rotation ROM has also been suggested to correlate with low back pain in a variety of populations participating in athletics. However, there is a lack of literature examining injury risk and active hip rotational ROM changes in a variety of overhead athlete populations. Results from early research efforts in this area indicate that retired competitive javelin throwers exhibit reduced hip IR ROM, and suffer from hip arthrosis at a rate three times higher than age and body mass index (BMI) matched controls.

Despite the gaps in the literature, increasing ROM is a common goal when preparing athletes for sport through the use of warm-up activities. Historically, static stretching and dynamic warm-ups have been the primary components of interventions used to increase hip and shoulder ROM in athletes. While warm-up activities are often designed based on previous experience, support exists in the literature for the sequencing of activities, such as aerobic exercise, static and dynamic stretching, and sports specific exercises. Stretching activities to improve hip ROM have often been targeted at the piriformis muscle, with the ‘modified lunge’ and ‘figure 4’ stretches being common strategies. Bremner et al however, found no significant change in hip passive IR or ER ROM with the use of these stretches when compared to a control group. Despite the commonality of warm-up and stretching protocols, research is not definitive on whether these interventions achieve short or long term improvements in hip IR and ER.

Recently, researchers have suggested that rapid increases in ROM can be achieved through the use of a technique called ‘Total Motion Release’ (TMR®) citing gains in shoulder ROM in overhead athletes and the alleviation of apparent hamstring tightness. Theoretically, TMR® acts largely on neuromuscular control via cross education, neural coupling, and the common core hypothesis, as well as the interconnected nature of fascial and muscular tissues throughout the body known as biotensegrity. Operating with the notion that pain may affect motor control, clinicians using TMR® seek to alleviate pain and dysfunction through the specific use of pain free movement to alter pain and dysfunction in other body regions. When using TMR®, patients are directed to perform movement patterns bilaterally, while comparing pain, quality of movement, and or ROM on a scale of 0-100. On this scale, 0 represents no pain, dysfunction, or strength deficit, with the patient/athlete perceiving normal quality and quantity of movement. A score of 100 on the scale represents extreme pain, complete dysfunction, complete unilateral strength deficit, or severe loss of quality or quantity of motion. If a given movement pattern is bilaterally painful treatment with TMR® in that specific motion is contraindicated. After these self-determined ratings are established, the patient is treated by performing the motion with the largest TMR® score on the “good” side (i.e., healthy side) instead of the “bad” side (i.e., dysfunctional side) utilizing static holds at end range or set/rep schemes.
through the ROM. The intervention is continued until the patient reports less than 5% asymmetry in the treated motion or has been addressed in excess of five rounds of treatment in a given session.25

Given the previous findings of TMR® ROM studies, and the relationships between hip ROM, injury, and performance deficit risk in overhead athletes,7,9,12 further investigation into the effects of these TMR® methods on active hip ROM in overhead athletes is important. The purpose of this study was to explore the effects of a TMR® based intervention on active hip rotational ROM in overhead athletes compared to a traditional athletic warm-up.

METHODS

The University of Idaho Institutional Review Board granted approval prior to data collection. A randomized control trial design was used to investigate the effects of a TMR® intervention (TMRG) and commonly used athletic warm-up strategies (TWG) on active hip rotational ROM. A convenience sample 22 student-athletes (n = 11 from National Collegiate Athletics Association [NCAA] Division I volleyball and track and field; n = 3 from NCAA Division I Club Baseball; n = 3 from NCAA Division III track and field; n = 5 from high school baseball and volleyball teams) were recruited to participate in the study. For inclusion, participants were required to be between the age of 18-25, be able to complete all warm-up activities and ROM measurements, and have been competitive in their respective sport for at least three consecutive years. Exclusion criteria included any orthopedic surgery to the hip, knee, ankle, spine, shoulder, or elbow in the previous three months. Those who suffered orthopedic injuries older than three months yet remained symptomatic were also excluded. Participants were also excluded if they were unable to complete hip ROM testing or had painful motion with both left and right straight leg raise or trunk rotation during pre-screening as this is a contraindication for the use of the included TMR® motions.25 All participants signed informed consent with the understanding that participation was voluntary and withdrawal from participation would be accepted at any time. Participants were also informed that their data could be withdrawn from use in this study after collection was complete. No participants were excluded after prescreening or discontinued participation after data collection had begun. Gender and sport differences between groups are displayed via a CONSORT flow chart (Figure 1).

PROCEDURES

The Clinometer® digital smartphone application by Plaincode Software Solutions (https://play.google.com/store/apps) was used to measure active hip IR and ER immediately before and after intervention. The examiner affixed a smartphone to the participant's anterior shin with the top edge of the smartphone in line with the proximal terminus of the tibial tuberosity using an Ailkin Running Sports Armband for Droid Turbo™ Android Smartphone by Motorola (app; Figure 2). For IR and ER measurements, participants were seated with the hip and knee of the limb being measured at 90° with the lower leg draped over the edge of the plinth. An adjustable strap was positioned across each participant's thigh at the distal third of the femur to limit compensation during ROM testing. The unmeasured limb was positioned at a diagonal with the knee at 90° draped over the lateral edge of the plinth to ensure unimpeded rotational AROM to the measured limb (Figure 3).

The examiner was seated across from the participant near the leg during active IR and ER to allow the examiner access smartphone for use of the Clinometer® application. In order to determine dominance, participants were asked to select the arm they primarily use for competitive activity. Hip dominance was determined to be the limb ipsilateral to the dominant arm.3,4 The leg was positioned with the gastrocnemius two inches away from the edge of the plinth. Once positioned, the participants were instructed to internally rotate then externally rotate the hip, making sure to minimize accessory motion by keeping the gluteal region level and in contact with the plinth and the knee flexed to 90°. Asking the participant to keep their hands in their lap, limiting their ability to stabilize against the plinth, minimized accessory stabilization. Measurements were recorded when the participants reached self-determined end range (Figure 4; Figure 5). The sum of hip IR and ER was used to determine total hip rotational ROM.

Prior to the completion of this study, intra-rater reliability pilot data was collected using the Clinometer® application. The examiner measured hip IR and ER
five times with the smartphone application, thigh strap, and sport band averaging the values. The examiner placed the smartphone and participants in the position for measurement. Measurements were conducted on each participant (n = 10) twice over a period of five days. A two-way mixed effects model Intraclass Correlation (ICC) was used to assess intra-rater reliability (test-retest) for the Clinometer® smartphone application with absolute agreement. The standard error of the mean (SEM) values were calculated for hip IR and ER using the formula (SEM = SD/\sqrt{1-ICC}) where SD is the standard deviation from the test.\textsuperscript{27} Minimal Detectable Change (MDC) was calculated using the formula (MDC = SEM × 1.96 × \sqrt{2}).\textsuperscript{26} The intrarater reliability ICC, SEM, and MDC values were excellent for both measurements and exceeded those previously reported in the literature for both active seated hip IR (ICC = .84, SEM = 3.4) and hip ER (ICC = .63, SEM = 2.8) (Table 1).\textsuperscript{26,27} Data collection and intervention were conducted in a single session for each participant prior to any

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**Figure 1.** CONSORT diagram showing the breakdown of participant by intervention, gender, and sport.
Figure 2. The Smartphone Clinometer application affixed in the Ailkin Running Sports Armband for Droid Turbo™.

Figure 3. The Adjustable Belt used for Leg Stabilization during Active Hip Internal and External Rotation measurements.

Figure 4. Measurement of Active Hip Internal Rotation.

Figure 5. Measurement of Active Hip External Rotation.
sport-specific warm-up activities, training, or competition. Participants were assigned to either the TMR® group (TMRG) or the traditional warm-up group (TWG) randomly based on the order of signup or arrival for participation. Pre-intervention measurements of active hip IR and ER were measured beginning on the dominant side and then moving to the non-dominant side prior to performing the activity assigned to either the TMRG or TWG.

After baseline AROM measurements were collected, the participants in the TMRG performed one SLR with each leg and FFTT with the arms folded across the chest and the palm of the hand at the anterior deltoïd. During the FFTT, the participant's hips were slightly hinged as if performing a deadlift, with the torso at an angle that produced no discomfort in the participant's back. Hip angle, hinge depth, and trunk posture were not controlled for per the TMR® systems suggestion that participants reach self-determined end range and that changes in joint angles and position during testing and intervention are required to do so. All interventions and measurements were provided by an athletic training student and certified strength and conditioning coach (CSCS) who had been trained in TMR® up to level III. Measurement and application of interventions took place indoors in athletic training facilities.

**TOTAL MOTION RELEASE® GROUP (TMRG INTERVENTION)**

Participants in the TMRG then established a “side of ease”, per their own perception, for both the TMRG SLR (Figure 6) and FFTT (Figure 7) per TMR® recommendations. Afterward, participants performed these movement patterns in order from most asymmetrical to least asymmetrical. The FFTT and SLR were chosen because previous research on TMR® has indicated that related movements could produce either regionally interdependent or local changes in ROM. For example, the TMR® FFTT and arm raise (AR) significantly increased shoulder rotational range of motion in baseball players.

<table>
<thead>
<tr>
<th>Table 1. Intra-rater reliability for Hip Internal &amp; External Rotation using the Clinometer application (N = 10).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Range of Motion (AROM)</td>
</tr>
<tr>
<td>Hip Internal Rotation</td>
</tr>
<tr>
<td>Hip External Rotation</td>
</tr>
</tbody>
</table>

Figure 6. The Total Motion Release® (TMR®) Seated Leg Raise (SLR).
Furthermore the TMR® FFTT was reported to significantly increased measures of hamstring extensibility, including the sit and reach and active straight leg raise tests. The researchers sought to test the effect of the TMR® FFTT and a comparable lower extremity TMR® motion (i.e., the SLR is similar to the AR technique in TMR®) coupled with the FFTT on hip rotational AROM.

The seated SLR (3 sets of 20-second static holds at end range) and the standing FFTT (3 sets of 20-second static holds) were performed to the side of ease in the case of the SLR or the direction of ease during the FFTT. After each set, a 30-second rest interval was taken by the participants. End range holds of 20 seconds were performed in an attempt to reduce cumulative fatigue while completing multiple rounds of high-volume repetitions and sets. Upon completion, hip IR and ER AROM were again recorded. The TMRG, including pre and post-participation AROM measurements, was completed in approximately seven minutes per participant.

TRADITIONAL WARM-UP GROUP (TWG INTERVENTION)

Participants in the TWG completed a four-part warm-up (Table 2), with Part I consisting of a three-minute steady state jog. Part II included dynamic full body warm-up drills consisting of upper and lower extremity dynamic stretches, dynamic movements through three planes of motion, and an emphasis on full range motion throughout the lower extremity, trunk, and upper extremity. The timing of Part II included three continuous rounds with a 30-second rest interval between each round. Part III included two rounds of 30 meter runs at 50%, 75%, and 90% of the participants' self-determined maximum, and included a 30-second rest interval after each effort. Part IV included three rounds of 30-second static stretches for the upper extremity done alternatingly to produce a 30-second rest interval between sides.

Programs to address pre-training and pre-competition warm-up are often aimed at increasing heart rate, as well as core and specific tissue temperature. Mobility and ROM are typically attended to through general exercise, static or dynamic stretching, and drills to address sport specific skills or performance aims. Static stretching of the hip was not included in the TWG due to a lack of definitive research regarding its effect on hip rotational ROM and its inconsistent use in overhead sports. Instead, dynamic training methods were utilized in Part II of the TWG because these movements were considered adequate for addressing the goals of a warm-up for overhead athletes who are preparing their lower extremity. Static stretching of the shoulder was included in part IV of the TWG because this is common practice among overhead athletes during pre-training and pre-competition.
The TWG intervention was completed in approximately 25 minutes per participant. Upon completion of either intervention, hip AROM measurements were immediately reassessed.

**STATISTICAL METHODS**

Data analysis was completed using the Statistical Package SPSS Version 21 (IBM Corp. Armonk, NY, USA). Group baseline differences for hip IR, ER, and total hip rotation were analyzed using independent t-tests. One-way ANOVAs were used to assess the difference between groups regarding change in hip IR, ER, and total hip rotation post-intervention. An α level of p ≤ .05 was considered significant for all statistical analyses. Partial eta squared was utilized to calculate effect size, with values lower than .0099 considered small, while .0588 was the benchmark for medium, and values greater than .1379 considered large.

**RESULTS**

All 22 recruited participants met inclusion criteria and completed participation in this study (Figure 1). Participants were randomly assigned to either the TMRG or the TWG using a numerical list generated by randomization.com in the order of participant arrival. Analysis of baseline testing indicated significant group differences in mean height (p = .003), but significant group differences were not found for age (p = .349) or weight (p = .188; Table 3). Additionally, no significant group differences were found in pre-intervention dominant hip IR (p = .388; Table 4), dominant hip ER (p = .362; Table 4) dominant total hip rotational ROM (p = .781; Table 4), nondominant hip IR (p = .851; Table 5), nondominant hip ER (p = .228 Table 5), or nondominant total hip rotational ROM (p = .421; Table 5).

Post intervention, significant differences were found between groups. Significantly greater increases in dominant hip ER (F [1,21] = 5.561, p = .019), nondominant ER (F [1,21] = 7.656, p = .012), dominant total hip rotation (F[1,21] = 7.128, p = .015) and nondominant total hip rotation (F[1,21] = 7.031, p = .015) were found in the TMRG compared to the

---

**Table 2. The Traditional Warm-up Protocol.**

<table>
<thead>
<tr>
<th>Warm-up Exercise</th>
<th>Repetitions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase I</strong></td>
<td></td>
</tr>
<tr>
<td>Jog</td>
<td>3 minutes at 25% effort</td>
</tr>
<tr>
<td><strong>Phase II</strong></td>
<td></td>
</tr>
<tr>
<td>Walking Knee Hug</td>
<td>10 meters</td>
</tr>
<tr>
<td>Alternating Forward Lunge w/ Rotation</td>
<td>10 meters</td>
</tr>
<tr>
<td>Alternating Reverse Lunge w/ Rotation</td>
<td>10 meters</td>
</tr>
<tr>
<td>Alternating Walking Quadriiceps Stretch</td>
<td>10 meters</td>
</tr>
<tr>
<td>Power Skips</td>
<td>10 meters</td>
</tr>
<tr>
<td>Alternating Lateral Lunges</td>
<td>10 meters</td>
</tr>
<tr>
<td>Walking dynamic forward overhead arm circles</td>
<td>10 meters</td>
</tr>
<tr>
<td>Walking dynamic reverse overhead arm circles</td>
<td>10 meters</td>
</tr>
<tr>
<td>Walking horizontal cross body arm swings</td>
<td>10 meters</td>
</tr>
<tr>
<td><strong>Phase III</strong></td>
<td></td>
</tr>
<tr>
<td>Sprint (50%)</td>
<td>2 x 30 meters</td>
</tr>
<tr>
<td>Sprint (75%)</td>
<td>2 x 30 meters</td>
</tr>
<tr>
<td>Sprint (90%)</td>
<td>2 x 30 meters</td>
</tr>
<tr>
<td><strong>Phase IV</strong></td>
<td></td>
</tr>
<tr>
<td>Alternating seated cross body stretch</td>
<td>3 x 30 seconds each</td>
</tr>
<tr>
<td>Alternating seated upper trapezius stretch</td>
<td>3 x 30 seconds each</td>
</tr>
<tr>
<td>Alternating side lying sleeper stretch</td>
<td>3 x 30 seconds each</td>
</tr>
</tbody>
</table>

**Table 3. Descriptive Statistics (Height, Weight, Age).**

<table>
<thead>
<tr>
<th></th>
<th>Height (cm)</th>
<th>Age (years)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants</td>
<td>178 ± 11.43</td>
<td>19.3 ± 1.1</td>
<td>76.2 ± 10.9</td>
</tr>
<tr>
<td>TMRG</td>
<td>184.7 ± 10.41</td>
<td>19.5 ± 1.29</td>
<td>79.3 ± 10.78</td>
</tr>
<tr>
<td>TWG</td>
<td>171.6 ± 7.64</td>
<td>19 ± 0.89</td>
<td>73.1 ± 10.66</td>
</tr>
</tbody>
</table>

preparation. The TWG intervention was completed in approximately 25 minutes per participant. Upon completion of either intervention, hip AROM measurements were immediately reassessed.
TWG (Table 5). Statistically significant differences between groups were not found for dominant hip IR ($F[1,21] = 2.276, p = .147$) or nondominant hip IR ($F[1,21] = 2.561, p = .125$); however, these analyses were underpowered (observed power equals 30% and 33% respectively). The effect sizes indicate a medium or large treatment effect ($\eta^2 > .058$) for each of the analyses (Table 6).

<table>
<thead>
<tr>
<th>Table 4. Dominant (DOM) Hip Range of Motion by Group.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active ROM</td>
</tr>
<tr>
<td>------------</td>
</tr>
<tr>
<td>TMRG</td>
</tr>
<tr>
<td>TWG</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 5. Non Dominant (NON DOM) Hip ROM by Group.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Range of Motion (ROM)</td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>TMRG</td>
</tr>
<tr>
<td>TWG</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 6. Change in Hip Internal and External Rotation from pre- to post-intervention between groups.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change from Baseline</td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>Dominant Hip Internal Rotation (IR)</td>
</tr>
<tr>
<td>Dominant Hip External Rotation (ER)</td>
</tr>
<tr>
<td>Dominant Total Hip Rotation</td>
</tr>
<tr>
<td>Non Dominant Hip IR</td>
</tr>
<tr>
<td>Non Dominant Hip ER</td>
</tr>
<tr>
<td>Non Dominant Hip Total Rotation</td>
</tr>
</tbody>
</table>

**DISCUSSION:**
The purpose of this study was to observe the effects of the TMR® unilateral Forward Flexion Trunk Twist (FFTT) and Seated Straight Leg Raise (SLR) on active hip IR and ER when compared to a traditional athletic warm-up in overhead athletes. Post-intervention, participants in the TMRG demonstrated significantly increased dominant hip ER
(mean change = +6.27°), dominant hip total rotational ROM (mean change = +12.2°), nondominant hip ER (mean change = +4.8°), and nondominant total hip rotational ROM (mean change = +11.9°) compared to the TWG. Participants in the TMRG also gained approximately +6° of dominant IR and +5° of non-dominant IR, but the between group differences were not statistically significant (Table 6). The lack of significant group differences for increases in IR could be explained by the sample size and moderate effect sizes for each variable (η² = .102, η² = .114, respectively), which resulted in reduced power of the analysis and may suggest that the sample size was too small to identify meaningful group differences that may have been present. Overall, the improvement in ROM for all of the measures is clinically meaningful given the effect sizes and MDC values established during pilot testing. The ROM improvements, coupled with large between group differences in time to completion (TMRG = 7 minutes, TWG = 25 minutes), suggests TMR® may be a more efficient and effective intervention strategy than traditional warm-up programs for increasing hip rotational ROM in overhead athletes. Furthermore, when compared to literature on passive ROM changes after static stretching, the results of the current study suggest that active, regionally interdependent interventions produce greater changes in rotational hip ROM.

While it is plausible that a number of factors contribute to deficits and alterations in active rotational ROM of the hip, research in the area of post intervention changes in active hip rotational ROM is lacking. It appears that this is the only study examining short-term changes in active hip rotational ROM in healthy overhead athletes following a warm-up protocol. When compared to the available literature, the participants in the current study exhibited relatively normal values for hip IR and ER ROM pre-intervention. For example, when compared to a study of college baseball pitchers by Shimamura et al., participants in this study presented with similar ROM values at baseline when measured in the seated position (dominant hip IR = 33° for right handers and 33.6° for left handers; dominant hip ER = 36.9° for right handers and 43.2° for left handers). However, it is important to note that measurement techniques, positions, inclusion of passive and/or active measures, normative values, injury risk, and the relationship between ROM and performance in overhead athletes vary greatly across the literature.

Shimamura et al. and Sauers et al., for example, measured participants passively in a seated position. In contrast, Van Dillen et al. and Bremner et al. measured passive ROM in a prone position. Ellenbecker et al. measured participants’ AROM in a similar prone position, while Li et al. measured passive ROM in a supine 90/90 position. The current study measured active hip rotation seated at 90/90 with a smartphone inclinometer. When combined, the paucity of literature on the effect of interventions for improving hip IR and ER, the differences in measurement position, type of ROM, and methods utilized make it challenging to draw conclusions or generalize recommendations.

It is likely that interventions designed to increase active hip ROM may be useful in the prevention of future injury in overhead athletes given the findings of previous researchers regarding hip ROM loss and injury in baseball players, degenerative joint disease of the hip in javelin throwers, and hip rotational ROM and lumbo-pelvic pain. Furthermore, other researchers suggest that bilateral symmetry in hip rotation should be a normal finding in healthy baseball players. It is also plausible that TMR®-based interventions are more effective than static stretching at “ball and socket” synovial joints, and may help reduce incidents of lumbo-pelvic pain and dysfunction in overhead athletes. Total Motion Release® methods, such as the FFTT that include active trunk rotation, more directly impact the hip, lumbo-pelvic complex, and core musculature due to alterations in motor control and strength that do not occur with static stretching. The significant improvement in bilateral hip ER and total hip rotation, along with strong effect sizes suggests the results of our study are likely clinically and practically meaningful. Considering these findings in conjunction with previous research on TMR®, the incorporation of TMR® methods may prove useful as part of larger performance readiness and injury prevention strategy in overhead athlete populations by quickly increasing AROM at both the hip and shoulder joints.
POSSIBLE MECHANISMS OF ACTION FOR TOTAL MOTION RELEASE®

When investigating and utilizing TMR®, it is important to consider the potential neuromuscular mechanisms of action at work. Irrespective of the TMR® application method (e.g., contralateral applications, ipsilateral applications, statics holds, repetitions), immediate alterations in motor control and strength may be due to increased neuromuscular and motor neuron activity. Total Motion Release® may utilize cross education, neural coupling, and the common core hypothesis to act on fascial and muscular tissues, as well as joint positioning via integrated central and peripheral nervous system feedback, creating alterations in strength, coordination, and AROM. It is plausible that the use of TMR® in the present study functioned on the principles of proximal trunk stability producing distal extremity mobility with the use of the FFTT. As an indirect intervention which avoids directly addressing dysfunction by treating into restriction (i.e., as would typically occur with a joint mobilization or stretching), TMR® techniques may produce positive changes due to neuro-physiological adaptation. Instead of reinforcing a restricted or dysfunctional pattern, TMR® may allow for the adaptation of spinal motor neurons via non-threatening movements, which then transfers to the opposite side, or related interdependent regions of the body.

LIMITATIONS & FUTURE RESEARCH:

A relatively small sample size (n = 22) and participation by a healthy athletic population makes the generalization of these findings across populations difficult. The examiner and the participants were not blinded as one clinician administered the intervention and collected measurements, and participants could not be blinded without the use of a sham intervention. Long-term ROM changes for either group were also not recorded, thus only short term effects should be considered when interpreting the findings of the current study. While remaining true to TMR® principles, the hip flexion angle and trunk posture of participants in the TMRG were not controlled for during the FFTT, potentially affecting standardization across participants. As a result, it is unknown what effect, if any, hip and trunk flexion angle play in the efficacy of this technique. However, these methods are in agreement with TMR® guidelines of allowing individuals to determine the motion that best allows them to access end-range of motion in a given movement pattern, and are in line with the application of TMR® in clinical practice.

Although no statistically significant between groups differences at baseline were found for any dependent variable, it is possible that the differences at baseline impacted final results. For example, because the participants in the TWG began with more ROM than the TMRG, a ceiling effect may have limited ROM gains in that group. However, it is important to note that despite participants in TWG having higher ROM at baseline, the TMRG had greater ROM than the TWG in every category post-intervention. Additionally, due to small sample size and randomization, sport and gender differences were not controlled for in this study which may have played a role in differences at baseline. It is also important to note that participants in the study fell within the ROM norms established by the literature for baseball players and overhead athletes.

Additionally, the static stretches included in the TWG in this study were not directed at the hip. In the TWG, participants performed a static stretching protocol that included a seated cross body stretch, a seated upper trapezius stretch, and a side lying sleeper stretch with the arm at 90 degrees of adduction and 90 degrees of shoulder and elbow flexion. Due to the inconclusive nature of static stretching literature, particularly when hip ROM is concerned, the choice of stretches was made in an attempt to mirror the process often undertaken during warm-up by those participating in overhead, upper extremity dominant sports. As a result, static stretching of the hip was purposefully omitted as the dynamic warm-up used in the TWG addressed lower extremity preparedness particularly with the inclusion of trunk rotational lunges and lateral lunges.

Future research should begin to examine time to completion differences of other intervention strategies designed to improve AROM and help guide clinical practice. Investigations into the duration, rate, and magnitude of change over time when utilizing TMR® are also needed to provide insight into the clinical utility of TMR®. Total Motion Release® as a bridge between rehabilitation and performance. Research
into the application of TMR® as a paradigm should be conducted to determine best practices and investigate treatment outcome differences across different populations. For example, the application of TMR® to maximize improvement in a desired outcome may vary if the technique is used in an injured population to reduce pain compared to a healthy, active population attempting to improve ROM before activity. Another example might assess if specific motions (e.g., rotational motions of the trunk) or application of the full TMR® assessment and treatment protocol produce different results as suggested per the recommendation of the paradigm creator.25

CONCLUSIONS:
The results of this study indicate that TMR® was more effective at immediately increasing bilateral hip ER and total hip rotation in overhead athletes than a traditionally designed athletic warm-up. Additionally, the TMR® intervention was completed significantly faster than the traditional warm-up. These results indicate that TMR® has the potential for use across sports performance professionals as part of warm-up design for improving ROM at the hip in the short term.

REFERENCES:


ABSTRACT

Background: Poor balance, lack of neuromuscular control, and movement ability are predictors of performance and injury risk in sports and physical activity participation. The Functional Movement Screen™ (FMS™) and lower quarter Y-Balance Test (YBT) have been used by clinicians to evaluate balance, functional symmetry, and static and dynamic movement patterns, yet little information exists regarding the relationship between the FMS™, YBT, and physical performance tests (e.g. vertical jump) within the high school population.

Purpose: The purpose of this study was to investigate the relationship between the FMS™, dynamic balance as measured by the YBT and physical performance tests (standing long jump, vertical jump, Pro Agility Test) in male and female high school athletes.

Study Design: Cohort study.

Methods: Fifty-six high school athletes (28 females, 28 males; mean age 16.4 ± 0.1) who participated in organized team sports were tested. Participants performed the FMS™, YBT, and three physical performance tests (standing long jump, vertical jump, Pro Agility Test).

Results: Females outperformed males on the FMS™ and YBT, while males outperformed females on the performance tests. In both sexes, the composite FMS™ score was positively correlated with the left and composite YBT scores. Agility was negatively correlated with composite FMS™ in males (p < 0.05) and the left and composite YBT in females (p < 0.05).

Conclusions: The FMS™ and YBT may evaluate similar underlying constructs in high school athletes, such as dynamic balance and lower extremity power. The results of this study demonstrate the utility of the FMS and YBT to relate multiple constructs of muscular power to an individual's ability to balance. Furthermore, establishing the need for the utilization and application of multiple field-based tests by sports medicine professionals and strength and conditioning coaches when evaluating an athlete's movement and physical performance capabilities. Utilization of multiple field-based tests may provide the first step for the development of injury prevention strategies and long-term athlete development programs.

Level of Evidence: 2b.

Key words: Functional Movement Screen™, movement system, sport performance, Y-Balance Test

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Conflicts of interest statement: The authors declare that there are no conflicts of interest.

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INTRODUCTION

Sport and physical activity require musculoskeletal fitness (e.g. muscular strength and power) and adequate motor coordination and control to produce high levels of force during activity. Inadequate functional strength or movement deficiencies may negatively influence sport performance or lead to an increased risk of injury.1,2 The Functional Movement Screen (FMS™) and lower quarter Y-Balance Test (YBT) are examples of functional screening tools used by athletic trainers and physical therapists to identify physical dysfunction or functional asymmetries.3-7 The constructs measured through the FMS™ and YBT tests are indicative of an individual's ability to balance, motor coordination, and control.8,9 While these tools are used by sports medicine providers for movement evaluation, they may also have implications for an individual's performance in sport and physical activity as decreased balance, lack of neuromuscular control and movement dysfunction have been suggested to be predictors of poor athletic performance.10-12 Athletes who present with contralateral imbalances are at an increased risk of injury during sport, which results in compensatory movement patterns and muscle inhibition, potentially resulting in lower performance levels.5

The FMS™ and YBT tests are examples of field-based measurement tools that can be used quickly and effectively by sports medicine professionals to screen for movement and balance deficiencies in individuals who intend to enter sport performance competition. The FMS™ is a screening tool that was developed to identify functional or physical asymmetry or limitations.11,12 The FMS™ may evaluate an individual's muscular strength, balance, range of motion, and coordination at some level.11,12 Current evidence suggests this screening tool may be used to evaluate preparedness for physical activity.11-14 The YBT is a reliable tool developed as a standardized measure of dynamic balance and neuromuscular control.15 The YBT measures balance during a single leg stance and requires an individual to possess strength, flexibility, and proprioception to adequately perform the test.16,17 Performance on the YBT improves with sports training and is also a way to evaluate an athlete's preparedness for sport participation.16, 18-20

Although the YBT and FMS™ were developed for the purposes of assessing functional movement patterns and balance which may provide insight to inefficiencies throughout the kinetic chain that can cause a decrease in performance and increase injury risk, little evidence exists regarding their relationship to field tests of physical performance (e.g. standing long jump, Pro Agility test). Limitations in flexibility,21-24 strength,23,28,29 and power30,31 also may have negative consequences on performance in fundamental movements in sport.32 Due to the time demand for medical professionals' (e.g. physical therapists and athletic trainers) care towards athletes during rehabilitation and treatment hours, it is not possible to perform multiple screening tests/tools prior to an athletic season to determine if athletes have poor mobility and fundamental movements that may alter sport performance. Understanding associations between movement performance and global screening tools (FMS™ and YBT) could provide a foundation for prevention programs and performance enhancement for athletes.

To date, there is limited research regarding the relationship between the FMS™, YBT, and field tests of physical performance in high school sport athletes. Using the FMS™ or YBT independently or in tandem may aid sports medicine and strength and conditioning professionals in their ability to identify individuals with an increased risk of injury during sport participation through identification of physical or functional movement deficiencies. Thus, the purpose of this study was to investigate the relationship between the FMS™, YBT and physical performance tests (standing long jump, vertical jump, Pro Agility Test) in male and female high school athletes.

METHODS

Participants

Fifty-six participants (28 females, 28 males; mean age = 16.4 ± 0.1) from a rural high school in South Carolina volunteered to participate. The study was approved by the University's Institutional Review Board and parental consent and participant assent were obtained prior to testing. Participants were excluded if they had a current injury that limited their sport participation or if they had any movement related disorders that restrained the participant from performing testing protocols.
Procedures
Demographic and anthropometric data (age, height, weight, BMI) were collected at the start of the first testing session. Participants were randomly assigned to begin testing with either the screening tests (FMS™ and YBT) or the performance tests (e.g. standing long jump, vertical jump, Pro Agility Test).

Functional Movement Screen (FMS™)
The FMS™ was administered using standard equipment (Functional Movement Systems, Lynchburg, VA, USA), procedures, and verbal instructions. The seven FMS™ tasks performed included: deep squat, hurdle-step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push-up, and rotary stability test. Participants completed clearing tests to identify pain (active shoulder impingement, trunk flexion, and trunk extension tests). A maximum of three trials of each movement were performed and live coded. A score of 3 was given if the movement was performed as instructed with full range of motion and postural control. A score of 2 was given if the movement was completed in a compensatory position or lacked full range of motion or postural control. A score of 1 was given if the participant could not complete the movement. A score of 0 was given if the participant indicated the presence of pain during the movement. According to FMS™ testing guidelines, the highest score from the trials was recorded. For complete bilateral movement (i.e. hurdle step, in-line lunge, shoulder mobility, active straight leg raise and rotary stability) the lower of two scores was utilized in the composite score. The FMS™ was administered and scored live by a member of the research team certified in FMS™ scoring ($k_w = 0.867$). The strength of agreement between members of the research team ranged from “good” ($k = 0.860, p = 0.002$) to “very good” ($k = 0.990, p < 0.001$).

Lower Quarter Y-Balance Test
Participants performed the YBT using the Y-Balance Test kit (Move2Perform, Evansville, IN) in three reach directions: anterior, posteromedial, and posterolateral. All testing was conducted using standard procedures and instructions. Before screening, the researcher demonstrated how each movement was performed and explained the errors in performance that would void trials: 1) touching the floor, failing to return the moving foot to the center of the apparatus; 2) touching the top of the slider with any part of the foot; 3) kicking the indicator forward; 4) the heel lifts off the platform. Participants performed four practice trials in each direction. Feedback was given to the participant if they performed a void trial but no instruction was provided. Each participant's right leg length was measured for data normalization (anterior iliac spine to medial malleolus). Participants performed the assessment on both the right and left extremities while they reached with the contralateral limb. A total of three successful reaches were performed. The maximal reach distance (cm) in each direction was used for data analysis. The YBT aggregate score was calculated for each side (right and left) by summing the maximal reach distance in the three directions, dividing by three times the right leg length, and multiplying by 100. The YBT composite score was calculated by taking the mean of the right and left scores. These scores were representative of reach as a percentage of limb length.

Standing Long Jump
The standing long jump was used to provide a measure of lower extremity horizontal power. The participant was instructed to place the toes of both feet behind a designated starting line and to “jump as far forward as possible, ensuring a two-footed landing”. Distance was recorded (cm) by measuring from the starting line to the most posterior surface of the foot at landing. Three trials were performed, and the best trial was used for data analysis.

Vertical Jump
The vertical jump was utilized to measure lower extremity power in the vertical plane. The Vertec (Swift Performance Equipment, Wacol, Australia) is a standardized device, with color coded vanes, used to measure jump height performance. First, each participant stood flat-footed to the side of the Vertec (dominant hand side toward the Vertec). The participant was instructed to “reach upward and displace as many vanes as possible”. The highest vane was recorded as the standing reach height. The
participant was then instructed to jump as high as possible using a two-foot take off without a preparatory step. Height was recorded (cm) from the highest vane moved and the vertical jump height was calculated by subtracting the standing reach height from jump height. Three trials were completed, and the best trial was used for data analysis.

**Pro Agility Test**
The Pro Agility Test was used to identify an individual's ability to change direction—a whole body movement that involved the capability to accelerate and decelerate quickly in addition to change of direction in response to a stimulus. Three markers were positioned five yards apart on the floor. Participants started in the middle marker and accelerated five yards to their right, then ten yards to their left, and finally sprinted five yards to their right through the middle marker. All times were recorded to the hundredths of a second using a hand-held stopwatch. Time began upon the individual's movement and ended as he or she crossed the final marker. Three trials were completed, and the best trial was used for data analysis.

**Statistical Methods**
Participant descriptive statistics (mean and standard deviations) were calculated for the total sample and by sex. Independent t-tests were performed to determine sex differences for all measures. Pearson correlational analyses were conducted on z-transformed measures to examine associations among health-related fitness measures and sex. Statistical analyses were computed using SPSS (Version 24; IBM Corporation, New York, USA), and $p < 0.05$ was utilized for statistical significance.

**RESULTS**
Descriptive statistics and differences between the sexes are presented in Table 1. Results indicated males were significantly older, taller, heavier, and had a higher BMI compared to females ($p < 0.01$). Females performed significantly better on the FMSTM (female: 14.2 ± 2.1, male: 12.7 ± 2.6). There was no difference between males and females for aggregate YBT performance scores; however, when evaluating YBT scores by reach direction, females outperformed males on both the right anterior (female: 63.8; male: 59.0; $p < 0.01$) and left anterior reaches (female: 64.6; male: 58.9; $p < 0.01$). For all physical performance tests, males significantly outperformed females ($p < 0.01$).

Pearson correlations between measures are presented in Tables 2 (males) and 3 (females). For both sexes there were significant positive correlations between the composite FMSTM score and left YBT scores (male: $r = .447$; moderate, female: $r = .446$; moderate) and the composite FMSTM score and composite YBT scores (male: $r = 0.424$; moderate, female $r = .408$; moderate). For both sexes there

<table>
<thead>
<tr>
<th>Table 1. Descriptive Statistics.</th>
</tr>
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<tbody>
<tr>
<td><strong>Male</strong> ($n = 28$)</td>
</tr>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td>Weight (kg)</td>
</tr>
<tr>
<td>BMI</td>
</tr>
<tr>
<td>Composite FMSTM</td>
</tr>
<tr>
<td>Right YBT*</td>
</tr>
<tr>
<td>Left YBT*</td>
</tr>
<tr>
<td>Composite YBT*</td>
</tr>
<tr>
<td>SLJ (cm)</td>
</tr>
<tr>
<td>Vertical (cm)</td>
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<tr>
<td>Pro Agility (seconds)</td>
</tr>
</tbody>
</table>

BMI = body mass index; FMSTM = Functional Movement Screen; YBT = Y-Balance test; SLJ = standing long jump
*reach represented as percentage of leg length; $^1p < 0.05$; $^2p < 0.01$
was also a significant positive association between vertical jump height and SLJ distance (male: \( r = .850 \); strong, female: .647; moderate). For males, there were significant inverse associations between agility (time) and the composite FMSTM score (\( r = -.436 \); moderate), vertical jump height (\( r = -.683 \); moderate), and SLJ distance (\( r = -.712 \); strong). For females, there were significant inverse associations between agility (time) and the left YBT scores (\( r = -.504 \); moderate), composite YBT scores (\( r = -.446 \); moderate), and SLJ distance (\( r = -.693 \); moderate).

**DISCUSSION**

The purpose of this study was to examine associations between movement ability (i.e., FMSTM), dynamic balance (i.e., YBT), and physical performance in male and female high school athletes. Males outperformed females on all tests of physical performance (SLJ, vertical jump, Pro Agility Test). Across youth and into adulthood, normative reference data demonstrate that males tend to have greater musculoskeletal strength and power compared to females, therefore the results of the physical performance tests were expected.\(^{41,42}\)

Females outperformed males on the FMSTM (male = 12.7, female = 14.2). Across the FMSTM literature there has been conflicting evidence regarding sex differences in youth and the composite FMSTM score.\(^{3,43-44}\) The normative data for youth (ages 10-17) from India demonstrate that males outperform females regarding the composite FMSTM score (male = 14.93, female = 14.17).\(^{43}\) However, recent studies of youth in the southeastern US revealed that females perform better on the FMSTM when evaluating composite scores (male = 14.67, female = 15.16; male = 12.62; female = 14.40).\(^{3,44}\) Therefore, this study provides another reference for sex comparison using the composite FMSTM score in young participants, specifically the high school population.

The lack of a significant association between the FMSTM and most performance measures in both males and females may be due in part to the differences in ranges of motion required for maximum performance in the FMSTM and the ballistic movements associated with tests of power. The FMSTM evaluates movement to identify physical and functional asymmetries and requires substantial ranges of motion to achieve

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**Table 2. Correlations between tests in Males.**

<table>
<thead>
<tr>
<th></th>
<th>Composite FMSTM</th>
<th>Left YBT*</th>
<th>Right YBT*</th>
<th>Composite YBT*</th>
<th>SLJ</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left YBT*</td>
<td>0.447(^1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right YBT*</td>
<td>0.373</td>
<td>0.813(^2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composite YBT*</td>
<td>0.424(^1)</td>
<td>0.935(^2)</td>
<td>0.967(^2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLJ</td>
<td>0.254</td>
<td>0.091</td>
<td>-0.064</td>
<td>0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical</td>
<td>0.259</td>
<td>0.176</td>
<td>0.1</td>
<td>0.138</td>
<td></td>
<td>0.850(^1)</td>
</tr>
<tr>
<td>Pro Agility</td>
<td>-0.436(^1)</td>
<td>-0.206</td>
<td>-0.017</td>
<td>-0.101</td>
<td>0.817(^2)</td>
<td>-0.712(^2)</td>
</tr>
</tbody>
</table>

FMS™ stands for Functional Movement Screen; YBT = Y-Balance test; SLJ = standing long jump.

* reach represented as percentage of leg length; \(^1\) \( p < 0.05; \) \(^2\) \( p < 0.01\)

**Table 3. Correlations between tests in Females.**

<table>
<thead>
<tr>
<th></th>
<th>Composite FMSTM</th>
<th>Left YBT*</th>
<th>Right YBT*</th>
<th>Composite YBT*</th>
<th>SLJ</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left YBT*</td>
<td>0.446(^1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right YBT*</td>
<td>0.350</td>
<td>0.899(^2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composite YBT*</td>
<td>0.408(^1)</td>
<td>0.973(^2)</td>
<td>0.975(^2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLJ</td>
<td>-0.228</td>
<td>0.096</td>
<td>0.044</td>
<td>0.071</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical</td>
<td>-0.254</td>
<td>-0.140</td>
<td>-0.233</td>
<td>-0.192</td>
<td>0.647(^2)</td>
<td></td>
</tr>
<tr>
<td>Pro Agility</td>
<td>-0.084</td>
<td>-0.504(^2)</td>
<td>-0.367</td>
<td>-0.446(^1)</td>
<td>-0.693(^2)</td>
<td>-0.258</td>
</tr>
</tbody>
</table>

FMS™ stands for Functional Movement Screen; YBT = Y-Balance Test; SLJ = standing long jump.

* reach represented as percentage of leg length; \(^1\) \( p < 0.05; \) \(^2\) \( p < 0.01\)
maximum scores. Limitations in the performance of the FMSTM may be indicative of increased injury risk and reduced performance outcomes.\textsuperscript{45} Due to the FMSTM evaluating the quality of movement, higher scores require substantial neuromuscular coordination & control, while the performance measures are evaluating only the outcome of the movement.\textsuperscript{46} However, movement patterns associated with maximum outcomes in performance tests (e.g., SLJ and vertical jump) require substantially less range of motion compared to the FMSTM for maximum outcomes. For example, during the FMSTM deep squat test, a position in which “the femur is below horizontal” is required for a maximum score. In contrast, outcomes in the SLJ and vertical jump tests are not dependent on the use of a full range of motion. Instead, the SLJ and vertical jump rely on exploiting the stretch-shortening cycle, which uses rapid stretching of agonist musculature in an abbreviated squatting motion, followed by a reflexive contraction of lower limb extensors resulting in maximal muscle activation.\textsuperscript{48,49}

There was a significant association between FMSTM and the Pro Agility tests found only in males, and on average female performances in the Pro Agility test were slower than males. Differences in Pro Agility performance may be due in part to strength and power differences between the sexes or due to previous familiarization to the test.\textsuperscript{50-52} Most males participated in sports (e.g., football, soccer) that utilize the Pro Agility movements for recruiting and may have provided familiarization to the task, while most females were samples from sports that do not typically use the test (e.g., volleyball). The relationship between FMSTM and agility for males may be due to similar coordinative patterns between the tests. During change of direction and accelerating tasks, an individual’s core activation and single leg stabilization is tasked which is similar to the core activation and single leg stabilization required during the rotary stability and inline lunge of the FMSTM.\textsuperscript{53,54} Furthermore, proper core activation is required for foundational movements in sport (e.g., agility change of direction tests) and is essential in the development and transfer of force through the kinetic chain.\textsuperscript{54,55}

The results of the current study revealed no significant differences between sexes on the right, left, or composite YBT score. The current literature regarding sex performance on the YBT discloses conflicting findings. While in a different population, Chimera, Smith, and Warren found no differences between the sexes in Division I athletes for the YBT composite score.\textsuperscript{15} Another study done within Division I basketball athletes and non-athlete recreational participants, also concluded no difference between sexes in the normalized reach directions and average reach.\textsuperscript{56} In high school athletes, Gorman et al. found that males outperformed females on all three normalized reach directions and the composite score.\textsuperscript{57} A similar dynamic balance task, the Star Excursion Balance Test (SEBT), also has conflicting results in the literature. Gribble and Hertel found no sex differences on performance after normalizing reach directions.\textsuperscript{58} This study supports the findings of Gribble, Robinson, and Hertel who found that overall females outperformed males, contradicting the notion of no difference in performance between sexes.\textsuperscript{59} However, those two studies were conducted using college-aged students. Although significant differences were not found between sexes in this study, there are apparent sex differences on the YBT and SEBT performance, which demonstrates the need for further research defining sex-specific normative values for dynamic balance in youth.

In both sexes there were significant positive correlations between FMSTM composite score and YBT left scores and YBT composite scores. The relationship between the FMSTM and YBT composite scores may be due to similar components being utilized within each screening tool. Both tools test an individual's range of motion, mobility, and stability of the lower extremity. The YBT's dynamic balance is similar to three tasks in the FMSTM: the in-line lunge, rotary stability, and hurdle step. Each of these tasks involve unilateral movement or a narrow base of support. Furthermore, to perform the tasks of the FMSTM and YBT an individual needs musculoskeletal strength and core stability to maintain single leg balance.\textsuperscript{11,12} These results represent the first significant relationship between the FMSTM and YBT composite scores, indicating the two screening tools may evaluate similar underlying constructs.

The negative relationship between agility and the left and composite YBT scores in females may be due to the underlying need for coordination and control of musculature during both static and dynamic balance
tasks. Previous research suggests that balance is considered a feature of agility and that improving balance may in fact improve agility.60,61 Agility hinges on an individual's ability to coordinate and control their center of mass (CoM) and extremities to effectively accelerate and decelerate during athletic movements. Furthermore, individuals must effectively control their CoM while on one leg to promote effective acceleration and deceleration.62 The YBT examines the coordination and control of an individual's CoM on a unilateral base of support. Muscular strength and stability (i.e., control) are essential for an individual during movement (i.e., during dynamic balance and acceleration/deceleration movements). The lack of stability during unilateral movements may lead to coordinative and performance issues in sport.62 Thus, to perform well on the YBT, an individual must possess adequate balance, coordination, muscular strength, and neuromuscular control, which is similar to the requirements of agility tests.

The relationship between vertical jump and SLJ in both sexes was anticipated as both tasks are related to the underlying construct of muscular power.63 The strong relationship ($r = 0.70$ to $0.91$) between these two tests is well established in the literature.64 The relationships of agility and SLJ for both sexes as well as agility and vertical jump for males was expected as there is crossover with the underlying constructs of lower extremity power between the tasks. The relationship between agility and the SLJ has been previously expressed in first year collegiate athletes for both sexes (male: $r = -0.61$; moderate, female: $r = -0.79$; strong).37 Peterson, Alvar, & Rhea also found a significant relationship between the broad jump and sprint acceleration for both sexes (male $r = 0.48$; moderate; female $r = 0.61$; moderate).37 Furthermore, it has been reported that plyometric training to increase muscular power increases an individual's vertical jump height and decreases an individual's agility times.40 Thus, the reported negative relationship between agility and vertical jump for males follows suit with the previous relationships that are well established in the literature.37,65

**CONCLUSION**

The FMS™ and YBT are two screening tools used by sports medicine professionals to identify strength, balance, and movement patterns. As a result, imbalances in mobility and stability as well as asymmetries in compensatory movement patterns may be identified. The FMS and YBT may evaluate similar underlying constructs, such as dynamic balance and movement coordination. Results from this study identified moderate relationships between the FMS and YBT screens and tests of physical performance (e.g., SLJ, VJ, and Pro Agility Test) in both males ($p < 0.05$) and females ($p < 0.05$). Females outperformed males on both the FMS™ and YBT tests, while males outperformed females in measures of physical performance. Out of the three physical performance measures (SLJ, VJ, and Pro Agility Test), the Pro Agility Test was the only test that was significantly correlated with the composite FMS™ in males and YBT (left and composite) in females. These results demonstrate the utility of the FMS and YBT to relate multiple constructs of muscular power to an individual's ability to balance. This study's results establish the need for the utilization and application of multiple field-based tests by sports medicine professionals and strength and conditioning coaches when evaluating an athlete's movement and physical performance capabilities. Future research is warranted to determine if the strength of these relationships remain constant with larger samples of males and females across multiple sport disciplines.

**REFERENCES**

6. Kiesel K, Plisky PJ, Voight ML. Can serious injury in professional football be predicted by a preseason


ABSTRACT

Background and Purpose: Restrictions in hip rotational motion of the baseball athlete can alter throwing mechanics in a manner that is inefficient and increases risk of injury. The purpose of this study was to assess for differences in hip external rotation (ER) and internal rotation (IR) range of motion (ROM) between baseball players with an ulnar collateral ligament (UCL) tear and healthy baseball players.

Design: Case-control

Methods: Eighty-seven baseball players with a UCL tear (UCL) were compared with 87 age, experience, and position-matched healthy baseball players (CONT). UCL were enrolled at the initial visit to the outpatient sports medicine facility while CONT were measured before their baseball season. Passive hip ROM (ER and IR) of the stance and lead limbs was measured in the prone position using a bubble goniometer. Hip total range of motion (TRM) was calculated by adding ER and IR of each limb. Independent t-tests were run to compare mean group differences for hip ROM (p<0.05).

Results: No differences between groups were discovered for hip ER on the stance (UCL = 33.9°±9.9°, CONT = 34.3°±10.6°, p = 0.8) or lead (UCL = 32.9°±9.9°, CONT = 34.4°±10.0°, p = 0.3) limbs. Similarly, there were no group differences in hip IR on the stance (UCL = 30.6°±10.5°, CONT = 29.6°±9.5°, p = 0.5) or lead (UCL = 33.5°±17.5°, CONT = 29.5°±9.0°, p = 0.1) limbs. The groups were also similar in hip TRM on the stance (UCL = 64.5°±13.7°, CONT = 64.0°±17.2°, p = 0.8) and lead (UCL = 66.4°±17.4°, CONT = 63.9°±15.6°, p = 0.3) limbs.

Conclusions: When measured in the prone position, hip passive ROM is not different between baseball players with a UCL tear compared to a matched healthy cohort.

Keywords: baseball, hip ROM, ulnar collateral ligament.

Level of Evidence: Level 3
INTRODUCTION

The overhead throwing motion is a dynamic activity that requires interaction of sequential moving parts of the upper and lower extremity. Integration of the kinetic chain allows for energy to be created in the lower limbs and transferred through the core and spine to the throwing arm. The hip joint serves as a critical link between the lower and upper extremities and helps to position the lead limb at stride foot contact during the throwing motion. Rotational motion (internal rotation = IR, external rotation = ER) at the hips during throwing is critical for energy transfer and when analyzed in combination with separation of rotation of the hips and shoulders has been shown to increase ball velocity in youth and adolescent pitchers. Conversely, if hip rotational motion is restricted in either the stance (limb on same side of throwing arm) or lead (limb on opposite side of throwing arm) limb, throwing mechanics could be altered in a manner that is inefficient and increases risk of injury.

Clinical assessment of hip rotational motion has been studied in youth, college, and professional baseball players with varying results. Youth baseball players demonstrate greater hip IR and total rotational motion (TRM) in younger (7-11 years) athletes when compared to the older (12-18 years) youth. Additionally, healthy youth baseball pitchers (11.3 ± 1.0 years) have no significant differences in TRM between sides (stance and lead limbs). Decreased hip IR (hip flexed to 90°) of the stance and lead limbs was found in youth baseball players (12.0 ± 1.9 years) who had experienced elbow pain when compared to those who had no elbow pain. At the collegiate level, pitchers (20.0 ± 1.4 years) were found to have no significant hip rotational motion differences between the stance or stride limbs. College baseball pitchers (19.4 ± 1.4 y/o) who were measured before the season and then again at the conclusion of the season were found to have reductions in the lead and trail (stance) limb hip ER as well as lead and trail (stance) limb TRM. Although these results hint at the fact that adaptive changes at the hip may occur across the course of a collegiate baseball season, they were not associated with the overall pitching workload of these athletes. Finally, in professional baseball players, hip rotational motion (IR and ER) is similar at the beginning of the season; however, deficits in rotational motion at the hip (stance or lead limbs) were found to be correlated with faulty pitching biomechanics. Specifically, the loss of hip IR in the stance and lead limbs is associated with injuries to the hip, groin, abdominal, hamstring, and back injuries at the professional level. The results of the aforementioned studies suggest that alterations in hip rotational motion may occur across the developmental stages of baseball players peaking at the professional level.

The majority of the previous studies examining hip rotational motion in baseball players have been performed in a healthy population. While these studies have tried to establish a link between deficits in or loss of hip rotational motion as a causative factor for injury to the throwing arm, currently there is little evidence exploring this relationship within the literature. Additionally, those studies that have demonstrated a relationship between hip rotational motion and injury seem to point toward a loss of hip IR as the associated factor with injury at both the youth and professional level. With the dramatic increase in the number of injuries to the ulnar collateral ligament (UCL) in baseball players across the age spectrum, there is a heightened awareness of the need to identify risk factors that may predispose these individuals to injury. Likewise, the development of the breakdown of the UCL may surface at the professional level, but more than likely originates with the increased workload that begins to accumulate during the years of playing youth baseball. Therefore, the purpose of this study was to assess for differences in hip external rotation (ER) and internal rotation (IR) range of motion (ROM) between adolescent baseball players with an ulnar collateral ligament (UCL) tear and age-, position-, and experience-matched healthy baseball players.

METHODS

Participants

This was a retrospective case-control study; the Institutional Review Board of Texas Health Resources approved the research procedures. A total of 174 male competitive high school and collegiate baseball players volunteered to participate in this study from 2013 to 2015 during a 23-month timeframe. Eighty-seven baseball players with a UCL tear (UCL group;
Participants were identified during regularly scheduled visits to the participating physician and/or physical therapist. Inclusion criteria for the UCL group included the following: (1) a baseball player between the ages of 14 and 23 y/o, (2) the athlete’s ability to throw was affected by the injury, (3) the athlete was unable to continue participating in baseball at the level he did before UCL tear, (4) clinical examination results were positive for a primary UCL tear diagnosed by a fellowship-trained, board certified orthopedic surgeon, (5) there was confirmation of a UCL diagnosis via MRI, and (6) the athlete was attempting to return to sport at a competitive level. Exclusion criteria were (1) a previous UCL reconstruction that failed, (2) a previous shoulder surgery for labral or rotator cuff involvement, and (3) if the patient did not plan to return to baseball after treatment. The same exclusion criteria were applied to the control participants. Participants were enrolled and consented into the study by an investigator in the outpatient sports medicine facility once they were confirmed to meet the inclusion and exclusion criteria (Figure 1).

Measurements of Passive Range of Motion
Hip ROM testing was performed at the UCL participant’s initial visit to the outpatient sports medicine center. All control participants were measured either before their fall or spring baseball seasons using the same methods as the UCL group. Measurements were taken by two physical therapists who had undergone training and demonstrated excellent reliability for hip ER (intraclass correlation coefficient \(2, k = 0.94\); standard error of the mean = 2.6) and hip IR (intraclass correlation coefficient \(2, k = 0.98\); standard error of the mean = 3.8). Passive hip ER and IR of the stance (limb on same side of throwing arm) and lead (limb on opposite side of throwing arm) limbs were measured using a standard goniometer fitted with a bubble level attachment (Figure 2). The participant was positioned in a prone position and stabilized with a belt around the

Figure 1. Flow Diagram for Allocation of Healthy Controls vs. UCL-Injured.

Figure 2. Hip internal rotation range of motion measurement.
hips while the investigator passively moved the limb until end range was noticed by an abrupt end feel or movement was elicited at the sacroiliac joint.

**Main Outcomes Measures**

Mean passive hip ER and IR ROM of both the stance and lead limbs was calculated and compared between groups. Hip total range of motion (TRM) was calculated by adding ER and IR of each limb and for each group.

**Statistical Analysis**

A priori statistical power analysis was performed using hip IR motion as the primary outcome, and it was determined that a total of 80 participants (40 in the control group and 40 in the UCL group) would be needed to detect statistically significant differences based on an 80% power calculation. Independent t-tests were computed to compare mean group differences for hip ROM.

**RESULTS**

Table 1 highlights the descriptive demographic characteristics of the participants. There was a slight difference for age ($p = 0.007$), but no differences for height ($p = 0.079$), weight ($p = 0.643$), or years of experience ($p = 0.061$) between groups. Eighty-three percent of the participants were right hand dominant in both groups, while 68.9% were pitchers in the UCL group and 54.0% were pitchers in the healthy group.

No differences between groups were detected for hip ER on the stance (UCL = 33.9° ± 9.9°, CONT = 34.3° ± 10.6°, $p = 0.77$) or lead (UCL = 32.9° ± 9.9°, CONT = 34.4° ± 10.0°, $p = 0.31$) limbs. Similarly, there were no group differences in hip IR on the stance (UCL = 30.6° ± 10.5°, CONT = 29.6° ± 9.5°, $p = 0.53$) or lead (UCL = 33.5° ± 17.5°, CONT = 29.5° ± 9.0°, $p = 0.06$) limbs. The groups were also similar in hip TRM on the stance (UCL = 64.5° ± 13.7°, CONT = 64.0° ± 17.2°, $p = 0.83$) and lead (UCL = 66.4° ± 17.4°, CONT = 63.9° ± 15.6°, $p = 0.33$) limbs (Table 2).

**DISCUSSION**

Adolescent baseball players with a UCL tear do not demonstrate differences in hip rotational motion in either the stance or lead limbs when compared to a matched, healthy cohort. The hip joint has been shown to be the primary source of movement for trunk twisting or rotation, which is necessary to achieve optimal positioning for the trunk and pelvis during the throwing motion. Inadequate mobility in the hips of a baseball player may limit the transfer of energy to the upper extremity and consequently predispose the athlete to alterations in the throwing motion and subsequent risk of injury.

The similarities between both hip IR and ER motions between limbs and across groups in the present study suggest that the available ROM needed for this population of baseball players may not help to differentiate those with and without injury to the UCL when measured in a prone position.

The findings of the current study are similar to previous hip rotational motion data in healthy youth baseball players when measured in the prone position. When 44 healthy adolescent baseball players were measured for hip ROM, the lead (IR = 32.0° ± 8.9°, ER = 30.3° ± 6.1°, TRM = 62.1° ± 7.5°) and stance (IR = 30.6° ± 6.2°, ER = 30.0° ± 7.4°, TRM = 60.4° ± 6.8°) limbs were comparable to values in the present study. Additionally, between limb hip rotational ROM symmetry was very similar in the adolescent healthy group when compared to the current findings in the UCL group. In the same way, hip ROM has previously been studied in relation to glenohumeral ROM and overall pitch volume in youth baseball pitchers, showing hip ROM values that are similar to the ones in the current study.

**Table 1. Participant Demographics.**

<table>
<thead>
<tr>
<th></th>
<th>UCL</th>
<th>Control</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>17.7±2.0</td>
<td>18.6±1.9</td>
<td>$p = 0.01$</td>
</tr>
<tr>
<td>Years of Experience</td>
<td>13.0±3.1</td>
<td>13.7±2.0</td>
<td>$p = 0.06$</td>
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<tr>
<td>Height (cm)</td>
<td>183.4±6.8</td>
<td>185.3±6.5</td>
<td>$p = 0.08$</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>85.1±10.2</td>
<td>85.8±8.5</td>
<td>$p = 0.64$</td>
</tr>
</tbody>
</table>
presented in the current study on both the lead and stance limbs. Although some significant relationships across the variables were found, further study is required to determine the clinical relevance. While the age of these baseball players in these earlier studies was slightly younger (15.4 ± 2.1 and 13.9 ± 2.9 y/o) than those individuals in the existing investigation, equivalent measurement techniques (prone) were used. Differences in hip IR ROM have been demonstrated between preadolescent (9.9 ± 15 y) and adolescent (15.1 ± 1.3 y) baseball players with the younger athletes exhibiting significantly greater ROM on both the dominant (preadolescent = 40.81°, adolescent = 33.09°) and nondominant (preadolescent = 38.37°, adolescent = 34.35°) limbs. While the adolescent hip IR ROM values of Beckett et al. study were similar to the values in the present study, hip ER ROM was greater across both groups and on both limbs (preadolescent_dominant = 37.65°, adolescent_dominant = 38.54°; preadolescent_nondominant = 38.70°, adolescent_nondominant = 38.85°). The results of these earlier studies in combination with the current findings imply that when measured in the prone position, youth baseball players have similar hip ROM on both the stance and leads limbs and hip ROM may not necessarily be associated with upper extremity injury.

In contrast, previous work has found a relationship between deficits in hip ROM and elbow pain in adolescent baseball players. One hundred twenty-two adolescent baseball players were measured for hip ROM in a supine position with the hip flexed to 90°. Those who reported elbow pain at time of assessment or during the previous month while throwing demonstrated a decrease in hip IR in both the lead and stance limbs when compared to the no elbow pain group. The differences in findings between the Saito et al. study and the current study could be attributed to the measurement technique of IR at 90° of hip flexion and the overall younger mean age of the individuals (12.0 y/o versus 17.8 y/o). When these same participants were measured in prone, there were no differences in hip ROM between the pain and no pain groups, similar to the current findings of this paper. When measured in a seated position, youth baseball pitchers (11.3 ± 1.0 y/o) demonstrated greater hip ER on the lead limb with greater hip IR ROM on the stance limb. Similarly, stance limb hip IR ROM (seated) increases as throwing arm scapular posterior tilting decreases at maximal humeral ER in youth baseball pitchers following a simulated game pitching protocol. The results from these studies suggest that position of the hip during measurements may play a role in identifying those who may be at risk for throwing arm elbow pain and positioning of the hip in a flexion may alter the available hip ROM, thus producing different values. Additionally, the lack of hip mobility in the seated position could be attributed

| Table 2. Participant Hip ROM Means and Standard Deviations between Groups. |
|-----------------|-----------------|-----------------|-----------------|
|                 | UCL (n=87)      | Control (n=87)  | p-value         |
| Hip ER ROM      |                 |                 |                 |
| (Stance)        | 33.9±9.9°       | 34.3±10.6°      | p = 0.77        |
| (Lead)          | 32.9±9.9°       | 34.4±10.0       | p = 0.31        |
| Hip IR ROM      |                 |                 |                 |
| (Stance)        | 30.6±10.5°      | 29.6±9.5°       | p = 0.53        |
| (Lead)          | 33.5±17.5°      | 29.5±19.0°      | p = 0.06        |
| Hip TRM         |                 |                 |                 |
| (Stance)        | 64.5±13.7°      | 64.0±17.2°      | p = 0.83        |
| (Lead)          | 66.4±17.4°      | 63.9±15.6°      | p = 0.33        |

* ER = external rotation; IR = internal rotation; ROM = range of motion; UCL = ulnar collateral ligament; Stance = limb on same side of throwing arm; Lead = limb on opposite side of throwing arm

** Significance set at p<0.05
to osseous (femoroacetabular impingement) and/or soft tissue changes.7,29 Previous analyses have established a relationship between high-level sports participation (hockey, basketball, and soccer) in males and osseous changes at the femoral head-neck junction;30 however, these bony changes have not been identified in the baseball athlete and further investigation is warranted.

The current study presents with certain limitations that need to be considered. Hip ROM measurements were only captured with the participant in the prone position. As documented earlier, the position in which hip IR and ER ROM is measured may influence both values and the ability to identify potential relationships within the kinetic chain that may be associated with upper extremity injury1,6,7,10 Throwing volume at time of hip ROM measurements were not controlled for during data collection which could affect the available mobility of the hip. While enrollment into the study occurred at time of injury for the UCL group, and prior to either the fall or spring baseball season for the healthy group, throwing volume was not captured. Finally, the current study population consisted of high school and college age baseball players, thus the findings of this study may not be extrapolated to the professional or little league baseball player.

CONCLUSION

The results of the current study indicate that passive hip rotational ROM does not differ between adolescent baseball players with an elbow UCL tear and a group of healthy controls when measured in the prone position. Although hip rotational ROM is thought to be related to throwing mechanics and possibly with upper extremity injuries in baseball players, the results from the current study suggest that hip ROM is similar between UCL injured and uninjured baseball athletes in this sample. The manner in which the available hip ROM is utilized may play a role in differentiating between groups.

REFERENCES


ABSTRACT

Purpose/Background: There are a few studies investigating the reproducibility of the Upper Quarter Y Balance Test (YBT-UQ) in adults. However, no study has determined test-retest reliability and the minimal detectable change of the YBT-UQ in adolescents from different age cohorts. The aim of the present study was to establish test-retest reliability and minimal detectable change of the YBT-UQ in a sample of healthy adolescents.

Methods: In a school setting, 111 students (59 female, 52 male) aged 12-17 years performed the YBT-UQ twice, separated by one week. Normalized maximal reach distances (% arm length) for all three directions (i.e., medial, inferolateral, superolateral) and the composite score were used as outcome measures. Intraclass correlation coefficient (ICC3,1) and standard error of measurement (SEM) were calculated to assess both relative and absolute test-retest reliability. In addition, the minimal detectable change (MDC95%), an index that is defined as the minimal amount of change in performance that falls outside the measurement error or performance changes due to variability was determined.

Results: Irrespective of age cohort, reach arm, and reach direction, the measure of relative reliability ranged from "moderate-to-good" to "excellent" ICC values and the proxy of absolute reliability was rather small (i.e., SEM ≤ 7.6%). The MDC95% needed to identify relevant effects in repeated measurements of the YBT-UQ performance ranged between 4.8% and 21.1%, depending on age, reach arm, and reach direction.

Conclusions: The detected values imply that the YBT-UQ is a reliable field test that can be used to detect changes of upper quarter mobility/stability in healthy adolescents aged 12-17 years.

Level of Evidence: 2b

Key Words: adolescent, motor control, movement system, practical relevance, reproducibility, school setting, upper quarter mobility/stability
INTRODUCTION
The Upper Quarter Y Balance Test (YBT-UQ) is a field-based method used to investigate upper quarter mobility and stability. From a practical perspective, it is important to know whether the results obtained from the YBT-UQ are reliable. In other words, to be certain that differences between test and retest assessment of YBT-UQ performance can be considered “real” and outside the error range, reliable measures on an individuals’ performance are needed. Further, distinct ranges of meaningful change need to be established. This allows practitioners to derive an accurate evaluation on the magnitude of changes between repeated YBT-UQ performance assessments.

Previous studies on the test-retest reliability of the YBT-UQ have investigated healthy young adults, only. For example, Gorman et al. examined test-retest reliability (between-test period: 20 minutes) of the YBT-UQ in 22 subjects (10 men, 12 women) aged 19-47 years and found “excellent” intraclass correlation coefficients (ICC) ranging between 0.80-0.99; irrespective of reach direction. Further, Westrick et al. determined test-retest reliability (between-test period: 28 days) in 13 subjects. The obtained ICC values ranged from 0.91-0.92, which is indicative of “excellent” reproducibility. However, transferring these results obtained from adults to adolescents appears to be questionable, given that anthropometric and physiological differences due to growth and maturation exist. As a consequence, performance levels achieved during the assessment of upper quarter mobility and stability may differ between age groups. For example, Borms and Cools showed age-related differences in upper-extremity functional performance (i.e., YBT-UQ, Closed Kinetic Chain Upper Extremity Stability test, Seated Medicine Ball Throw test) in 206 adults (age range: 18-50 years). For the YBT-UQ, the 18- to 25-year-olds showed significantly better performance data compared to the 26- to 33-year-olds and the 34- to 50-year-olds, indicating an age-related reduction of upper-extremity function.

There is no study available that has determined test-retest reliability and minimal detectable change of the YBT-UQ in healthy adolescents including males and females from several age cohorts. Given the anthropometric and physiological differences between adolescents and adults, the aim of the present study was to establish test-retest reliability and minimal detectable change of the YBT-UQ in a sample of healthy adolescents aged 12-17 years.

METHODS
Participants
One-hundred twenty students in grades 6-11 (i.e., 12-17 years) were recruited from randomly chosen urban public schools. The characteristics of the students are shown in Table 1. Students were excluded from study participation if they (1) were outside of the aforementioned age range, (2) had a musculoskeletal, neurological or orthopedic disorder during the last three months prior to the beginning of the study, (3) had other medical conditions that could have affected their ability to execute the YBT-UQ or (4) performed the test or retest only. Nine students were excluded from study participation because they performed only the test / retest (n=3) or were below (n=3) / above (n=3) the age range. As a consequence, 111 (93%) of the initially recruited subjects were included in the present study. Prior to the start of the study, participants’ assent and parents’ written informed consent was obtained. The study protocol was approved by the Human Ethics Committee at the University of Duisburg-Essen, Faculty of Educational Sciences.

Procedures
All participants performed the YBT-UQ twice, separated by one week during physical education (PE) classes in the school setting. Upon entering the gym, all participants received standardized verbal instructions and a visual demonstration regarding the testing procedure that included the assessment of arm dominance and anthropometric variables followed by performance measurement in the YBT-UQ.

Assessment of anthropometric variables
Standing height was assessed with shoes off to the nearest 0.1 cm with a stadiometer (seca 217, Basel, Switzerland). Further, body mass was determined in light clothing and without shoes to the nearest 100 g with an electronic scale (seca 803, Basel, Switzerland). Body mass index was calculated using body mass divided by height squared (kg/m²). For
normalization purposes, right and left arm length (cm) was determined with a cloth tape measure in accordance to the YBT-UQ test instructions provided by Plisky.7

Assessment of Upper Quarter Y Balance Test performance

YBT-UQ performance was assessed using the commercially available Y-Balance-Test-Kit (Functional Movement Systems, Chatham, USA) that was positioned on the gym floor. The Y-Balance-Test-Kit consists of a centralized platform to which three polyvinyl chloride pipes are attached representing the medial (MD), inferolateral (IL), and superolateral (SL) reach directions. Each pipe is marked in 0.5-cm increments for measurement purposes and equipped with a moveable reach indicator. Each participant was instructed to reach with one arm as far as possible while maintaining his/her push-up position in the MD, IL, and SL directions (Figure 1 A-C). The YBT-UQ was performed with the left and right arm. Prior to its execution, standardized instructions and demonstrations were provided. Three practice trials were conducted followed by three data-collection trials. Participants started with the right thumb placed behind the starting line that is marked on the centralized platform in a weight bearing one-arm push-up position with feet shoulder width apart. Afterwards, the participant sequentially moved the reach indicator with the left hand in the three directions as indicated by YBT-UQ.

Table 1. Characteristics of the study participants (N = 111) by age cohort.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>12 yrs (n=14)</th>
<th>13 yrs (n=20)</th>
<th>14 yrs (n=24)</th>
<th>15 yrs (n=20)</th>
<th>16 yrs (n=18)</th>
<th>17 yrs (n=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (f/m)</td>
<td>6/8</td>
<td>7/13</td>
<td>13/11</td>
<td>11/9</td>
<td>13/5</td>
<td>9/6</td>
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<tr>
<td>Height (cm)</td>
<td>160.5 ±</td>
<td>167.2 ±</td>
<td>168.4 ±</td>
<td>169.7 ±</td>
<td>168.5 ±</td>
<td>167.7 ±</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>48.4 ±</td>
<td>52.1 ±</td>
<td>59.3 ±</td>
<td>62.7 ±</td>
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<td>64.8 ±</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>18.7 ± 2.6</td>
<td>18.7 ± 3.6</td>
<td>21.0 ± 3.5</td>
<td>21.7 ± 4.5</td>
<td>21.7 ± 2.9</td>
<td>23.0 ± 3.3</td>
</tr>
<tr>
<td>Left arm length (cm)</td>
<td>81.6 ± 6.3</td>
<td>81.9 ± 4.7</td>
<td>84.4 ± 4.2</td>
<td>85.8 ± 5.5</td>
<td>85.5 ± 5.1</td>
<td>86.2 ± 5.1</td>
</tr>
<tr>
<td>Right arm length (cm)</td>
<td>81.6 ± 6.9</td>
<td>81.9 ± 4.9</td>
<td>84.6 ± 4.2</td>
<td>86.0 ± 5.3</td>
<td>85.6 ± 4.9</td>
<td>86.3 ± 5.0</td>
</tr>
<tr>
<td>Arm dominance (l/r)</td>
<td>2/12</td>
<td>0/20</td>
<td>2/22</td>
<td>1/19</td>
<td>1/17</td>
<td>0/15</td>
</tr>
</tbody>
</table>

Values are mean values ± standard deviations. BMI = body mass index; f = female; m = male; l = left; r = right.

Figure 1. Participant performing the Upper Quarter Y-Balance Test medial (A), inferolateral (B), and superolateral (C) reach.
test instructions. This procedure was repeated until three valid trials in each reach direction were registered. Subsequently, participants completed three trials in the same manner with the opposite arm. In order to prevent effects of fatigue, participants rested for one minute between trials. After each reach, the obtained distance (i.e., from the center of the centralized platform to the maximal reach indicator distance) was documented to the closest 0.5 cm. Trials were discarded and repeated if the participants (1) did not maintain the one-arm push-up position at any point during the trial (i.e., touched down to the floor with the reach hand), (2) did not maintain reach hand contact with the reach indicator (i.e., shoved the reach indicator), (3) used the reach indicator for support (i.e., placed reach hand on top of the reach indicator) or (4) failed to return the reach hand to the starting position under control. Due to the amount of time needed for administering the YBT-UQ (i.e., three practice trials followed by three data-collection trials), two skilled examiners documented the reach distances in a group setting (i.e., examiner-to-student ratio of 1 to 5). The same examiners completed the test and retest for a particular group of subjects after they had trained their competence for YBT-UQ assessment in a study course. The normalized maximal reach distance per reach direction and arm was used as an outcome measure and calculated as follows: normalized maximal reach distance (% arm length [AL]) = (absolute maximal reach distance [cm]) / AL [cm] × 100. Further, the normalized composite score ([CS] i.e., sum of the three maximal reach distances per reach direction) per arm was calculated by using the following formula and additionally used as outcome measure: CS (% AL) = ((MD + IL + SL) / (AL × 3)) × 100.

Statistical analyses
Descriptive statistics (i.e., group mean values ± standard deviations [SDs]) were calculated for the maximum distance reached in each of the three directions for both arms. An independent samples t-test was used to quantify YBT-UQ performance differences between females and males and a dependent samples t-test was performed to detect performance differences between the dominant and the non-dominant arm. Relative reliability was assessed using the ICC3,1 and the 95% confidence interval (CI). In accordance to Fleiss, ICC ≥ 0.75 was considered “excellent”, 0.40 < ICC < 0.75 was considered “moderate-to-good”, and ICC < 0.40 was considered “poor”. The absolute reliability of the data was determined using the standard error of measurement (SEM). The lower the SEM value, the more reliable the measurement. In addition, Bland–Altman plots were used to define the magnitude of agreement between test-retest values. Here, the performance difference between the test and retest measurements were plotted against the mean of the respective measurements. Bland and Altman recommended that 95% of the data points should lie within the mean ± 1.96 SD (i.e., limit of agreement) of the differences for the test and retest measurements. Further, we determined the minimal detectable change (MDC). The MDC95% is an index used to define the difference needed between repeated measures on one subject for the difference in the measures to be considered real. All statistical analyses were performed using SPSS software (version 24.0, SPSS Inc., Chicago, IL, USA). The significance level was set at p < 0.05.

RESULTS
YBT-UQ performance
Group mean values and SDs for the normalized (% AL) YBT-UQ performance by age are presented in Table 2. For the left arm reach, performance data ranged between 85.4-99.9%, 72.8-92.7%, and 58.8-66.3% for the MD, IL, and SL direction, respectively. The corresponding CS ranged from 74.4-83.8%. With respect to the right arm reach, YBT-UQ performance ranged between 84.3-98.3% (MD direction), 72.3-91.0% (IL direction), and 56.7-63.0% (SL direction). The respective CS ranged from 72.7-82.8%. Except for the right arm reach in the IL direction (p = 0.035; lower in girls than in boys), no significant differences between female and male participants were detected. Further, the limb comparison revealed no statistically significant differences between the dominant and the non-dominant arm for any of the three reach directions or the CS.

Reliability
Irrespective of age cohort, reach arm, and reach direction, the ICC3,1 values ranged from “moderate-to-good” to “excellent”, i.e. from 0.67-0.90 for
12-year-olds, from 0.67-0.88 for 13-year-olds, from 0.63-0.93 for 14-year-olds, from 0.47-0.83 for 15-year-olds, from 0.81-0.90 for 16-year-olds, and from 0.86-0.97 for 17-year-olds (Table 3). In addition, the SEM values ranged from 2.9-6.1% for 12-year-olds, from 3.5-7.4% for 13-year-olds, from 1.9-5.3% for 14-year-olds, from 3.4-7.6% for 15-year-olds, from 2.7-6.0% for 16-year-olds, and from 1.8-4.3% for 17-year-olds (Table 3). Examples of Bland–Altman plots for the CS during left arm reach for each age category are shown in Figure 2 A-F. Overall, the plots illustrate that a relatively large amount of data points (87.5-100%) was within the limits of agreement (i.e., mean ± 1.96 SD lines). For the other measures, the percentages of data points, which were within the limits of agreement, were in the same range (data not shown).

**Minimal detectable change**

The MDC95% values ranged from 8.1-16.9% for 12-year-olds, from 9.7-20.4% for 13-year-olds, from 5.4-14.8% for 14-year-olds, from 9.5-21.1% for 15-year-olds, from 7.6-16.5% for 16-year-olds, and from 4.8-11.9% for 17-year-olds (Table 4).
Given that there is no study available that examined test-retest reliability of the YBT-UQ in healthy adolescents, the present results have to be compared with results originating from studies\(^1,2\) that investigated older age cohorts. For example, Gorman et al.\(^1\) investigated healthy young adults (age range: 19-47 years) and reported ICC values between 0.80 and 0.99 for the three reach directions indicating “excellent”

**DISCUSSION**

In the present study, test-retest reliability of the YBT-UQ was investigated in a relatively large-sized sample of 111 healthy female and male adolescents aged 12-17. With reference to the relevant literature,\(^1,2\) it was expected that the YBT-UQ would be a reproducible test for the assessment of upper quarter mobility and stability in this population.

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**Figure 2.** Bland-Altman plots for the composite score (CS) during left arm reach for the 12-year-olds (A), the 13-year-olds (B), the 14-year-olds (C), the 15-year-olds (D), the 16-year-olds (E), and the 17-year-olds (F). The difference between the test and retest measurements is plotted against the mean of the respective measurements. Solid lines indicate the average of the differences. Dotted lines indicate the mean ± 1.96 standard deviations (i.e., limit of agreement).
The authors reported significant performance reductions of 2 to 18%, which corresponds to the aforementioned MDC95% value range. Further, the present analyses showed no statistically significant differences in performance on the YBT-UQ between females and males (except for the right arm reach in the IL direction in favour of boys) as well as between the dominant and the non-dominant arm. This is in line with previous studies\(^1\),\(^2\),\(^13\),\(^14\) that investigated sex and/or limb differences in the YBT-UQ performance. For example, Gorman et al.\(^1\) compared normalized YBT-UQ performance between 45 women and 51 men and did not observe statistically significant sex differences. In terms of limb differences, Borms et al.\(^14\) investigated 29 healthy adults and reported no significant differences on the YBT-UQ between the dominant and the non-dominant arm.

The present findings were obtained from typically developing adolescents aged 12 to 17 years and are thus only applicable in healthy adolescents in this specific age group. Thus, these results cannot be generalized to other populations with physical/motor deficits (e.g., adolescents suffering from developmental coordination disorder) or other age groups, such as younger (i.e., children) persons. Further, the presented findings are specific to the YBT-UQ, which is a well-established field-based method of investigating upper quarter mobility and stability.\(^1\)\(^-\)\(^3\) As a reliability. Further, Westrick et al.\(^2\) studied healthy, college-aged adults and observed ICC values ranging from 0.91 to 0.92 that are indicative of "excellent" reliability. The present findings are mainly in accordance with the previous studies.\(^1\),\(^2\) This implies that the YBT-UQ is a reproducible test that can be used for the assessment of intervention-based (e.g., physical exercise) changes of upper quarter mobility and stability in adolescents from several age cohorts as well as in young adults. However, we observed solely "excellent" ICC values in the 16- and 17-year-olds while the 12- to 15-year-olds crossed over from "moderate-to-good" into "excellent" ICC values. Thus, particular care (e.g., ensuring a high level of attention and concentration by the tested subjects) is needed when performing the YBT-UQ in younger compared to older adolescents. Further, the "excellent" ICC values in the 16- and 17-year-olds corresponds with those obtained in adults\(^1\),\(^2\) which seems indicative for the adoption of an adult-like YBT-UQ control in this age group.

The MDC95% ranged between 4.8% and 21.1%. Thus, a change in YBT-UQ performance exceeding these values, seems to be a true response, and an examiner can be 95% confident that a true change has occurred beyond measurement error. In this regard, a study by Salo and Chaconas\(^12\) repeatedly performed the YBT-UQ performance before and after a fatigue protocol in healthy adults (mean age: 26 ± 3 years). The authors reported significant performance reductions of 2 to 18%, which corresponds to the aforementioned MDC95% value range.

Further, the present analyses showed no statistically significant differences in performance on the YBT-UQ between females and males (except for the right arm reach in the IL direction in favour of boys) as well as between the dominant and the non-dominant arm. This is in line with previous studies\(^1\),\(^2\),\(^13\),\(^14\) that investigated sex and/or limb differences in the YBT-UQ performance. For example, Gorman et al.\(^1\) compared normalized YBT-UQ performance between 45 women and 51 men and did not observe statistically significant sex differences. In terms of limb differences, Borms et al.\(^14\) investigated 29 healthy adults and reported no significant differences on the YBT-UQ between the dominant and the non-dominant arm.

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<table>
<thead>
<tr>
<th>Left arm reach</th>
<th>12 yrs (n=14)</th>
<th>13 yrs (n=20)</th>
<th>14 yrs (n=24)</th>
<th>15 yrs (n=20)</th>
<th>16 yrs (n=18)</th>
<th>17 yrs (n=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MD (% AL)</td>
<td>9.1</td>
<td>12.8</td>
<td>14.5</td>
<td>12.3</td>
<td>15.2</td>
<td>8.0</td>
</tr>
<tr>
<td>IL (% AL)</td>
<td>11.2</td>
<td>20.4</td>
<td>11.4</td>
<td>20.2</td>
<td>16.5</td>
<td>7.1</td>
</tr>
<tr>
<td>SL (% AL)</td>
<td>15.0</td>
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<td>13.1</td>
<td>12.3</td>
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</tr>
<tr>
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<td>10.5</td>
<td>8.9</td>
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</table>

<table>
<thead>
<tr>
<th>Right arm reach</th>
<th>12 yrs (n=14)</th>
<th>13 yrs (n=20)</th>
<th>14 yrs (n=24)</th>
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<td>12.6</td>
<td>12.7</td>
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<tr>
<td>IL (% AL)</td>
<td>16.9</td>
<td>17.1</td>
<td>9.6</td>
<td>21.1</td>
<td>11.9</td>
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<tr>
<td>SL (% AL)</td>
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<td>5.4</td>
<td>9.6</td>
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<td>6.4</td>
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</tbody>
</table>

AL = arm length; CS = composite score; IL = inferolateral; MD = medial; SL = superolateral.
consequence, further research is needed to confirm the present results for other upper quarter field tests (e.g., closed kinetic chain upper extremity stability test, seated medicine ball throw).

**CONCLUSIONS**

The results of the current study indicate “moderate-to-good” to “excellent” ICC values in 12- to 15-year-olds, “excellent” ICC scores in 16- and 17-year-olds, and rather low SEM values (i.e., ≤ 7.6%) when considering all adolescents. These findings indicate that the YBT-UQ is a feasible and reproducible test for the assessment of upper quarter mobility and stability in healthy female and male adolescents aged 12 to 17 years. The observed MDC95% values ranged from 4.8 to 21.1% (depending on age cohort, reach arm, and reach direction) and represent the minimum amount of change needed to exist between pre- and post-testing YBT-UQ scores to indicate a real change in performance. Future research is needed to establish the responsiveness of the YBT-UQ to upper body training and conditioning programs and to determine the amount of training-related performance changes, which may occur in adolescents.

**REFERENCES**


ABSTRACT

**Background:** Hyperactivity of the anterior deltoid (AD) has been shown to produce adverse effects on subacromial space width as a result of humeral head superior translation during rehabilitation exercises used with overhead athletes. Also, the importance of the ratio of upper trapezius (UT) to lower trapezius (LT) muscle activity has been examined during rehabilitation exercises particularly for those who develop scapular dyskinesis.

**Hypothesis/Purpose:** The purpose of this study was to investigate the level of LT and SA muscle activity during scapular plane elevation (scaption) in three positions while maintaining a moderate level of AD muscle activity. A secondary purpose was to identify the ratio of UT to LT muscle activity during the varied scaption exercises. The authors hypothesized that the activation of these two important muscles and the UT/LT ratio would vary with exercise position and throughout the range of scapular plane elevation.

**Methods:** Fourteen active young subjects performed scaption exercises in three different positions: standing (STAN), quadruped (QUAD), and prone (PRON) with three different weight loads: 0 kg, 1.8 kg, and 4.1 kg. Surface electromyography (EMG) was used to record muscular activity. Tested muscles included the UT, LT, SA, AD, and posterior deltoid muscles on the dominant side.

**Results:** QUAD scaption exercises with a load of 1.8 kg at 4 sec after the initial movement activated the LT muscle up to 49% of maximum voluntary isometric contraction (MVIC) while maintaining a moderate level of AD muscle activity (30% MVIC). STAN scaption exercises with the weight load of 1.8 kg at 3 sec after the initial movement activated 43% MVIC of the SA muscle while maintaining a moderate level of AD muscle activity (39% MVIC). The PRON condition generated significantly less SA muscle activity with both 1.8 and 4.1 kg weight loads than during the QUAD condition. The ratios of UT to LT muscle activity were significantly less in QUAD than those of STAN up to 4 sec after the initial movement. No significant difference was observed in the UT/LT ratio between QUAD and PRON conditions.

**Conclusion:** QUAD scaption exercise effectively activated both LT and SA muscles without over activating the AD and produced favorable ratios of UT to LT muscle activity.

**Level of Evidence:** Descriptive Cohort Study, Level 4

**Keywords:** Electromyography, lower trapezius, scapular plane elevation, serratus anterior, upper trapezius

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The authors report no conflicts of interest.
INTRODUCTION
Upward rotation of the scapula is necessary to elevate the arm, and coordinated muscular activity during scapulothoracic movement is essential to stabilize the scapula during the glenohumeral movements. Muscle activation of the lower trapezius has been particularly interesting to researchers and clinicians who deal with preventive shoulder injury exercises for overhead athletes. The importance of the balance of muscular activity has also been advocated, specifically, the ratio of the upper trapezius muscle to the lower trapezius muscle (UT/LT ratio) during scapular exercises because hyperactivity of the UT muscle impairs the quality of upward rotation of the scapula during arm elevation. Patients with subacromial pain syndrome demonstrated a significant increase in the UT/LT ratio during glenohumeral joint abduction in the scapular plane, also known as scaption, compared to their uninjured counterparts. Furthermore, in patients with subacromial pain syndrome the activity of the serratus anterior muscle decreases during scaption exercises with different weight loads compared to the healthy population. In contrast, collegiate baseball players have demonstrated decreased activity of the UT on the dominant side during both GHJ flexion and abduction exercises compared with the non-dominant side, with increased activity of the LT on the dominant side. The LT muscle attaches to the spine of the scapula and plays a critical role in the posterior tilt of the scapula during upward rotation while producing a force couple with other scapular muscles, which helps to maintain subacromial space width. Hyperactivity of the deltoid has been suggested to reduce the amount of subacromial space width as a result of superiorly directed humeral head translation during arm elevation relative to the glenoid fossa. Thus, clinicians need to be aware of deltoid activity during shoulder and scapular exercises to avoid over recruitment of the deltoid muscle, especially when working with overhead athletes. Additionally, the appropriate intensity for external rotation isometric exercise has been examined with respect to the EMG activity of the deltoid and infraspinatus by Bitter et al, who concluded that 40% of maximal voluntary isometric contraction in the infraspinatus muscle was optimal. Moreover, the scapular plane has been suggested as the position to maintain optimal bony congruity between the humeral head and glenoid fossa as well as the optimal length-tension relationship of the scapulohumeral musculature. Modulation of rotator cuff muscle activation has been observed across different weight loads at two different angular velocities during scaption exercises while measuring deltoid muscle activity. No study, however, has investigated the activity of the LT and SA muscle relative to the activity of the anterior deltoid (AD) muscle during scaption exercises. Therefore, the purpose of this study was to investigate the level of LT and SA muscle activity during scapular plane elevation (scaption) in three positions while maintaining a moderate level of AD muscle activity. A secondary purpose was to identify the ratio of UT to LT muscle activity during the varied scaption exercises. The authors hypothesized that the activation of these two important muscles and the UT/LT ratio would vary with exercise position and throughout the range of scapular plane elevation.

METHODS
Participants
Fourteen active healthy male collegiate subjects belonging to the university badminton club (age: 20.3 ± 2.2 years, height: 172 ± 6.0 cm, weight: 66 ± 6.9 kg, competitive experience: 6.3 ± 1.8 years) agreed to participate in this study. All subjects gave informed consent to the procedures as approved by the Institutional Review Board of the University (IRB protocol: F1304019) prior to the examination. All subjects indicated no history of injuries, neurologic or physiologic deficits in the upper body on a preliminary screening questionnaire. The subjects were instructed to wear their own athletic shoes during the examination which required approximately 45 minutes to complete.

Experimental procedure
The subjects elevated the dominant arm with their elbow extended in the scapular plane (scaption), from the side of the body to 180 degrees of GHJ abduction or as much abduction as possible, in three different positions: 1) standing (STAN), 2) quadruped (QUAD), and 3) prone (PRON). The subjects performed the scaption exercises with three different weight loads (dumbbells) for each of the exercise
positions: 0 kg (no weight) 1.8 kg and 4.1 kg. Those three weight loads were determined based on the results of a previous study.20 The subject performed the standing scaption exercise from the lateral side of the hip to full abduction (Figure 1a). The subject was instructed to avoid leaning the upper body backward. The subject was also instructed to maintain the arm in a position such that the thumb was pointing upward toward the ceiling up to 90°, after which they were instructed to point the thumb backward. The QUAD position was performed on a treatment table, the subjects started to move the arm with the hand at the level of the hip (Figure 1b), whereas in the PRON position the subjects lay down at the edge of treatment table and started to move the arm from the hand placed on the table (Figure 1c). Prior to scaption exercises, the subjects were instructed on how to adjust the arm to 40° (in order to be in the scapular plane) as measured by a goniometer, and learned the angle for all three testing positions. The subjects performed scaption exercises without volitional retraction or protraction of the scapula for three repetitions for each of the three weight loads in each of the three positions. The weight loads were progressively increased from 0 kg to 4.1 kg for all of the subjects. The movement speed for each of the exercises was also controlled by a metronome set at a frequency of 1 Hz or 1 beat per second (sec).

Accordingly, the subjects were asked to move the arm smoothly throughout the range of motion from the side of the body to as much abduction in the scapular plane as possible for 5 sec with a steady and constant tempo.

Data Management and Analyses
Surface electromyography (EMG) was utilized to measure three scapular muscles on the dominant side: the LT, the SA, and the UT. Surface EMG was also utilized to measure the AD and PD muscles, which enabled the identification of the level of muscle activity during the movement for these muscles. The skin surface was prepared by vigorously cleaning with an alcohol swab to minimize skin impedance before electrode placement. This study used bipolar surface silver EMG electrodes (model Delsys Bagnoli-8; Delsys Inc, Natick, MA) with a bar length of 10 mm, a width of 1 mm, and a distance of 1 cm between active recording sites. The electrodes were placed at an oblique angle from the scapular spine and just outside the medial border of the scapula for the LT muscle; below the axilla between the latissimus dorsi and pectoralis major at the level of the scapular inferior angle for the SA muscle; and at halfway between the C7 spinous process and the acromion process for the UT muscle.21 Also, the electrodes were placed 2 cm inferior to the lateral border of the clavicle and angled...
parallel to the muscle fibers for the AD muscle, and at an oblique direction parallel to the muscle fibers of the deltoid muscles at the lateral border of the scapular spine for the PD. The reference electrode was placed between the LT and PD electrodes.

Once the electrodes were secured using tape, the maximum voluntary isometric contraction (MVIC) for each of the muscles was measured by using the manual muscle-testing procedures for the normalization of EMG data. The root-mean-square (RMS) values of the EMG signals for the UT, SA, and AD were normalized to the MVIC of the corresponding muscles during scapular plane elevation at 90° of GHJ in a standing position, whereas the EMG signal for the LT was normalized to the MVIC of the corresponding muscle at 180° of GH flexion or with as much flexion as possible in a quadruped position in which the hips and knees were flexed at 90°. Also, the EMG signal for the PD was normalized to the MVIC of the corresponding muscle at 90° of GH horizontal abduction. Input signals of EMG activities were recorded using a data collection system (MP 150 Data Acquisition System; BIOPAC System Inc, Goleta, CA, USA) with a sampling rate of 1000 Hz, and all data was stored in a hard drive for off-line analyses. The EMG electrodes were preamplified (10×) and routed through the EMG mainframe, which further amplified (100×), a total gain of 1000× and band-pass filtered (20-450 Hz) signals. The RMS for the LT, SA, UT, AD, and PD were normalized to the MVIC of the corresponding muscles as described above for further analyses.

Each of the data sets consisted of 5000 samples of RMS activity as a dependent variable measured for 5 sec from initial muscle activity to the completion of each exercise (1000 Hz × 5 sec). This study analyzed the dependent variables of the LT, SA, and UT, which were simultaneously blocked at every 1000 samples of the RMS activity or every 1 sec during each of the exercises. Consequently, 5000 samples of RMS activity for each exercise were divided into five blocks of dependent variables from the initial EMG activity to the end of the exercise.

For data analyses of the normalized RMS activity of the muscle, a 3 × 3 × 5 (position × weight load × block) repeated-measures analysis of variance (ANOVA) design within subjects crossed with positions, weight loads and blocks was used to identify differences in each mean value of the normalized RMS activities of the LT and SA muscles. Also, a 3 × 3 × 5 repeated-measures ANOVA design was used to identify differences in ratios of the UT to LT muscle activities. Where appropriate, the simple main effect and Tukey’s honestly significant different post hoc test (Tukey’s HSD) were used to identify any significant difference for each normalized RMS activity. This study further used Pearson correlation coefficients to determine if there was a relationship across EMG activities. All statistical tests were performed at the 0.05 level of probability (p < .05).

RESULTS

Lower Trapezius and Serratus Anterior

A within-subject (subject 3 trial) ANOVA design was used to calculate the ICCs. The highest mean of the ICCs (2, 1) as tested by the same tester was 0.74 of an individual’s true score, which showed the consistency of the measure, for LT muscle activity with the weight load of 4.1 kg. It was also 0.75 for the QUAD position. The highest mean of the ICCs (2, 1) was 0.75 for SA muscle activity with 4.1 kg. It was also 0.71 for the STAN position. Each of the ICCs is presented in the Table 1.

Mean values and 95% confidence intervals for LT EMG activities are presented in Table 2 and Figure 2. The mean values of LT EMG activity in STAN were significantly lower at all of the range of motion blocks with the weight loads of 1.8 kg and 4.1 kg than those of both of QUAD and PRON, except for the mean value at the block of 5 sec with the weight load of 1.8 kg [the critical value of the Tukey HSD (D_{Tukey}) = 7.86%, p < .05]. No difference was observed in the mean values between QUAD and PRON, except for the mean values at the block of 2 sec with the weight load of 4.1 kg in which the mean value was significantly greater in QUAD than that of PRON (40.8% and 30.2% of MVIC, respectively).

The mean values of LT EMG activity were significantly increased at all of the blocks in QUAD while the weight loads were progressively increased for each of the positions (D_{Tukey} = 7.85, p < .05). Last, the mean values were significantly greater at the blocks of 4 sec and 5 sec than those of the blocks of 1 sec and 2 sec in all of the positions (D_{Tukey} = 11.4,
Mean values and 95% confidence intervals for SA EMG activities (% MVIC) are presented in Table 3 and Figure 3. The mean value of SA EMG activities in STAN was significantly greater at all of the blocks with the weight loads of 1.8 kg and 4.1 kg than those of both of QUAD and PRON, except of the mean values at the block of 5 sec (ΔTukey = 8.50%, p < .05). Also, a significant difference in mean values was observed between QUAD and PRON at the block of 4 sec with both weight loads of 1.8 kg and 4.1 kg (29.7% and 52.0% of MVIC for QUAD with the weight load of 1.8 kg vs. 20.4% and 37.7% of MVIC for PRON; 41.6% and 65.6% of MVIC for QUAD with the weight load of 4.1 kg vs. 30.7% and 54.6% of MVIC, respectively) (p < .05). Finally, the mean value was significantly greater in QUAD at the block of 3 sec with the weight load of 4.1 kg than that of PRON (16.2% and 9.5% respectively) (p < .05).

The mean values of SA EMG activity were significantly increased at all of the blocks in STAN while the weight loads were progressively increased (ΔTukey = 6.17, P < .05). However, the mean values were

| Table 1. Intraclass Correlation Coefficients for Reliability of Lower Trapezius and Serratus Anterior Muscle EMG Activities, across the three repetitions for all positions, loads, and across blocks. |
|----------------------------------------|-------------------|-------------------|-------------------|
| Lower Trapezius                     | STANDING 0 kg | QUADRUPEP 0 kg | PRONE 0 kg |
| BLOCK (sec)                         | STANDING 1.8 kg | QUADRUPEP 1.8 kg | PRONE 1.8 kg |
|                                      | STANDING 4.1 kg | QUADRUPEP 4.1 kg | PRONE 4.1 kg |
| 1                                    | 0.69 0.91 0.71 0.58 0.85 0.88 0.29 0.70 0.87 | 0.59 0.78 0.80 0.63 0.73 0.89 0.60 0.62 0.74 | 0.48 0.63 0.75 0.52 0.75 0.86 0.43 0.42 0.67 |
| 2                                    | 0.59 0.78 0.80 0.63 0.73 0.89 0.60 0.62 0.74 | 0.48 0.63 0.75 0.52 0.75 0.86 0.43 0.42 0.67 | 0.83 0.61 0.41 0.76 0.73 0.79 0.50 0.62 0.55 |
| 3                                    | 0.61 0.62 0.72 0.91 0.49 0.88 0.68 0.71 0.57 | 0.59 0.78 0.80 0.63 0.73 0.89 0.60 0.62 0.74 | 0.48 0.63 0.75 0.52 0.75 0.86 0.43 0.42 0.67 |

Serratus Anterior

| Table 2. Mean EMG activity of Lower Trapezius, reported as % MVIC (95% CIs). |
|----------------------------------------|-------------------|-------------------|-------------------|
| STANDING 1.8 kg                      | QUADRUPEP 1.8 kg | PRONE 1.8 kg |
| BLOCK (sec)                         | STANDING 4.1 kg | QUADRUPEP 4.1 kg | PRONE 4.1 kg |
| 1                                    | 0.73 0.51 0.49 0.33 0.82 0.83 0.19 0.70 0.67 | 0.24 0.70 0.87 0.40 0.59 0.87 0.32 0.58 0.80 | 0.84 0.84 0.82 0.43 0.38 0.92 0.28 0.56 0.53 |
| 2                                    | 0.70 0.60 0.72 0.63 0.74 0.67 0.48 0.71 0.73 | 0.92 0.90 0.77 0.85 0.87 0.58 0.45 0.89 0.91 | 0.73 0.73 0.72 0.63 0.74 0.67 0.48 0.71 0.73 |

Numbers 1-5= the time period, in seconds, from the initial activity to the completion of the performed movement.

* indicates a significant difference across the different positions at each block and each weight load [the critical value of the Tukey HSD (D_{Tukey}) = 7.86%, p < .05]. † indicates a significant difference across the different weight loads in each position at each block (D_{Tukey} = 7.85%, p < 0.05). ‡ indicates a significant difference across the different blocks at each weight load in each position (D_{Tukey} = 11.4%, p < 0.05).
not increased at all of the blocks in both of QUAD and PRON until the block of 4 sec. Finally, the mean values were significantly increased in STAN up to the blocks of 4 sec \((D_{tukey} = 9.23, p < .05)\). In contrast, the mean values were significantly greater in both of the QUAD and PRON at the blocks of both of 4 sec and 5 sec than those of the blocks from 1 sec to 3 sec.

**Ratio of Upper Trapezius to Lower Trapezius**

The UT/LT ratio decreased as the arm was elevated during the STAN position, while the UT/LT ratio increased as the arm was abducted in the scapular plane during the QUAD position. Specifically, the UT/LT ratio in STAN was significantly greater at the blocks between 1 and 3 sec than that during both QUAD and PRON \((1.95, 1.85, \text{and } 1.69 \text{ for STAN}; .49, .53, \text{and } .69 \text{ for QUAD}; .89, .76, \text{and } .86 \text{ for PRON, respectively})\) \((D_{tukey} = .33, p < .05)\). The UT/LT ratio in STAN was also significantly greater than that of QUAD at the block of 4 sec \((1.41 \text{ and } .95, \text{respectively})\) \((p < .05)\). No difference in the UT/LT ratios was observed between QUAD and PRON, regardless of blocks.

### Table 3. Mean EMG activity of Serratus Anterior reported as % MVIC (95% CI's).

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>STANDING</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg</td>
<td>10.5 (7.8, 13.1)***</td>
<td>18.3 (14.6, 22.0)***</td>
<td>23.9 (21.0, 26.7)***</td>
<td>28.6 (24.5, 32.7)***</td>
<td>32.8 (24.6, 41.0)***</td>
</tr>
<tr>
<td>1.8 kg</td>
<td>15.5 (11.7, 19.3)***</td>
<td>29.1 (23.6, 34.6)***</td>
<td>42.9 (37.0, 48.8)***</td>
<td>52.8 (45.4, 60.2)***</td>
<td>54.5 (44.7, 64.3)***</td>
</tr>
<tr>
<td>4.1 kg</td>
<td>18.9 (13.2, 24.6)***</td>
<td>41.7 (32.3, 51.1)***</td>
<td>65.7 (57.2, 74.2)***</td>
<td>80.3 (72.4, 88.2)***</td>
<td>72.0 (59.8, 84.2)***</td>
</tr>
<tr>
<td>QUADRUPEDE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg</td>
<td>3.0 (2.2, 3.7)***</td>
<td>4.0 (2.8, 5.2)***</td>
<td>9.3 (7.0, 11.7)***</td>
<td>20.2 (17.1, 23.2)***</td>
<td>34.1 (24.9, 43.4)***</td>
</tr>
<tr>
<td>1.8 kg</td>
<td>4.8 (3.4, 6.3)***</td>
<td>4.7 (3.4, 5.9)***</td>
<td>11.1 (8.9, 13.3)***</td>
<td>29.7 (24.8, 34.6)***</td>
<td>52.0 (39.5, 64.5)***</td>
</tr>
<tr>
<td>4.1 kg</td>
<td>5.9 (4.0, 7.7)***</td>
<td>5.6 (4.2, 7.1)***</td>
<td>16.2 (12.7, 19.6)***</td>
<td>41.6 (33.7, 49.4)***</td>
<td>65.6 (53.6, 77.6)***</td>
</tr>
<tr>
<td>PRONE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg</td>
<td>3.1 (1.6, 4.5)***</td>
<td>2.9 (2.2, 3.7)***</td>
<td>7.0 (4.7, 9.2)***</td>
<td>17.5 (12.3, 22.7)***</td>
<td>27.0 (20.3, 33.8)***</td>
</tr>
<tr>
<td>1.8 kg</td>
<td>4.8 (3.2, 6.5)***</td>
<td>3.7 (2.4, 4.9)***</td>
<td>6.9 (5.2, 8.7)***</td>
<td>20.4 (14.6, 26.1)***</td>
<td>37.7 (28.9, 46.4)***</td>
</tr>
<tr>
<td>4.1 kg</td>
<td>9.5 (5.3, 13.7)***</td>
<td>6.7 (4.1, 9.2)***</td>
<td>9.5 (7.0, 11.9)***</td>
<td>30.7 (22.4, 38.9)***</td>
<td>54.6 (43.5, 65.7)***</td>
</tr>
</tbody>
</table>

Numbers 1-5 = the time period, in seconds, from the initial activity to the completion of the performed movement.

* indicates a significant difference across the different positions at each block and each weight load [the critical value of the Tukey HSD \(D_{tukey} = 7.86\%, p < 0.05\)]. † indicates a significant difference across the different weight loads in each position at each block \(D_{tukey} = 7.85\%, p < 0.05\). ‡ indicates a significant difference across the different blocks at each weight load in each position \(D_{tukey} = 11.4\%, p < 0.05\).
With regard to a comparison of different blocks, the UT/LT ratios were significantly greater at both blocks of 1 sec and 2 sec than those of blocks of 4 and 5 sec for STAN (1.95, 1.85, 1.41 and 1.10, respectively) ($D_{Tukey} = .35, p < .05$). Also, the ratio for STAN was significantly greater at the block of 3 sec than that of the block of 5 sec (1.31 and 1.10, respectively). In contrast, for QUAD, the UT/LT ratios at both blocks of 1 and 2 sec were significantly less than those of both blocks of 4 and 5 sec (.49, .53, .95, and 1.30, respectively) ($p < .05$). Likewise, in PRON, the UT/LT ratios were significantly less at the blocks of 1 to 3 sec than that of the block of 5 sec (.89, .76, .86, and 1.34, respectively) ($p < .05$) (Figure 4).

**Anterior Deltoid and Posterior Deltoid**

Mean values for AD and PD EMG activities (% MVIC) are presented in Table 4. It was observed that STAN scaption exercises activated the AD muscle more than the PD muscle with each of the weight loads across different blocks while QUAD and PRON exercises activated the PD muscle more than the AD muscle. It is plausible that the high effect of PD in both QUAD and PRON exercises was due to the effect of gravity. It is interesting to note that the correlation coefficient in the amount of EMG activity between the SA and AD muscle was .82 ($p < .001$), regardless of the position, weight loads, and blocks, whereas the correlation coefficient between the SA and PD muscle was .05. It is plausible to suggest that the SA and AD muscles were activated as the manner of synergy activation in contractions.

**DISCUSSION**

**Quadruped Scaption Exercise**

Exercise intensity can be determined by the guideline generalized by DiGiovine et al. (1992) in which a range of 0% to 20% MVIC was considered low activity, 21% to 40% for moderate activity, 41% to 60% for high activity, and greater than 60% for very high activity. With this concept, this study determined the maximum amount of LT muscle activity occurred when there was a moderate level (40% MVIC or less) of AD muscle activity. Accordingly, QUAD scaption with the weight load of 1.8 kg at 4 sec after the initial movement in the scapular plane activated the LT muscle up to 49%, which was normalized to the MVIC of the corresponding muscle (MVIC), followed by PRON scaption with the same weight load, which activated up to 47% MVIC. These amounts were significantly greater than activation of LT during STAN scaption exercise (32% MVIC).

![Figure 4](image)

Figure 4. The means of the ratio of upper trapezius muscle activity to lower trapezius muscle activity are shown in three different positions: standing, quadruped, and prone. The error bars denote the standard error of the mean.

<table>
<thead>
<tr>
<th>% MVIC</th>
<th>STANDING</th>
<th>QUADRUPED</th>
<th>PRONE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ANT DELTOID</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg</td>
<td>12 19 23 28 39 3</td>
<td>5 10 23 39 2</td>
<td>4 9 20 32</td>
</tr>
<tr>
<td>1.8 kg</td>
<td>17 28 39 44 47 6</td>
<td>10 16 30 50 4</td>
<td>7 13 27 40</td>
</tr>
<tr>
<td>4.1 kg</td>
<td>18 43 65 71 63 10</td>
<td>18 28 45 58 10</td>
<td>16 24 40 55</td>
</tr>
<tr>
<td><strong>POST DELTOID</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 kg</td>
<td>3 5 8 13 20 10</td>
<td>15 19 22 22 11</td>
<td>16 21 25 25</td>
</tr>
<tr>
<td>1.8 kg</td>
<td>4 9 16 22 26 26 37 41 42 35</td>
<td>30 41 49 48 37</td>
<td></td>
</tr>
<tr>
<td>4.1 kg</td>
<td>6 17 30 36 36 47 61 64 55 43</td>
<td>58 68 71 65 53</td>
<td></td>
</tr>
</tbody>
</table>

Numbers 1-5 = the time period, in seconds, from the initial activity to the completion of the performed movement.
The arm elevated at 120° of GHJ abduction has been suggested to be aligned with the muscle fiber orientation of the lower trapezius. Oyama et al 7 examined six scapular-retraction exercises with a variety of shoulder angles in the prone position, including 120° GHJ abduction. These authors demonstrated that prone 120° GHJ abduction exercise activated the LT muscle up to 68% MVIC without weight loads while the participants were instructed to “squeezed the shoulder blades together.” The prone 120° GHJ abduction exercise with scapular retraction, however, increased UT muscle activity up to 72% MVIC. This current study instead revealed that the activity of UT muscle was 41% for QUAD and 40% for PRON, which was defined as a moderate level of muscle activity. Thus, QUAD and PRON scaption exercises could effectively minimize UT muscle activity, compared with Oyama’s results. In addition, unlike middle deltoid activity, the hyperactivity of the PD muscle has not been evident in the adverse effect on the subacromial space width as a result of humeral head translation.16,17,19

**Standing Scaption Exercise**

STAN scaption exercise with the weight load of 1.8 kg at 3 sec after the initial movement in the scapular plane still produced moderate levels of AD muscle activity (39% MVIC) while generating 22% MVIC of the LT muscle and 43% MVIC of the SA muscle. Alpert et al 19 examined standing scaption exercises with two different angular velocities and five different weight loads: 0%, 25%, 50%, 75%, and 90% of normalized maximum weight (NMW), whose averages ranged between 2.3 and 8.4 kg. These authors found that the nearly 100% or even more than 100% MVIC of AD EMG activity was observed between 60° and 90° of GHJ in the scaption exercise with 25% and 50% NMW at the angular velocity of 100°/sec or 1.75 rad. This angular velocity was three time faster than the angular velocity used in the current study that required the subjects to bring the arms to the maximum elevation over 5 sec, which is equivalent to 36°/sec (180°/5 sec) or .63 rad. Thus, the amount of AD EMG activity seems to vary with angular velocity or movement speed. Clinically, it is suggested that scaption exercises be performed more slowly in order to minimize AD EMG activity. Tsuruike et al 21 found that the mean value of AD muscle activity was 47% MVIC during GHJ flexion exercise with the weight load of 1.8 kg and 43% MVIC in GHJ abduction exercise at 3 sec after the initial movement. Consequently, it appears that scaption exercise in the standing position relatively minimizes AD muscle activity compared with GHJ flexion and abduction. Recently, exercise at 30° of GHJ abduction, flexion, and 90° of elbow flexion with the thumb up, called the “champagne toast position,” has been demonstrated to minimize deltoid muscle activity (38% of maximal manual testing: MMT), compared with the traditional “full can” test position at 90° of GHJ abduction (60% MMT). Consequently, the “champagne toast” needs to be compared with the results of the current study.

**UT/LT Ratio**

The ratio of UT to LT is important to consider during shoulder rehabilitation exercise. Particularly, the activity of the LT muscle should be emphasized in the early stage of rehabilitation to improve scapular kinesis while minimizing UT muscle activity.9,14 This study identified significantly high UT/LT ratios in STAN scaption exercise up to the block of 4 sec compared with those of QUAD exercise. STAN scaption with a weight load of 1.8 kg could be performed up to 90° of GHJ elevation while the exercise maintained a moderate level of AD muscle activity. Additionally, the results of the current study indicate that QUAD scaption exercise with a weight load of 4.1 kg can be performed up to 4 sec after the initial movement to enhance SA muscle activity (42% MVIC) at slightly more than the moderate levels of AD muscle activity (45% MVIC).

The LT and SA muscles have been identified as fatigue-resistant muscle fibers, compared with the rotator cuff muscles. With this, the number of repetitions in exercise can be more important than the amount of weight loads, which readily activate AD and UT muscle. Scapular exercises which activate the LT and SA muscles have been demonstrated in a number of previous studies for sport-related specific rehabilitation. However, the AD muscle, whose hyperactivity possibly superiorly translates the humeral head, leading to a decrease in subacromial space width. Also, the exercises with high ratios of UT/LT may deteriorate the scapulohumeral
rhythm, which may be associated with individuals with scapular dyskinesis. Those two concerns must be addressed in rehabilitation programs especially for overhead athletes. Further studies are warranted to investigate LT and SA muscle activity in the application of rotator cuff and scapular exercise, such as horizontal abduction with the elbow flexed in the quadruped position against gravity.

**Limitations**

This study included a sample delimited to active male collegiate participants in the badminton club with habitual adaptations and a sports specific arm dominance. Thus, the participant cohort may limit the generalization of these findings to injured populations. Also, the methods used in the study did not allow identification of the range of motion while using the metronome that consistently controlled the pace of the arm movement. Thus, exactly where peak activity occurred in the range of motion was not able to be described. This study identified LT and SA muscle activities during scaption exercises while the AD maintained muscle moderate activity. However, the authors are unable to identify if there would be any compensation or changes that could occur with greater levels of the AD muscle. Finally, this study did not measure rotator cuff muscle activation, which may be a further limitation and be a suggestion for inclusion in future studies.

**CONCLUSION**

The results of the current study indicate that both LT and SA muscle activation was dependent upon the relative movement of the arm into elevation during the varied scaption exercises. Up to 63% MVIC of LT muscle activity was observed in QUAD scaption exercise, whereas up to 80% MVIC of SA muscle activity was associated with STAN scaption exercise. However, based on UT/LT ratios QUAD scaption exercise could be recommended with weight load up to 4.1 kg to improve both LT and SA muscle activation in young active overhead athletes with asymptomatic shoulders.

**REFERENCES**


ABSTRACT

Background: Achilles tendinopathy is a common overuse injury sustained by athletes (including runners) that often becomes chronic. There is evidence that chronic musculoskeletal pain conditions exhibit signs of nervous system sensitization.

Hypothesis/Purpose: The objective of this study was to compare pain sensitivity (pressure pain threshold [PPT], heat pain threshold [HPT], and heat temporal summation [HTS]) between active healthy adults with and without chronic Achilles tendinopathy in order to determine if signs of peripheral and/or central sensitization exist in chronic Achilles tendinopathy.

Study Design: Cohort study

Methods: Seventeen participants with chronic (≥ 3 months) Achilles tendinopathy (39.0 years ± 10.81) and 24 healthy controls (31.83 years ± 8.92) were included. All participants completed the Pain Catastrophizing Scale (PCS). Participants in the Achilles group also completed the Lower Extremity Functional Scale (LEFS) and the Victorian Institute of Sport Assessment-Achilles (VISA-A). Pain processing was quantified using PPT, HPT and HTS tests.

Results: There were no significant differences in PCS scores between groups. In the Achilles tendinopathy group, the mean VISA-A score was 58.5 ± 18.4; the mean LEFS was 63.7 ± 8.0. Primary hyperalgesia (decreased pain threshold at injury site) was detected in the Achilles tendinopathy group, as evidenced by lower PPT (p<0.0001) and lower HPT (p=0.028). Mechanical secondary hyperalgesia, a sign of central sensitization, was found in the Achilles tendinopathy group at the tibialis anterior (p=0.042) and non-involved Achilles (p=0.025), but not at the thenar eminence (p=0.276). The degree of HTS was not different between groups (p = 0.981).

Conclusion: Active participants with chronic Achilles tendinopathy showed signs of both peripheral and central sensitization; however, widespread hyperalgesia into the upper extremities and elevated temporal summation were not observed. Evidence of differences in pain sensitivity lend support to the theory for a multifactorial model of tendinopathy, which consists of an impaired motor system, local tendon pathology, and changes in the pain/nociceptive system. Physical therapy management of chronic Achilles tendinopathy may need to address potential changes in the nervous system. Interventions used to treat chronic tendinopathies should be investigated for their potential to resolve peripheral and central sensitization.

Level of Evidence: Therapy, level 2b

Keywords: Achilles, movement system, pain, tendinopathy
INTRODUCTION

Achilles tendinopathy (AT) is a common overuse injury sustained by athletes that often becomes chronic.1, 2 In recreational runners, the lifetime incidence has been reported to be approximately 52%, 3 and intermittent symptoms can reoccur over time.4 Recurrence rates have been reported to be as high as 27% based on a prospective study of elite athletes.5 Insertional AT occurs less frequently, representing approximately 23% of cases as compared to 66% for non-insertional tendinopathy in a retrospective study of athletes with Achilles tendon pain.6 AT is typically characterized by localized pain in the midportion (2-6cm proximal to the insertion) or at the insertion of the Achilles tendon at the calcaneus.7 Symptoms are generally provoked with activities that load the Achilles tendon such as running, jumping, uphill walking, or stair climbing.8,9

Symptoms associated with AT are sometimes recalcitrant to conservative management,10 and persistent tendon pain does not always correlate with pathological changes in the tissue via diagnostic imaging.11, 12 Sensitization of the nervous system has been proposed as a mechanism to explain continued and persistent tendon pain and can occur in the peripheral and central nervous system.12-15 Signs of peripheral sensitization from quantitative sensory testing (QST) include primary hyperalgesia, defined as the lowering of pain thresholds within the location that is injured/affected by a condition. Signs of central sensitization from QST in humans can be inferred from the presence of secondary hyperalgesia, or the presence of increased temporal summation of pain. Secondary hyperalgesia is defined as the lowering of pain thresholds outside the location that is injured/affected by a condition.15 Whereas, the increased temporal summation of pain is defined as an elevated/exaggerated increase in the pain response over a series of repeated supra-threshold pain stimuli.16, 17 There is evidence that people with chronic musculoskeletal pain conditions, such as knee osteoarthritis, low back pain, and subacromial pain syndrome show signs of central sensitization.18-20 Furthermore, deficits in both the sensory and motor systems are observed to occur bilaterally in unilateral tendinopathy suggesting central nervous system involvement.21, 22 A recent systematic review found evidence for central sensitization in tendinopathy, but the majority of studies were focused on the upper extremity.15

Recent reports offer conflicting evidence for the presence of changes to the nociceptive system in individuals with chronic Achilles tendon pain.23, 24 Tompra and colleagues,23 found that people with chronic AT had primary hyperalgesia and deficient conditioned pain modulation (central/descending inhibition) compared to active controls (runners), whereas Plinsinga and colleagues,24 found no evidence for primary hyperalgesia, secondary hyperalgesia, or mechanical pain (pin prick) temporal summation. Tompra et al,23 reported on pain processing in a population of runners, with a mean weekly running distance of 27.5km, whereas Plinsinga et al,24 reported on minutes of activity per week but did not limit to runners.

The objective of this study was to compare pain sensitivity (pressure pain threshold [PPT], heat pain threshold [HPT], and heat temporal summation [HTS]) between active healthy adults with and without chronic Achilles tendinopathy in order to determine if signs of peripheral and/or central sensitization exist in chronic Achilles tendinopathy. It was hypothesized that signs of both peripheral and central sensitization would be found in participants with chronic AT when compared to active controls.

METHODS

Participants with and without chronic AT were recruited through flyers posted in two local running shoe stores, along a popular running trail, and from the local University community. Recruitment of people with AT occurred from September 2012 to October 2013, and controls were recruited from September 2012 to September 2016. The study protocol was approved by the Institutional Review Board of Arcadia University. The protocol was reviewed with each participant and informed consent was obtained prior to data collection. Sample size for this study was based on our access to a sample of convenience and an ability to detect a moderate effect size of 0.7, $1-\beta = 0.80$, which yielded an estimated sample of 21 participants per group (G*Power 3.31). The effect size was estimated from Achilles pressure pain
threshold data on 40 healthy participants and estimating a 3 kg difference in force.

Inclusion criteria for the AT group consisted of active participation in regular physical activity (i.e. running, sports that involved running/jumping) of at least three days per week, self-report of pain at the insertion or mid-portion of the Achilles tendon for at least three months duration, pain with palpation to the involved Achilles tendon and/or its insertion, pain with Achilles tendon loading activities (i.e. heel raise or hopping), and Achilles pain with active single-leg heel raises (plantarflexion against bodyweight). Participants with unilateral or bilateral symptoms were included. Participants were excluded if they noted a history of a complete or partial tear of the Achilles tendon, a history of surgical intervention to the Achilles tendon, reported the presence of any chronic inflammatory condition, or having a chronic pain condition aside from their Achilles tendon(s). Participants were screened for any issues related to the lumbar spine or lower extremity, including neurodynamic testing, and were excluded if the symptoms in the Achilles region were reproduced with the screening tests.

Inclusion criteria for the healthy control group consisted of no musculoskeletal pain conditions currently or within the past year (based on self-report). Additional inclusion criteria for the control group was self-report of active participation in regular running (at least 5 miles per week), and no pain with a minimum of fifteen single-leg active heel raises (plantarflexion against bodyweight).

Additional exclusion criteria for either group were current use of prescription pain medications, current use of selective-serotonin or norepinephrine reuptake inhibitors, diagnosis of any neurological condition, other orthopaedic injury to the spine or lower extremities within the previous year, loss of sensation to the lower legs, a history of fainting spells, or a loss of protective sensation on the plantar surface of their feet (inability to detect <10g from a monofilament) associated with or without the presence of diabetes. Participants were asked to refrain from taking over the counter NSAIDS on testing days.

Prior to testing, participants in both groups completed a running history questionnaire and the Pain Catastrophizing Scale (PCS). In addition, participants in the AT group completed the Victorian Institute of Sport Assessment Achilles (VISA-A) and the Lower Extremity Functional Scale (LEFS). The PCS is a 13-item questionnaire, which is a valid and reliable self-report measure designed to quantify an individual’s negative behaviors and thoughts in response to actual or potential pain. It is designed to capture the degree of three pain-related behaviors: rumination, magnification, and helplessness. A score of 30 or more on the PCS has been shown to represent a clinically relevant level of catastrophizing.

The VISA-A is a valid and reliable self-report outcome designed to assess the severity of AT through an eight-item questionnaire, which covers stiffness, pain, and function. The final score is expressed as a percentage, with 100% indicating full function. No established cut-off scores for severity of AT on the VISA-A have been reported in the literature. The LEFS is a valid and reliable patient self-report outcome measure for lower extremity conditions which consists of 20 questions, with a maximum score of 80 points. These two scales were included to capture the degree of functional deficits in the AT participants from a pathology-specific and region-specific perspective.

Quantitative sensory testing consisted of the following in a standardized order: Pressure Pain Threshold (PPT), Heat Pain Threshold (HPT) and Heat Temporal Summation (HTS). The PPT test sites occurred bilaterally over the Achilles tendon (dermatome S1), tibialis anterior muscle belly (dermatome L4), and over the thenar eminence (dermatome C6). Peripheral sensitization was assessed through the comparison of the PPT of the involved Achilles in the tendinopathy group to the Achilles in the control group, and between the PPT of the involved and non-involved Achilles in the tendinopathy group. We assessed for signs of central sensitization by using comparisons of PPTs at the following sites: 1) non-involved Achilles of the tendinopathy group to Achilles of the control group, 2) the tibialis anterior of the tendinopathy group to tibialis anterior of the control group, and 3) thenar eminence of the tendinopathy group to thenar eminence of the control group. Testing of heat stimuli was performed to look for evidence of peripheral sensitization (e.g. lower...
HPT over involved Achilles compared to control group) and as a sign of central sensitization (HTS). HTS is a test of central facilitation of pain; and if found to be greater in the AT group, would be an additional sign of central sensitization.\textsuperscript{16,17}

For the PPT, a handheld digital pressure algometer with a 1cm\textsuperscript{2} diameter tip (Model FDIX25, Wagner Instruments, Greenwich, CT) was applied with a standardized rate of force application to the Achilles tendons and tibialis anterior muscle at 1 kg/s, and to the thenar eminence at 0.5 kg/s. The tibialis anterior site was determined from a measurement from the midpoint of a measurement from the fibular head to the medial malleolus, and the PPT was tested with the subject in supine. The thenar eminence site was found as the midpoint between the first metacarpal phalangeal joint and the scaphoid tubercle, and the PPT was tested with the subject in supine. Participants were instructed using standardized scripts and asked to identify the first instance of pain (transition from pressure to pain), at which point the algometer was withdrawn and the peak force was recorded. A minimum of a 1-minute rest between trials for PPT testing of the non-Achilles sites was provided to allow for adequate washout, with testing performed in a standardized order of right thenar, left tibialis anterior, left thenar, then right tibialis anterior. Randomizing the order of test sites could have resulted in the same site being tested sequentially, so a standardized order was utilized to allow for sufficient washout time between successive testing to prevent local sensitization from the test stimuli at each specific site. This test was repeated for a total of two trials at each site. Next, the Achilles tendon was tested at the maximum point of tenderness, which was identified via manual palpation. The most tender point in the tendinopathy group ranged from the insertion to 5cm proximal to the insertion point at the calcaneal tubercle (mean 2.17±1.72cm). In the control group, PPT was measured 2cm proximal to the insertion of the Achilles tendon. The participants were positioned in prone with the ankle stabilized in neutral plantarflexion/dorsiflexion with an inelastic strap. Achilles tendon PPT was performed to the involved side (tendinopathy group) or dominant side (control group) followed by the non-involved or non-dominant side, then repeated for a total of two trials on each limb, with a minimum of a one-minute rest time between sites. The mean peak force from the two trials at each site was used for data analysis. In a prior study, test-retest for Achilles tendon PPT was high (ICC = 0.91, SEM = 1.24 kg/cm\textsuperscript{2}).\textsuperscript{31}

For the HPT, a computer-controlled thermode with a 3-cm\textsuperscript{2} contact area (TSA-II Neurosensory Analyzer, Medoc, Ramat Yishai, Israel) was secured to the involved Achilles tendon of the tendinopathy group or dominant side of the control group with the subject in prone and ankle stabilized in neutral dorsiflexion with a mobilization belt secured around a treatment plinth. The dominant leg was determined by asking the participant which leg they would typically use to kick a ball. The temperature of the thermode was set to increase at 0.5 °C/s from a baseline of 35 °C. Participants were provided with a response indicator. The test was stopped when they perceived a change in sensation from warmth to pain, or when the temperature reached a maximum of 51 °C. The HPT was repeated after one minute rest time, and the mean temperature between trials was used for data analysis. A prior study showed moderate test-retest reliability (ICC = 0.78, SEM = 1.05 °C).\textsuperscript{31}

Prior to the formal HTS test, a modified training sequence of this test was performed to the forearm of the subject to familiarize them to the protocol followed by several minutes of rest. For the HTS, the subject remained in the same testing position as the HPT. The neurosensory analyzer and thermode was utilized to apply 10 consecutive heat pulses at a rate of one pulse every three seconds to the Achilles tendon (in the tendinopathy group, at the site of PPT test; in the control group on the dominant leg at the Achilles tendon site used for the PPT test). The thermode temperature oscillated or pulsed between 42 °C and 52 °C at a rate of 10 °C/s. Participants rated their perception of the pain intensity for each heat pulse via a standardized rating visual analog scale (100mm) when verbally prompted by the investigator. The visual scale was provided with written descriptor anchors attached to a 100mm scale (0mm = no pain, 20mm = pain threshold, 100mm = worst pain imaginable), and was adapted from Staud and colleagues.\textsuperscript{16} For the HTS test, the first rating (measured in mm) was subtracted from the maximum rating of the series to quantify the amount of heat
pain summation. Using this methodology for HTS, a prior study obtained a high reliability (ICC = 0.89; SEM = 6.39mm).31

STATISTICAL METHODS
Data were analyzed with SPPS (IBM Corp. Released 2013. IBM SPSS Statistics for Mac, Version 24.0. Armonk, NY: IBM Corp). Normality, homogeneity, and outliers of the data were examined. Descriptive statistics were calculated for VISA-A and LEFS scores in the AT group. Between group means (± standard deviations) for age and PCS were assessed with independent t-tests. Because bilateral PPT data were collected (Achilles tendon, tibialis anterior, and thenar eminence), side-to-side comparisons of PPT data for both tendinopathy and control groups were performed with independent t-tests. When no side-to-side differences were found, right and left data were pooled together for subsequent between-group analyses. This occurred for the control group Achilles PPT, the tendinopathy and control group tibialis anterior PPT, and the tendinopathy and control group thenar eminence PPT. Between group (tendinopathy vs. control) comparisons were made using an analysis of covariance (ANCOVA) with sex and age as the covariates for PPT, HPT, and HTS testing. Both age and sex differences have previously been documented for various QST measures, so ANCOVA was used for between group comparisons.32 All bilateral cases were excluded from analyses that used the non-involved Achilles PPT as part of the comparison. Homogeneity was checked and effect sizes were calculated. For all statistical calculations, p values < 0.05 were considered significant. Effect sizes from the ANCOVA's were calculated using the partial eta-squared (η²) method in SPSS; guidelines for interpretation of the magnitude of this effect size calculation are: small ≥ 0.01, medium ≥ 0.05, and large ≥ 0.14.33

RESULTS
Forty-one participants met inclusion criteria and agreed to participate in the study. All of the healthy individuals who were screened met inclusion criteria to participate. One subject was excluded from the AT group, because of a history of chronic lower back issues. There were 17 participants (8 male, 9 female) in the AT group and 24 participants (11 male, 13 female) in the control group. Three people in the tendinopathy group presented with bilateral symptoms. The mean age of the tendinopathy group was different (t(39) = 2.32, p = 0.026) from the mean age of the control group (Table 1); therefore, all between group comparisons included age as a covariate. The duration of symptoms of those in the AT group ranged from three months to eight years, with a mean of 19.76 (± 30.28) months. Participants in both groups had reported continuous participation in aerobic lower-extremity loading activities for a minimum of three days per week for at least the past 8 weeks. There was no significant difference in PCS

| Table 1. Group characteristics and self-reported outcome measures of participants included in the study |
|--------------------------------------------------------|------------------------|
| Achilles Tendinopathy Group                           | Control Group          |
| Number of Participants                                | 17 (8m, 9f)            |
| Subject Age                                           | 39.00 ± 10.81 (range 24-55) |
| PCS                                                   | 10.00 ± 8.94 (range 0-28) |
| Numeric Pain Rating With Performing 10 Repetitions of Single Leg Heel Raises | 6.88 ± 2.85 (range 2-10) |
| VISA-A                                                | 58.47 ± 18.36 (range 19-89) |
| LEFS                                                  | 63.64 ± 8.02 (range 50-78) |
| f= female; LEFS= lower extremity functional scale; m= male; PCS= pain catastrophizing scale; VISA-A= Victorian Institute of Sport Assessment Achilles. |
found between groups; both groups had scores indicative of non-clinically relevant levels of catastrophizing (tendinopathy group mean = 10.0 ± 8.94; control group mean = 7.83 ± 4.65; t(39) = 1.02, p = .318). Participants in the tendinopathy group had a mean score of 58.5 ± 18.4 out of 100 on the VISA-A, and a mean score of 63.6 ± 8.0 out of 80 on the LEFS.

Tables 2 and 3 present the differences between sides for PPT values at the Achilles tendon, tibialis anterior, and thenar eminence for the tendinopathy group and control group, respectively. Table 4 presents the between group differences for PPT, HPT, and HTS values using the combined right and left means from the control group participants values for statistical comparison. After examining the data plots for normality, two outlier cases in the control and one outlier case in the AT group were excluded from analysis for PPT of the Achilles tendon (Table 4).

### Table 2. Comparison of PPT values between sides for the Achilles tendinopathy group (n=14), excluding bilateral cases (n=3).

<table>
<thead>
<tr>
<th></th>
<th>Achilles Tendinopathy Group INVOLVED Side†</th>
<th>Achilles Tendinopathy Group NON-INVOLVED Side†</th>
<th>Mean Difference Between Sides†</th>
<th>Within group comparison (t-test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achilles Mean PPT (kg/cm²)</td>
<td>6.47 ± 3.06 (4.87, 8.07)</td>
<td>10.45 ± 3.81 (8.45, 12.45)</td>
<td>3.98 ± 1.31 (1.30, 6.66)</td>
<td>t(26) = -3.040, p = 0.005</td>
</tr>
<tr>
<td>Anterior Tibialis Mean PPT (kg/cm²)</td>
<td>7.93 ± 4.64 (5.50, 10.36)</td>
<td>7.68 ± 2.79 (6.22, 9.14)</td>
<td>-0.25 ± 1.45 (-3.22, 2.72)</td>
<td>t(26) = .168, p = .868</td>
</tr>
<tr>
<td>Thenar Eminence Mean PPT (kg/cm²)</td>
<td>5.20 ± 2.17 (4.06, 6.34)</td>
<td>5.67 ± 2.11 (4.56, 6.78)</td>
<td>0.47 ± 0.81 (-1.19, 2.13)</td>
<td>t(26) = -.590, p=.560</td>
</tr>
</tbody>
</table>

CI= confidence interval; kg/cm² = kilograms per centimeter squared; PPT= pressure pain threshold
† Values in parentheses represent the 95% confidence interval

### Table 3. Comparison of PPT values between sides for the Healthy Control group (n=24).

<table>
<thead>
<tr>
<th></th>
<th>Healthy Control Group DOMINANT Side†</th>
<th>Healthy Control Group NONDOMINANT Side†</th>
<th>Mean Difference Between Side†</th>
<th>Within group comparison (t-test) †</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achilles Mean PPT (kg/cm²)</td>
<td>12.80 ± 5.31 (10.68, 14.92)</td>
<td>12.60 ± 5.57 (10.37, 14.83)</td>
<td>-0.20 ± 1.57 (-3.36, 2.96)</td>
<td>t(46) = .122, p = .903</td>
</tr>
<tr>
<td>Anterior Tibialis Mean PPT (kg/cm²)</td>
<td>9.92 ± 5.06 (7.90, 11.94)</td>
<td>9.21 ± 4.81 (7.29, 11.13)</td>
<td>0.00 ± 1.39 (-2.80, 2.80)</td>
<td>t(46) = .494, p = .624</td>
</tr>
<tr>
<td>Thenar Eminence Mean PPT (kg/cm²)</td>
<td>5.83 ± 2.38 (4.88, 6.78)</td>
<td>5.45 ± 2.65 (4.39, 6.51)</td>
<td>0.00 ± 0.77 (-1.54, 1.54)</td>
<td>t(46) = .532, p = .597</td>
</tr>
</tbody>
</table>

CI= confidence interval; kg/cm² = kilograms per centimeters squared; PPT= pressure pain threshold
† Values in parentheses represent the 95% confidence interval
Peripheral Sensitization
There was a difference in PPT values between sides of the Achilles tendons in the tendinopathy group, excluding the three bilateral AT participants (involved 6.47 ± 3.09 kg/cm²; non-involved 10.45 ± 3.81 kg/cm²; t(26) = -3.04, p = 0.005; Table 2). In the between-group analysis, the AT group had a lower PPT at the involved Achilles tendon compared to the control group (F(1,37) = 21.83, p < 0.0001, partial η² = .371) (Table 4). A lower value on PPT testing indicates an increase in sensitivity of the tested structure.

There was a difference found for HPT between the AT group (44.69 ± 1.99 °C) and control group (46.45 ± 2.68 °C) conditions (F(1,37) = 5.20, p = 0.028,
for all 10 heat pulses of the temporal summation test.

**DISCUSSION**

Participants with chronic AT showed signs of both peripheral and central sensitization. The presence of secondary hyperalgesia, indicated by reduced PPT at sites not related to the injury in the AT group (the non-involved Achilles and bilaterally at the tibialis anterior), is a sign that central sensitization may have occurred. These signs of central sensitization, however, appear to be modest and not widespread into an upper extremity dermatome. PPTs have been previously studied as a means to detect changes in mechanical sensitivity of a variety of musculoskeletal conditions including tendinopathy. A systematic review by Plinsinga et al. concluded that an association exists between chronic tendon pain and nervous system sensitization; however the majority of the studies were in upper extremity tendinopathies. The findings of the current study also lend support to the theory for a multifactorial model of tendinopathy, which consists of an impaired motor system, local tendon pathology, and changes in the pain system.

The finding of no difference between AT and controls for PPT of the upper extremity remote site is...
consistent with prior literature available for AT (thenar eminence,\textsuperscript{23} and lateral epicondyle\textsuperscript{24}). However, secondary hyperalgesia was observed within the lower extremities (tibialis anterior and non-involved Achilles). The increased sensitivity recorded at the tibialis anterior in this study may be due to the tibialis anterior (dermatome L4) being in closer proximity to the spinal segments where peripheral nociceptive information is entering the dorsal horn and possibly sensitizing local neurons and microglia (Achilles dermatome S1). Evidence from an animal model of overuse indicate that spinal pronociceptive agents (substance-P, interleukin-1 beta) are found in elevated levels within the superficial lamina of the spinal cord dorsal horns of the spinal segments related to the limbs performing the repetitive tasks.\textsuperscript{41-43} The changes in spinal pro-nociceptive agents have also been related to peripheral musculoskeletal tissue levels of inflammation and behavioral performance.\textsuperscript{41-43} Elliott and colleagues,\textsuperscript{43} showed that the significant elevation in spinal cord pronociceptive cytokines also occurred in the dorsal horns associated with the non-reaching forelimb. This “mirror” response also has been described in other animal models of unilateral inflammation and neuropathic pain.\textsuperscript{44,45} It has been hypothesized that the local release of the pronociceptive cytokines and neuromodulators that occurs within the involved spinal dorsal horns can spread to neighboring spinal segments,\textsuperscript{13,44} which would support our current findings of increased PPT at the uninvolved Achilles and bilaterally at the tibialis anterior.

The findings of this study are contradictory to those of Plinsinga et al,\textsuperscript{24} who found no significant group differences in PPT locally (at the involved Achilles) between participants with and without AT. Both the current study and that of Tompra and colleagues,\textsuperscript{23} found lower involved Achilles PPT compared to a control group. Although Plinsinga and colleagues,\textsuperscript{24} did not find lower PPT at the involved Achilles tendon, pain with palpation of the involved Achilles tendon (compared to non-involved) is one of the diagnostic hallmarks of AT.\textsuperscript{25} In the study by Plinsinga et al,\textsuperscript{24}, a standardized location for PPT on the Achilles was utilized, whereas the current study and Tompra et al,\textsuperscript{23} performed the PPT at the most symptomatic location on the tendon, which was identified during initial screening. In addition, the ankle position was fixed at neutral plantarflexion/dorsiflexion for testing in the current study and in that of Tompra et al,\textsuperscript{23} but Plinsinga et al,\textsuperscript{24} did not describe controlling the ankle position during testing. If ankle position was not controlled, this may have affected their ability to detect differences in PPT because the force from the PPT would be partially dissipated and transferred into muscle-tendon unit deformation and talocrural movement.

The current study found an increase in sensitivity to heat (lower HPTs; primary heat hyperalgesia) at the involved Achilles tendon among individuals with chronic AT. Prior reports have found that lower heat pain thresholds occur during inflammatory conditions in experimental human and animals models.\textsuperscript{46-48} Mechanistically, lowering of HPTs is thought to occur via various tissue inflammatory molecules interacting with the TRPV1 (transient receptor potential-vanilloid 1) receptors found on type II A-delta and C fibers.\textsuperscript{46} While beyond the scope of this study, the finding of lower HPTs would be consistent with the findings of greater numbers of inflammatory cells and molecules in studies of human AT,\textsuperscript{49-51} and in animal models of voluntary upper extremity overuse during the early phase (weeks 6 and 12) of increased loading.\textsuperscript{41-43} The findings of this current study contradict those by Plinsinga et al,\textsuperscript{24} who did not find a significant difference in HPT at the Achilles tendon between controls and those with AT. Plinsinga and colleagues,\textsuperscript{24} used a faster rate of rise of temperature of 1°C/s compared to our 0.5°C/s protocol. The faster rate of rise of temperature could cause the experimenter to miss smaller differences in HPT. Consistent with this, both tendinopathy and control participants in our study had lower HPTs ($44.69 \pm 1.99°C \& 46.45 \pm 2.68°C$) in comparison to Plinsinga and colleagues,\textsuperscript{24} ($48.51 \pm 2.84°C \& 48.19 \pm 1.76°C$).

The current study did not find any evidence for enhanced central facilitation of pain as observed through HTS testing.\textsuperscript{16,17} Elevated temporal summation of pain is considered to be another potential sign of central sensitization.\textsuperscript{16,17} Tests that employ delivering repetitive stimuli at a rate of at least 0.3 stimuli/sec generate a progressive increase in action potential output from dorsal horn neurons in
animal models, therefore, this protocol is believed to affect the transmission neurons in the dorsal horn in humans. Temporal summation protocols, however, may also result in enhanced activity in other regions of the CNS involved in pain processing. Despite the AT group having lower HPTs, the perceptual magnitude of the increase in pain sensation during HTS was not different between groups. Although differences in temporal summation have been previously seen in people with fibromyalgia, osteoarthritis, temporomandibular disorder, chronic post-mastectomy pain, and migraine, it has rarely been assessed in chronic tendinopathies.

Limitations of this study include a sample of convenience and a relatively small sample size, although it was similar in size to other recent reports. This study did not assess heat pain threshold outside of the local site of pain or conditioned pain modulation, which would have yielded additional information about changes in pain sensitivity/modulation and allowed additional comparison to other recent studies. Both groups were made up of primarily active individuals, with the tendinopathy group continuing to run through their symptoms; therefore, the results of the study might not apply to a more sedentary population of individuals. Another limitation is the lack of binding of the assessors, which is a possible risk of bias in this study; however, all tests were performed using standardized instructional sets explaining the test procedures, and rate of application of stimuli were controlled. Lastly, no diagnostic ultrasound or magnetic resonance imaging was available during the time of the study that could have more precisely aided in the diagnosis of AT.

Future research should be directed at describing the changes in quantitative sensory testing using a comprehensive battery of tests with larger sample sizes. Given the prior studies published, careful consideration of the testing methodologies must be given, which may explain some of the discrepancies. Additional directions of future research should examine the possible role of quantitative sensory testing for the prognosis of outcomes after conservative treatment of AT, and the potential ability of interventions used to treat chronic tendinopathies to resolve peripheral and central sensitization.

CONCLUSIONS

Participants with chronic AT showed signs of both peripheral and central sensitization; however, widespread hyperalgesia into the upper extremities and elevated temporal summation was not observed. The evidence from this study and that of Tompra et al. support the concept that some changes in pain sensitivity may be present in chronic AT. These findings also lend support to the theory for a multifactorial model of tendinopathy, which consists of an impaired motor system, local tendon pathology, and changes in the pain/nociceptive system.

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ABSTRACT

Background: Leg-length inequality (LLI) is a common condition that may contribute to various spinal, pelvic, and lower extremity dysfunctions. Iliac crest height difference (ICHD) has been demonstrated to be a good estimate for LLI and may be a useful measure for identifying individuals who are at risk for injury.

Purpose: To investigate the relationship between ICHD and other running-related variables with running injury.

Methods: An observational retrospective case-control design was used. Data were collected via questionnaire and physical examination from a purposive sample of 100 runners and were analyzed using chi-squared tests of independence.

Results: The prevalence of ICHD ≥ 5mm reported by subjects via questionnaire was ~40%. There was no difference in report of injury between subjects with ICHD >5mm and those with ICHD <5mm ($\chi^2=0.02$, $p=0.88$); however, lifetime history of injury ($\chi^2=15.68$, $p=0.00$) and the number of running events participated ($\chi^2=3.09$, $p=0.04$) were significant factors associated with injury; although not significant, there was a trend towards relationship with gender ($\chi^2=3.2$, $p=0.07$).

Conclusion: Small ICHD is not associated with running injury among recreational runners. There appears to be an increased risk of running injury among runners who participate in more than one running event annually and those that have had a past history of running injury. Also, males may be at slightly greater risk of sustaining a running injury compared to females.

Level of Evidence: Therapy, level 3b

Keywords: leg-length inequality, Palpation Meter, movement system, physical therapy, sports
BACKGROUND

Leg-length inequality (LLI) is a musculoskeletal condition where one lower extremity is longer than the other. The magnitude of LLI has been classified as either mild (0-30mm), moderate (30-60mm), or severe (60+mm). Friberg et al² defined LLI as a 5mm difference and reported prevalence to be 50% among the total population. Knutson,³ determined the prevalence of LLI between 0-4mm to be 41.3%, 5-9mm to be 37.4%, 10-14mm to be 15%, and >14mm to be 6.4%. Radiography is the gold standard mode of measurement for LLI.⁴,⁵ and is accurate within 3mm for determining LLI magnitude.⁶

While less accurate than imaging, non-imaging methods of LLI measurement are innocuous, pragmatic, and cost effective. Currently, several non-imaging methods of LLI measurement exist, one being the Palpation Meter (PALM) method (Figure 1). The PALM (Performance Attainment Associates, St. Paul, MN.) is a modified caliper with an integral inclinometer. The PALM is used while the subject is standing and enables an assessor to quickly estimate LLI via iliac crest height difference (ICHD) measurement. The PALM does not require multiple measurements and calculations to be made, making it an attractive tool for clinical use. The PALM has demonstrated excellent reliability (intra-rater ICC = 0.93-0.99; inter-rater ICC = 0.75-0.94) and criterion-related validity for measurement of ICHD (ICC = 0.80-0.96) and good criterion-related validity for estimating LLI (ICC = 0.50-0.89) compared to radiographic measurement.⁷

Subotnick,⁸ in a clinical commentary reported that 40% of his athletic patients had some type of LLI. He purported that LLI “causes disabling problems for runners”⁸,p.¹¹ which could affect the lumbar spine, pelvis, hip, and lower extremities. He asserted that LLI as little as 1/8 inch may require correction if associated with “imbalance symptoms.”⁸,p.¹¹ His rationale was that although minor LLI may be insignificant in a sedentary individual, it is more significant in an active athlete due to the “rule of three,”⁸,p.¹⁵ which is that “biomechanical abnormalities of the lower extremity tend to be three times more significant in running than in walking.”⁸,p.¹⁵

Subotnick’s assertions are not completely unfounded. Lower extremity misalignment has been suggested to be a predisposing factor for injury among athletes.⁹-¹¹ One such misalignment is LLI. The presence of LLI has been associated with patellofemoral pain syndrome,¹² scoliosis,¹³ gait asymmetry,¹⁴,¹⁵,¹⁷ low back pain,¹⁶ knee osteoarthritis,¹⁷ iliotibial band friction syndrome,¹⁸ and stress fractures.¹⁹-²⁰ Walsh et al²¹ concluded using 3D motion analysis that artificially induced LLI caused compensatory mechanisms of the pelvis, knee, and ankle during gait. Furthermore, gait asymmetry may become greater as the magnitude of LLI increases.¹⁴ In addition to asymmetrical gait kinematics, LLI has been associated asymmetrical kinetics.¹⁵ Pertunen et al¹⁵ found increased loading in the longer limb during gait among teenagers with moderate LLI (mean LLI = 2.8cm).

Figure 1. Palpation Meter (PALM), Performance Attainment Associates, St. Paul, MN. USA.
Subotnick's assertions are also supported by the fact that running athletes experience a high rate of injury.11,22,23,29,31 The in-season incidence of injury among high-school and collegiate cross-country runners has been reported to be between 38–44%,11,22 and prevalence as high as 88%.29

Although LLI may be associated with asymmetrical kinematics and kinetics during gait and runners experience a high rate of injury,11,22,23,29,31 no definitive evidence exists indicating a strong relationship between leg-length inequality (LLI) and running injury. Also, many other variables have been associated with running-injury, such as various training parameters and biometric data. Variables such as running equipment have not been extensively studied regarding their relationship to injury. Novel and known variables thought to be related to running injury could provide useful information in comparison to ICHD's relationship to injury. Therefore, the purpose of this study was to investigate the relationship between ICHD and other running-related variables with running injury. A secondary purpose of this study was to investigate the relationship between other running-related variables and running injury.

METHODS

Subjects:

A purposive sample of 100 recreational runners was obtained. Subjects were recruited via word-of-mouth at various running events (marathon, 5Km, and 10 mile races) in southeastern Louisiana from December 2016 – February 2017. Individuals eligible to participate were 14–60 years old who competed in at least one running event ≥ 5km. Those who reported to have any neurologic condition affecting their muscles, active pathological condition that could influence bone growth, or had body mass index (BMI) ≥30 were excluded.

Power analysis was performed a priori using G-Power 3.1.9.2 to estimate the required sample size. The sample size calculation for a chi-squared analysis indicated 69 subjects were required using the following parameters: $\chi^2=0.05$, with power $=0.80$, moderate-to-large effect size $=0.4$, and 3 degrees of freedom. In order to account for outliers, missing data points, and data entry errors, 100 subjects were recruited to participate in this study.

Test Administration:

ICHD was measured using the PALM. All ICHD measurements were performed by the principal investigator (PI), a physical therapist with seven years of total clinical experience and three years of experience using the PALM. Prior to use in this study, the PI tested accuracy of the PALM for measuring small distances and inclinations using the caliper and inclinometer parts of the device. A research assistant was used to blind the investigator to 10 measurements of both distance and inclination of various magnitudes using a metal ruler and a pitch and slope locator. The PI followed-up with measurements of these various distances and inclinations using the PALM.

Once adequate correlation with standard measurement was achieved, the PALM was used for ICHD measurements in the main study. All ICHD measurements were performed outdoors with subjects standing on the same platform. The platform was constructed of wood with adjustable steel levelers on bottom in order to standardize the standing surface on various terrains. Prior to each measurement, the platform standing surface was checked for levelness within 0.5 degree using the pitch and slope locator.

Once the platform was deemed level, subjects were instructed to stand with their feet approximately shoulder width apart with feet facing anteriorly without any angulation and with equivalent weight distribution to each lower extremity. Rauh et al.11 described a similar standing position for measurement of Q-angles. Then, each subject was instructed to stand in a fully erect position with no bending of the ankles, knees, hips, or spine, and to fold their arms across their chest. This position was used by Petrone et al.7 to validate the PALM method of measurement. Once subjects were in position they were asked to take a breath, exhale, and relax their abdominal muscles. This procedure allowed the investigator to more accurately palpate the iliac crests without interference from the abdominal muscles. The pointed tip attachments of the PALM's caliper arms were placed on the most protrusive superior aspect of the iliac crests while the PALM was stabilized in position using the device's lanyard. Once satisfied with the position of the device, the PI read the inclinometer to determine the angulation and laterality, if present, and the magnitude of the
distance between the caliper tips. The PALM’s sliding calculator (Figure 1) was then used to determine the ICHD.

**Data Collection:**
Eligibility for inclusion to participate in the study was determined via a questionnaire. Each subject completed the questionnaire based upon their own knowledge and experiences; however, the PI was available to clarify any misunderstanding or confusion about any of the questionnaire content. One purpose of this questionnaire was to identify individuals who experienced an injury within the prior 12 months. Gabbe et al. determined 100% agreement in report of the presence or absence of an injury between a 12-month retrospective report compared with prospective records among a group of 70 football players. In the current study, an injury was operationally defined as any painful condition of the low back, pelvis, or lower extremity with a gradual onset while running, that caused a loss of ≥ 1 session of unrestricted training or competition, and persisted for equal to or longer than seven days. Ristolainen et al. used a similar definition of injury in a 12-month retrospective study of athletic injury. Once each subject completed the questionnaire, the first page was analyzed by the PI to ensure eligibility to participate; however, the PI was blinded to the remainder of the questionnaire, which included detailed injury information. Once selected to be included in the study, each subject was assigned a subject number and received one ICHD measurement using the PALM method as previously described with their socks and shoes donned; this measurement along with the date and subject number was recorded. Once this procedure was completed on 100 subjects, the data were entered into SPSS and saved for statistical analysis.

**Data Analysis:**
All data were analyzed using SPSS version 25. Significance was set at $\chi^2 = 0.05$ and power ≥ 0.80 for all data analyses. Prior to any statistical analyses, the data were screened for errors and missing data points. If data entry errors or missing data were unable to be corrected, they were trimmed from the data set. One subject completed the questionnaire, but elected not to receive ICHD measurement. Eight subjects were omitted from data analysis due to exclusion criteria and multiple missing data points. Data from 91 subjects were included in final data analysis.

A chi-squared test of independence was used to determine whether or not any statistically significant difference in injuries existed between subjects with ICHD ≥ 5mm and those with ICHD <5mm. Homogeneity between groups was analyzed with independent t-tests for interval and ratio data variables and with chi-squared tests of independence for nominal data variables. Additional chi-squared tests of independence were performed to analyze whether or not relationships existed between injury and various predictor variables, such as past history of running injury, gender, BMI, etcetera; all continuous data were dichotomized. If observed frequency was less than five in any cross-tabulation cell, the continuity correction value and Fisher's exact test was used for interpretation. Means and percentages of group characteristics and variables were calculated.

**RESULTS**
The instrument calibration analysis revealed excellent validity of the PALM for measurement of known distances < one meter (ICC=1.00, 95% CI=0.95-1.00, $p=0.00$) and excellent validity for measurement of known angles < 30 degrees (ICC=0.99, 95% CI=0.95-1, $p=0.00$).

Data from 91 subjects were used in final data analysis; see Tables 1-4 for characteristics. The prevalence of ICHD ≥ 5mm in this sample was ~40%. The majority of subjects reported the following characteristics: female gender (~60%), ran on hard surfaces (~57%), ran on both even and uneven terrain (~71%), utilized a mid-foot striking pattern (~50%), and had medium foot arch type (~50%). The prevalence of previous 12-month self-reported running injury was ~19% and lifetime prevalence was ~57%. Among those injured in previous 12-months, the majority reported their injuries were caused by repetitive overuse (~88%) and the most common location of injury was the knee (~29%). Additionally, most injuries were reported on the left side (~59%). Interestingly, among all subjects, most displayed an elevated iliac crest on the right side (~45%). Additionally, most subjects participated in more than one running event (~82%), used more
than one pair of running shoes (~80%), and trained >20 weeks in the previous 12-months.

As for footwear, most subjects (~80%) reported using multiple pairs of running shoes within previous 12-months (avg. = 2.8 pairs). Also, most subjects (82%) reported their primary pair of running shoes were relatively new (avg. = 2.5 mo. old). Among the subjects in the sample, a total of 13 different primary brands of shoes were reported. Brooks was the most

<table>
<thead>
<tr>
<th>Table 1. Subject characteristics among continuous variables (n = 91).</th>
<th>Mean</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>35.5</td>
<td>1.3</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.7</td>
<td>0.0</td>
</tr>
<tr>
<td>Weight (Kg)</td>
<td>68.4</td>
<td>1.2</td>
</tr>
<tr>
<td>BMI (Kg/m²)</td>
<td>23.6</td>
<td>0.3</td>
</tr>
<tr>
<td>ICID (mm)</td>
<td>5.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Number of Running Events Participated</td>
<td>3.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Running Experience (yrs.)</td>
<td>7.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Training Duration (total wks.)</td>
<td>29.5</td>
<td>2.1</td>
</tr>
<tr>
<td>Training Distance (avg. miles/wk.)</td>
<td>18.9</td>
<td>1.4</td>
</tr>
<tr>
<td>Training Time (avg. hrs. /wk.)</td>
<td>6.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Number of Shoes Used</td>
<td>2.8</td>
<td>0.5</td>
</tr>
<tr>
<td>Age of Shoes (mo.)</td>
<td>2.5</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Abbreviations: yrs = years, m = meter, kg = kilograms, ICID = iliac crest height difference, mm = millimeters, wk = week, avg. = average, mo. = months

<table>
<thead>
<tr>
<th>Table 2. Subject characteristics among nominal variables (n = 91).</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trained on hard surface (i.e. concrete, asphalt, etc.)*</td>
<td>57.1</td>
</tr>
<tr>
<td>Trained on cushioned surface (i.e. rubberized track, dirt, grass)*</td>
<td>3.3</td>
</tr>
<tr>
<td>Trained on both hard and cushioned surfaces*</td>
<td>39.6</td>
</tr>
<tr>
<td>Injured in past 12 months (% yes)*</td>
<td>18.7</td>
</tr>
<tr>
<td>Used Shoe Orthotics (% yes)*</td>
<td>16.1</td>
</tr>
<tr>
<td>Gender (% female)*</td>
<td>60.4</td>
</tr>
<tr>
<td>History of Running Injury (% yes)*</td>
<td>57.1</td>
</tr>
<tr>
<td>Trained on even terrain (e.g. indoor flat track)*</td>
<td>25.3</td>
</tr>
<tr>
<td>Trained on uneven terrain (e.g. outdoor dirt track, hills)*</td>
<td>3.3</td>
</tr>
<tr>
<td>Trained on both even and uneven terrain*</td>
<td>71.4</td>
</tr>
<tr>
<td>Rear-foot strike pattern*</td>
<td>14.3</td>
</tr>
<tr>
<td>Mid-foot strike pattern*</td>
<td>49.5</td>
</tr>
<tr>
<td>Fore-foot strike pattern*</td>
<td>11.0</td>
</tr>
<tr>
<td>Unknown foot strike pattern*</td>
<td>25.3</td>
</tr>
<tr>
<td>High foot arch*</td>
<td>17.6</td>
</tr>
<tr>
<td>Medium foot arch*</td>
<td>49.5</td>
</tr>
<tr>
<td>Low foot arch*</td>
<td>12.1</td>
</tr>
<tr>
<td>Unknown foot arch*</td>
<td>20.9</td>
</tr>
<tr>
<td>No difference in iliac crest heights</td>
<td>27.5</td>
</tr>
<tr>
<td>Left iliac crest elevated</td>
<td>27.5</td>
</tr>
<tr>
<td>Right iliac crest elevated</td>
<td>45.1</td>
</tr>
</tbody>
</table>

*based upon self-report
commonly used shoe brand accounting for ~23% of total usage. In addition, ~5% of subjects wearing Brooks shoe brand reported being injured in previous 12-months (i.e. 1 out of 21). The second most popular shoe brand used was Asics, accounting for ~17% of total usage and ~33% reported injury. The percentage of those injured among subjects using Mizuno and Newton brands were the highest with 40% and 50%, respectively (Table 5). Finally, ~16% of the sample used foot orthotic in-soles. Although interesting, this study found no significant relationship between age of shoes, number of shoes used, shoe brand, or orthotic use with report of running injury.

A chi-squared test for independence revealed no significant difference in injury between groups with ICHD ≥ 5mm and <5mm ($\chi^2=0.02$, p = 0.88); groups were homogeneous (Table 6). Additional chi-squared tests for independence were performed. Past lifetime history of injury revealed significant dependence with injury within the previous 12-months.

<table>
<thead>
<tr>
<th>Table 3. Self-reported injury characteristics (n = 16-17).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Percentage (%)</strong></td>
</tr>
<tr>
<td>Cause of injury was repetitive overuse</td>
</tr>
<tr>
<td>Cause of injury was traumatic</td>
</tr>
<tr>
<td>Location of injury was knee</td>
</tr>
<tr>
<td>Location of injury was ankle</td>
</tr>
<tr>
<td>Location of injury was buttocks</td>
</tr>
<tr>
<td>Location of injury was hip</td>
</tr>
<tr>
<td>Location of injury was foot</td>
</tr>
<tr>
<td>Location of injury was both hip and knee</td>
</tr>
<tr>
<td>Left side injured</td>
</tr>
<tr>
<td>Right side injured</td>
</tr>
<tr>
<td>Both sides injured</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4. Dichotomized variable frequencies.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No</strong></td>
</tr>
<tr>
<td>Running Events Participated &gt; 1</td>
</tr>
<tr>
<td>Pairs of Shoes Used &gt; 1</td>
</tr>
<tr>
<td>Age ≥ 30 yrs.</td>
</tr>
<tr>
<td>Total Training Duration &gt;20 total wks.</td>
</tr>
<tr>
<td>Running Experience ≥ 5 yrs.</td>
</tr>
<tr>
<td>BMI ≥ 25 Kg/m²</td>
</tr>
<tr>
<td>ICHD ≥ 5mm</td>
</tr>
<tr>
<td>Age of Shoes &gt; 3 mo.</td>
</tr>
<tr>
<td>Weekly Training Duration ≥ 10 hr./wk.</td>
</tr>
</tbody>
</table>

Yrs. = years, wks. = weeks, BMI= body mass index, and ICHD= iliac crest height difference
Kg = kilograms, m = meters, mm = millimeters, mo = months, hr. = hours, mi. = miles

<table>
<thead>
<tr>
<th>Table 5. Reported primary shoe brand used within previous 12 months.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Percentage (%)</strong></td>
</tr>
<tr>
<td>Brooks</td>
</tr>
<tr>
<td>Asics</td>
</tr>
<tr>
<td>Nike</td>
</tr>
<tr>
<td>Saucony</td>
</tr>
<tr>
<td>Mizuno</td>
</tr>
<tr>
<td>New Balance</td>
</tr>
<tr>
<td>Adidas</td>
</tr>
<tr>
<td>Hoka</td>
</tr>
<tr>
<td>Newton</td>
</tr>
<tr>
<td>Under Armor</td>
</tr>
<tr>
<td>Zoot</td>
</tr>
<tr>
<td>Merrell</td>
</tr>
<tr>
<td>Altra</td>
</tr>
</tbody>
</table>
The concept is supported by Gurney1 who concluded the human body is able to compensate for small discrepancies in limb length, particularly individuals with long-standing LLI. Gurney et al1 recommended LLI treatment should be considered on a case-by-case basis and that intervention is likely unnecessary for LLI <20mm, particularly among younger persons. Furthermore, Gurney et al27 concluded that 2-3 cm is the cutoff value for LLI effecting physiologic parameters among older adults. However, it remains possible that larger ICHDs are associated with running injury, particularly among older persons. It is notable that all ICHD magnitudes measured in this study were small (mean=5.0mm, max.=20mm).

Although ICHD did not demonstrate a significant relationship with running injury in this study, a few other variables did. For example, reports of lifetime history of running injury and running injury within the prior 12-months (OR=0.67, 95% CI=0.56-0.81). Another chi-squared test revealed a non-significant trend towards dependence with gender (χ²=3.2, p=0.07) indicating males at greater risk of running injury (OR=2.64, 95% CI=0.90-7.75). Finally, the number of running events subjects participated in revealed significant dependence with injury within the prior 12-months when the variable called running events was dichotomized into either one event or greater than one event (χ²=3.09, p=0.04), indicating individuals participating in multiple events are at greater risk of running injury (OR=1.3, 95% CI=1.14 – 1.46) (Table 7).

**DISCUSSION**

The results of this study suggest that ICHD is not associated with running related injury, which is consistent with results from Goss et al26 who concluded that leg-length inequality 0.5 to 3.0 cm is not a significant factor for one-year incidence of running injury among military cadets. These findings indicate that small leg-length discrepancies do not significantly increase risk of running injury and that individuals may be able to effectively compensate for these discrepancies. This concept is supported by Gurney1 who concluded the human body is able to compensate for small discrepancies in limb length, particularly individuals with long-standing LLI.1 Gurney et al1 recommended LLI treatment should be considered on a case-by-case basis and that intervention is likely unnecessary for LLI <20mm, particularly among younger persons. Furthermore, Gurney et al27 concluded that 2-3 cm is the cutoff value for LLI effecting physiologic parameters among older adults. However, it remains possible that larger ICHDs are associated with running injury, particularly among older persons. It is notable that all ICHD magnitudes measured in this study were small (mean=5.0mm, max.=20mm).

Although ICHD did not demonstrate a significant relationship with running injury in this study, a few other variables did. For example, reports of lifetime history of running injury and running injury within the prior 12-months were related. Similarly, Reinking et al28 found past history of exercise-related leg-pain was significantly associated with in-season occurrence of injury among high-school cross-country runners (OR=9.1, 95% CI=1.4-61.2). Another significant finding in this study was participation in greater than one running event was associated with report of running injury; in fact, 100% of reported

<table>
<thead>
<tr>
<th>Gender</th>
<th>χ²=2.7</th>
<th>0.10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifetime Hx of injury</td>
<td>χ²=1.2</td>
<td>0.27</td>
</tr>
<tr>
<td>Orthotic Use</td>
<td>χ²=0.1</td>
<td>0.75</td>
</tr>
<tr>
<td>Shoe age</td>
<td>χ²=3.1</td>
<td>0.38</td>
</tr>
<tr>
<td>Shoe brand</td>
<td>χ²=7.3</td>
<td>0.84</td>
</tr>
<tr>
<td>Running surface</td>
<td>χ²=2.3</td>
<td>0.31</td>
</tr>
<tr>
<td>Running terrain</td>
<td>χ²=1.2</td>
<td>0.55</td>
</tr>
<tr>
<td>Foot striking pattern</td>
<td>χ²=3.6</td>
<td>0.31</td>
</tr>
<tr>
<td>Foot arch type</td>
<td>χ²=1.4</td>
<td>0.70</td>
</tr>
<tr>
<td>Age</td>
<td>F=0.7</td>
<td>0.79</td>
</tr>
<tr>
<td>Height</td>
<td>F=0.2</td>
<td>0.69</td>
</tr>
<tr>
<td>Weight</td>
<td>F=1.2</td>
<td>0.27</td>
</tr>
<tr>
<td>BMI</td>
<td>F=0.2</td>
<td>0.67</td>
</tr>
<tr>
<td>Running Experience</td>
<td>F=0.1</td>
<td>0.83</td>
</tr>
<tr>
<td>Number of Running Events</td>
<td>F=0.4</td>
<td>0.55</td>
</tr>
<tr>
<td>Training Duration</td>
<td>F=1.4</td>
<td>0.24</td>
</tr>
<tr>
<td>Number of Shoes Used</td>
<td>F=3.8</td>
<td>0.06</td>
</tr>
<tr>
<td>Training Distance</td>
<td>F=1.0</td>
<td>0.31</td>
</tr>
</tbody>
</table>

χ²= history, BMI = body mass index
in contrast to the 36-88% incidence and prevalence of running injuries previously reported.\textsuperscript{11,22,23,31} Chi-squared analysis of running distance divided into either <20, 20-40, or >40 average miles per week revealed no dependence with running injury; however, analysis was limited by the small sample size. Only 4.4% of subjects reported average running distance >40 mi./wk.; among these subjects, 25% sustained an injury, specifically, one man who reportedly ran an average 45 mi./wk.

In addition to the relatively low average running distance per week, greater running experience among subjects in the current study could be a contributing factor to the disparity in injury prevalence. Subjects in this study had a mean running experience of 7.5 years. Prior authors have indicated higher running injury rates among high-school athletes with less running experience.\textsuperscript{11,23,28} Hubbard et al.\textsuperscript{32} concluded that runners with less than five years of running experience were more likely to acquire medial tibial stress syndrome (p <0.002). A plausible explanation could be that individuals with greater than five years of running experience have learned better

injuries occurred among subjects who participated in multiple running events during the previous 12-month period.

Although not statistically significant, a trend was observed towards males being more likely than females to report running injury; males accounted for 59% of injuries. Daoud et al.\textsuperscript{29} concluded that gender was significantly associated with repetitive overuse injury (p <0.01) among collegiate cross-country runners, but found that females had higher injury rates (79-88% female, 68-79% male). This disparity may be explained by the difference in average weekly running distance. The average running distance among subjects in the current study was ~18 mi./wk. and was ~42.5 mi./wk. among subjects who participated in the study by Daoud et al.\textsuperscript{29} Macera et al.\textsuperscript{30} suggested that individuals running >40 miles per week were approximately three times more likely to experience running-related pain compared to individuals running <40 miles per week. This is a plausible explanation given the relatively low prevalence of injury of ~19% in the subjects in the current study. This low prevalence of injury is

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|}
\hline
& Test Statistic & p-Value \\
\hline
Lifetime Hx of injury & $\chi^2=15.7$ & 0.00* \\
Gender & $\chi^2=3.2$ & 0.07 \\
Shoe brand & $\chi^2=18.3$ & 0.15 \\
Foot arch type & $\chi^2=3.0$ & 0.40 \\
Iliac Crest Side Elevated & $\chi^2=1.73$ & 0.42 \\
Running surface & $\chi^2=0.7$ & 0.70 \\
Running terrain & $\chi^2=0.7$ & 0.71 \\
Foot striking pattern & $\chi^2=1.3$ & 0.72 \\
Orthotic Used & $\chi^2=0.0$ & 0.72 \\
Running Events (1 or >1 participated) & $\chi^2=3.09$ & 0.04* \\
Running Experience (<5 or ≥ 5 yrs.) & $\chi^2=2.10$ & 0.15 \\
Training Time (<10 or ≥10 avg. hrs./wk.) & $\chi^2=0.18$ & 0.48 \\
Training Distance (<20, 20-40, or >40 avg. mi./wk.) & $\chi^2=0.23$ & 0.90 \\
Total Training Duration (<20 or ≥20 total wks.) & $\chi^2=0.29$ & 0.59 \\
Pairs of Shoes Used (1 or >1) & $\chi^2=0.01$ & 0.74 \\
ICHD (≤5 or >5 mm) & $\chi^2=0.02$ & 0.88 \\
Age (<30 or ≥30 yrs) & $\chi^2=0.01$ & 0.91 \\
BMI (<25 or ≥25 Kg/m²) & $\chi^2=0.00$ & 0.96 \\
Age of Shoes (≤3 or >3 mo.) & $\chi^2=0.00$ & 1.00 \\
\hline
\end{tabular}
\caption{Relationships between variables and injury (chi-squared tests for independence).}
\end{table}

* denotes significance, ♦ denotes variable with >3 levels

Hx = history Yrs. = years, avg. = average, wk. = week, ICHD = iliac crest height difference, mm = millimeters, BMI = body mass index, Kg = kilograms, m = meter, mo. = months
training methods to avoid injury compared to less experienced runners or those that have experienced running injury have chosen not to continue running. Although plausible, the results in this study do not indicate a significant relationship with running experience and injury. Chi-squared analysis revealed that running experience greater than or equal to five years demonstrated no significant difference than less than five years of experience with regard to relationship with running injury ($\chi^2 = 2.10$, $p = 0.15$).

In addition, foot-striking pattern may have influenced injury prevalence in this study. Most subjects in this study reported they were mid-foot strikers (i.e. ~50%). This type of initial foot striking pattern may have had a protective effect among subjects. Almeida et al\textsuperscript{13} concluded that biomechanical differences exist among various foot-striking patterns, specifically, runners who initially strike with rear-foot may be at greater risk for certain types of injuries compared to fore-foot strikers due to greater vertical loading rates. The ability of the human foot and ankle to accommodate for differences in leg-length via adjusting plantarflexion ROM and triceps surae eccentric loading at initial foot contact may be an important factor explaining why small ICHDs and LLIs may not be clinically significant with regard to running injury.

Another limitation of this study is the small sample obtained from a focused geographic location. A sample of 100 recreational runners who participated in running events ranging in distance from 5-21 Km in southeastern Louisiana were recruited to participate in this study; however, complete data was only available for 73 subjects. Similar studies examining running injuries have used sample sizes ranging from 77 to 393.\textsuperscript{11,22,25,28} The power analysis performed a priori ($\chi = 0.20$) indicated a required sample size of 69 for adequate power using chi-squared tests, which indicates the analysis was adequately powered, but many of the chi-squared analyses required utilization of the continuity correction statistic and Fisher's exact test due to less than 5 values per cell; therefore, a larger sample size would have strengthened confidence in the results and allowed for other statistical procedures, such as logistic regression. Additionally, all subjects were recruited in southeastern Louisiana where the terrain is relatively flat, the altitude is near sea-level, and the climate is humid subtropical; therefore, the results may only be applicable to recreational runners in this geographical region.

Another limiting factor to consider in this study is footwear. The only variable that was not dichotomized for chi-squared analysis was “shoe brand.” There were 13 different shoe brands used by subjects in this sample. According to G-Power 3.1.9.2 a chi-squared analysis with 13 degrees of freedom would require a sample size of ~200, which is much larger than the $n=91$ in this study; therefore, this particular analysis was underpowered and the risk of a type II error is a possibility, especially considering the relatively low p-value ($p=0.15$).

Finally, the study design was a limitation. This study used a retrospective design due to lack of resources; a prospective design would have improved internal validity.

**CONCLUSION**

The results of the current study indicate no statistically significant relationship between ICHD and self-reported injury among runners. These results suggest that small ICHDs does not significantly increase risk of running injury among recreational runners. Presumably, they may be able to effectively compensate for minor leg length discrepancies.

**REFERENCES**


ABSTRACT

Purpose: Essential to the successful management of patients with sacroiliac joint pain (SIJP) is understanding how these joints move. The innomates tilt together in the same direction with symmetrical activities (i.e. forward-bending) but move opposite of one another when performing asymmetrical activities (i.e. walking). How they move in patients with SIJP is unknown. The purpose of this study was to examine inter-innominate movement (tilt) when assuming three different stance positions to describe how the innominate bones move in those with and without SIJP.

Study type: Observational Cohort Study

Methods: Twenty-eight participants were classified into two groups; SIJP with low back pain (LBP), and no SIJP or LBP. SIJP participants were further classified into groups with left or right pelvic tilt. Pelvic tilt was measured during neutral standing and in both left-sided and right-sided reciprocal stance, with a full-stride (one hip fully flexed the other fully extended) and in a half-stride position, which mimic the double-stance phase of gait. A repeated measure ANOVA assessed for differences between Groups (Level, Left or Right Pelvic Tilt), stance side position (left/right), and stride length (full/half).

Results: The was a significant Group main effect (F [2, 25] = 130.2, p < 0.0001), and a significant Side main effect (F [1, 25] = 429.7, p < 0.0001), qualified by a significant Side x Group interaction (F [2, 25] = 19.9 p < .0001). Follow-up comparisons showed that pelvic tilts for right and left stance were significantly different (p < 0.05) for each group (Level, left and right pelvic tilt). For the right stance condition, all groups were significantly different from each other (p < 0.05). For the left stance position, the right pelvic tilt and level pelvic tilt means were not different from each other (p > 0.05), but each was different from the mean for the left pelvic tilt group (p < 0.05).

Conclusions: When assuming an asymmetrical stance position, the innomates tilt opposite of each other in those without SIJP. In patients with SIJP they behave in the normal fashion in one asymmetrical stance position but not the other. Instead of tilting opposite, as expected, the innomates remain symmetrical, dependent on the side of the presenting pelvic tilt.

Level of Evidence: 2b

Keywords: Innominate tilt, low back pain, sacroiliac joint
INTRODUCTION
Low back pain (LBP) is a common problem that creates functional disability in both athletes and non-athletes alike. An often under-diagnosed cause of recurrent LBP is pain arising from the sacroiliac joints.¹ ² A likely reason for not recognizing sacroiliac joint pain (SIJP) in LBP patients is that individual tests are not very reliable for discerning sacroiliac joint movement.³ ⁶ This is an expected finding since little is known regarding how the sacroiliac joints of the pelvis move. Determining how the sacroiliac joints move in those with SIJP compared to those without SIJP would give therapists direction in both the assessment and the management of patients with LBP with contributions from the sacroiliac joints. A greater understanding of how the two joints of the hemi-pelvis move could potentially impact the treatment of femoroacetabular impingement. Pelvic posture and kinematics influence acetabular orientation and are involved in the pathomechanics of femoroacetabular impingement.⁷ ⁸

While numerous researchers have examined how much the sacroiliac joint moves,⁹ ¹⁴ which is very little, ⁹ ¹⁴ few have examined just how the sacroiliac joints move in those with SIJP.¹⁵ ¹⁶ The most often used in-vivo model for studying normal sacroiliac joint motion is observing the relative movement of the two innominate bones (inter-innominate motion) during reciprocal stance positions.¹³ ¹⁴ ¹⁷ ¹⁹ During normal standing, the two innominates mirror each other, each having the same amount of innominate tilt.¹⁷ ²⁰ ²¹ When assuming a reciprocal stance position, a double weight-bearing position where one hip is maximally flexed the other extended, the two innominates tilt in opposite directions of each other, the flexed hip anterior the extended hip posterior.¹³ ¹⁴ ¹⁸ This kind of innominate tilt is contrary to those with a leg length difference in which those with a long leg have a high innominate, with both ASIS and PSIS appearing higher on one side compared to the opposite or low side.²² The first study describing this phenomenon of opposite or antagonistic innominate tilt was by Pitkin and Pheasant.¹⁸ Subsequent researchers have also examined inter-innominate movement when assuming a reciprocal stance position and found similar results.¹³ ¹⁴ ¹⁷ ¹⁹ The purpose of this study was to examine inter-innominate movement (tilt) when assuming three different stance positions to describe how the innominate bones move in those with and without SIJP. The research hypothesis was that participants with SIJP would have altered innominate movement during reciprocal stance positions compared to those without SIJP. Understanding the difference between how the two innominates move in those with versus those without SIJP will provide therapists important information that will help in the management of those with LBP from SIJP and perhaps also those with femoroacetabular impingement.

METHODS
Twenty-eight participants, with and without LBP, were gathered from Maryville University students, and the greater St. Louis community. The Institutional Review Board at Maryville University approved this study protecting the rights of all included or excluded. Participants were asked to review and sign an informed consent. The cohort's mean age was 23.0; range 18-24, mean height = 172.5 cm.; mean weight = 72.5 kg, mean BMI = 24.1; 17 females and 11 males. Eligible participants in the LBP group were those who had unilateral low back located principally around the posterior superior iliac spine (PSIS).

After signing the informed consent, participants were screened for inclusion and exclusion criteria. The inclusion criteria for SIJP included: a chief complaint of unilateral PSIS pain. SIJP was confirmed by having a total score of at least four of six items on Kurosawa's diagnostic scoring system; with a finding of a positive one-finger test, groin pain, pain while sitting, positive sacroiliac shear test, and tenderness of PSIS or the sacrotuberous ligament (Specificity = 86.4; Sensitivity = 90.3).²³ The person performing these tests did not know who had LBP and who did not have LBP. Tests were also performed to assess the putative direction of left versus right innominate tilt, including assessing for uneven PSIS's while seated, the supine-long sitting test, and the prone knee flexion test.²¹ ²⁴ ²⁵ ²⁸ The mean LBP of participants was 2.3/10, which is characteristic of those with mechanical LBP (1.2 - 4.0/10 using the Numeric Pain Rating Scale).²⁹ All participants were first assessed for SIJP and then categorized into one of two groups, those with LBP and SIJP and those without SIJP and without LBP. The SIJP group was further classified into
either the left pelvic tilt or a right pelvic tilt group from the results of the tests to putatively determine innominate tilt direction.

Exclusion criteria included: lower extremity surgery within the prior three months, or current lower extremity injury. Exclusion criteria also included: signs of nerve root involvement including a positive straight leg raise test, myotomal weakness, absent deep-tendon-reflexes, or reported greater LBP with posterior/anterior pressure to the spinous processes of the lumbar vertebrae compared to the sacral sulcus, previous back surgery, or currently receiving therapy for LBP. Finally, participants were excluded if they had a history of fracture or surgery in either lower extremity, or if they reported they had a leg length difference or had clinical or radiographic confirmed leg length discrepancy or scoliosis that could affect the findings of the study. One participant was excluded because of having greater lumbar pain, as exhibited by greater pain with posterior/anterior pressure than sacral sulcus pressure.

Measuring Innominate Tilt
Three different stance positions were used to measure changes in innominate tilt. The three different stance positions were used to achieve both a resting (neutral) position and positions of maximal hip flexion on one side and maximal hip extension on the other side (bilaterally), duplicating previous sacroiliac joint research. The first was a neutral standing position with the feet placed shoulder width apart; the other two positions were a left and a right reciprocal stance where they stood in a position where one hip was flexed while the other was extended as far as possible without losing their balance (Figure 2). The stance position was operationally defined by the maximally flexed hip, so a maximally flexed left hip with a maximally extended right hip was a left reciprocal stance. The testing sequence of the reciprocal stance positions was randomly determined by the flip of a coin with each person.

The PALpation Meter device (Performance Attainment Associates, Lindstrom, MN, USA) was used to measure sagittal (anterior/posterior) innominate tilt and PSIS level (frontal tilt). The PALpation Meter has previously been shown to have excellent intra-rater reliability for assessing sagittal innominate position (ICC: 0.89-0.96). The PALpation Meters measurement scale, when attempting to measure innominate tilt, was too narrow to assess sagittal innominate tilt in many of the participants when standing in their reciprocal stance position, so in its place frontal plane horizontal heights using the PSIS's as landmarks with the PALpation meter (pelvic tilt) was assessed instead. Assessing PSIS heights is a commonly used clinical method to determine the direction of innominate tilt. Drrup and Heirholzer showed that the level of PSIS's can be used as indicators for pelvis movements, they found a near perfect correlation between bony landmark levels and pelvis movement measured with a rasterstereographic device an introducing artificial pelvic tilts. Walker et al demonstrated the reliability (ICC = .84) of the pelvic calipers for measuring innominate tilt. Also the construct validity of the pelvic calipers were demonstrated in a previous study where uneven horizontal PSIS heights measured in standing, in those without leg length disparity, were able to predict differences in sagittal plane tilt between the left and right innominate bones in those with SIJP, with the inferior PSIS side indicating a relative posterior tilt and the superior PSIS side a relative anterior tilt.

Prior to testing two small pilot studies were performed, one to confirm the relationship between sagittal to frontal innominate tilt, and the second to assess reliability. To confirm the relationship between sagittal to frontal innominate tilt a subsample of those with and without SIJD were compared. In those without a leg length disparity, a low PSIS suggests a posterior innominate tilt, while a high PSIS suggests an anterior innominate tilt. An anterior innominate tilt was defined as positive direction of movement while a posterior tilt was a negative direction of movement. Six participants, three with and three without SIJP were assessed for sagittal innominate tilt (Mean BMI = 22.7). In sacroiliac joint dysfunction, one innominate tilts anterior relative to the opposite posterior tilted innominate. All three participants without SIJP had a horizontally even or level pelvis during neutral stance with near perfect symmetry between the left and right PSIS's heights with a difference of just over 1°. When measuring the amount of sagittal tilt during neutral
stance, the degree of left innominate tilt equaled the right innominate tilt, suggesting pelvic symmetry. The measured difference during neutral stance in tilt between the left and right innominate in all three participants was 1°, suggesting that the posterior PSIS measurements reflected the direction of sagittal innominate tilt in those without SIJP. When assuming a reciprocal stance position, the superior PSIS side demonstrated an anterior tilt (a positive inclination where the ASIS was lower and PSIS was higher when compared to the opposite side), while the inferior or caudal PSIS side demonstrated a posterior tilt. The mean difference, when assuming a reciprocal stance, between the left and right PSIS was 20°. Thus, showing evidence that left to right horizontal PSIS inclination measurement could predict sagittal innominate tilt direction in those without SIJP (as long as they did not have a leg length disparity).

In the sub-sample of participants with SIJP, the side of the superior PSIS had a more anteriorly tilted innominate (mean of +17.3° of anterior tilt) when compared to the opposite inferior PSIS side (a mean anterior tilt of +1.9°). The mean difference between left and right PSIS was 8.5° Thus, the results showed that using posterior PSIS measurements can serve as a proxy measurement for sagittal innominate tilt in those with SIJP.

Frontal plane inclination (e.g. Pelvic Tilt) of the left and right PSISs were assessed by an experienced physical therapist (MTC; 40 plus years of clinical experience). Few, if any, studies have carefully examined the intratester reliability of assessing PSIS heights. Moreover, while recent systematic reviews showed that palpating PSIS having slight to moderate inter-tester reliability, all of the studies had serious design problems from using examiners with very little clinical experience (e.g. students), improper position (palpating PSIS position while lying prone), using very small sample sizes or employing asymptomatic populations. Thus, to ensure reliability for this study, intra-tester reliability of PSIS palpation and measurement was assessed on ten participants. The PSIS were palpated with a circular motion and then placing thumb pressure underneath each of the bony prominences of PSIS’s. Once assured of the thumb's position was under the bony prominence of

![Figure 1. Method used to Measure Horizontal PSIS difference with the PALmeter caliper (Palmeter, Performance Attainment Associated, St. Paul, MN, USA).](image1)

![Figure 2. Example of reciprocal stance position during which measurements were taken.](image2)
to the measurements taken. The ICC (3,1) = .96 (CI_{95}: .91-.98) were excellent. Minimal detectable change (MDC_{95}) = .86 degrees for pelvic tilt was determined using the formula for the standard error of the measure (SEM) = (baseline pooled standard deviation * $\sqrt{(1-.96)}$ * 1.96 *$\sqrt{2}$.

For testing in this study, a left pelvic tilt was defined a priori as an inferior or caudal position of the left PSIS compared to the right PSIS of greater than 4° which is denoted as negative (-), and a right pelvic tilt as an inferior position of the right PSIS compared to the left PSIS of greater than 4° which is denoted as positive (+). The 4° difference was established using mean measurement values from a previous study that examined innominate tilt in patients with SIJP. Thus, three different pelvis conditions were possible: no SIJP (level pelvic tilt) where the left/ right PSIS are level in the same frontal plane, and SIJP with left pelvic tilt or SIJP with right pelvic tilt. All SIJP patients were classified as either a left (-) or a right (+) pelvic tilt. To control for the possibility that a frontal plane pelvic list could influence the measurements, PSIS’s were assessed only during simulated double limb support phase of gait. The pelvis naturally drops during the mid-swing phase of single limb support but not during the double limb support phase of gait.

The assessment of innominate tilt was performed while standing. Participants were asked to stand with their feet shoulder-width apart. Participants were asked to take a big step backward, without losing their balance, so that one hip was maximally flexed, and the other hip maximally extended with both knees extended and the trunk neutral with weight equally distributed. The stance distance from the heel on the hip flexion side to the toe on the extended hip side was measured. To assess if the amount of stance (e.g. the degree of hip flexion and extension measured in) affected pelvic tilt, all were placed in a ½ stance position. The ½ stance position was determined by halving the measured full-stride stance position. Participants were placed in a half-stance position so that one hip was half-flexed while the other hip was half-extended. Three measures were recorded for each ½ stance positions. The participants then repeated the full stance and ½ stance process on the opposite side. Measurements were repeated using the exact same procedures. Therefore, all participants were measured in neutral and then in half-stance and full stance for both reciprocal stance positions. The investigators taking the pelvic tilt measures were blinded to those who had LBP and SIJP and who did not.

**Data Analysis**

Data were analyzed using the open source program, R. Measurements of innominate tilt were obtained from each participant and summarized using descriptive statistics. An ICC (3,1) was used to assess the intra-rater reliability for pelvic tilt measures on the first 10 participants in this study. Data were analyzed using a three-way between (Group) and within (Length, Side) repeated measure ANOVA (3x2x2). The dependent variable was innominate tilt measured in degrees. The independent variables consisted of Group (level pelvic tilt, left pelvic tilt, right pelvic tilt), Length (half or full stance), and Side (left stance, right stance). Follow-up comparisons of means were alpha adjusted using the Holm-Bonferroni method to adjust for family-wise error when making multiple comparisons. Residuals were checked for normality, and variance-covariance matrices checked for homogeneity. Given some violations, the inferences were verified using randomization tests. Confidence intervals [CI] were all reported as 95% CIs.

**RESULTS**

Twelve participants were classified into the no SIJP (Level Pelvic Tilt) group and 16 in the SIJP group, eight with a left pelvic tilt and eight with a right pelvic tilt. The dependent variable (pelvic tilt) residuals were normally distributed (all Shapiro-Wilk tests, p > .05). Tests for homogeneity of the variance-covariance matrix (M test, $x^2 (df = 20) = 55.1, p < .001$) indicated violation of this assumption.

During neutral standing the mean pelvic tilt without SIJP was 1.1° [CI .03: 2.2], while those with SIJP had a mean pelvic tilt of -7.2° [CI -8.3: -6.0] for left pelvic tilt (left low PSIS) and +6.0° [CI 4.8: 7.2] for right pelvic tilt (right low PSIS) (Figure 3.) During a full reciprocal stance, those without SIJP assuming a left stance had a mean pelvic tilt of +12.4° [CI 10.8: 14.0] while assuming a right stance the mean was -10.2° [CI -11.8: -8.6]. (Figure 4) In those with SIJP with a
left pelvic tilt and left stance the mean pelvic tilt was -0.7° [CI -2.6: 1.2] while with a right stance the mean was -13.7° [-15.6: -11.8]. For those with SIJP with a right pelvic tilt during a right stance mean pelvic tilt was +0.13° [CI -1.8: 2.0] while during a left stance the mean pelvic tilt was +11.9° [CI 10.0: 3.8] (Figure 3). The half-stride stance position results were similar to the full-stride position (Figure 5).

The repeated measure ANOVA found a significant Group main effect (F [2, 25] = 130.2, p < .0001), and a significant Side main effect (F [1, 25] = 429.7, p < .0001), qualified by a significant Side x Group interaction (F [2, 25] = 19.9 p < .0001) (Figure 3). Follow-up comparisons within groups using the Holm-Bonferroni correction procedure indicated that mean pelvic tilts for right and left stance were significantly different (p < .05) for each group (Level, right pelvic tilt, and left pelvic tilt). Within the right stance condition, all groups were significantly different from each other (p < .05). Within the left stance condition, the right pelvic tilt and level pelvic tilt means were not different from each other (p > .05), but each was different from the mean for the left pelvic tilt group (p < .05).

Because the data did not satisfy the homogeneity of variance-covariance matrices assumption, the inferences were verified using a randomization test, which does not require this assumption. For each of 10,000 trials, the factor labels (e.g., Level, Right...
Stance, etc.) for the data were randomly shuffled under the assumption that factor labels are arbitrary if the null hypothesis is true. The F-ratios were calculated for each trial with the reshuffled data. Across the trials, the proportion of F-ratios for each effect that exceeded the original F ratios were tallied. If the original F-ratios are unusual under the null hypothesis, then very few of the F-ratios from the randomization test trials should exceed the original F-ratios. None of the randomization test F-ratios were greater than the corresponding original F-ratios, verifying the robustness of the original results.

**DISCUSSION**

In those without SIJP, the results of the current study agree with results from most of the previous studies showing that the left and right innominates tilt in opposite directions when assuming a reciprocal stance position. In the current sample, in those with SIJP, the left and right innominates tilted opposite of one another in one of the reciprocal (asymmetrical) stance positions but not in the other reciprocal stance position. Instead of tilting in opposite directions, the left and right innominate bones remained horizontally level. This type of innominate movement was dependent on the side the pelvis was tilted (left or right pelvic tilt). When those with a left pelvic tilt (where the PSIS was found lower or inferior on the left in neutral stance, often called a posterior innominate) assumed a right reciprocal stance position (left hip extended; right hip flexed) the innominate position remained the same with no change in position, and they continued to remain in this same position also when in a neutral stance position (left low PSIS, right high PSIS). However, when assuming a left reciprocal stance position (left hip flexed; right hip extended), where expecting the left PSIS to be high (anterior tilt) and the right PSIS low (posterior tilt), the two innominate bones remained horizontally level. This same coupling pattern was noted for those with SIJP that had a right pelvic tilt, but in an opposite fashion. This finding suggests a coupling failure of the two innominates to fully tilt opposite of one another, meaning that the innominate bone on the posterior tilted side did not fully tilt anteriorly, and on the opposite side, the anterior innominate did not fully tilt posteriorly.

That the two innominate bones remained horizontal in those with SIJP during a reciprocal stance, when they should have tilted opposite of one another, suggests that they “attempted” to complete a full opposite (antagonistic) innominate tilt, but for whatever reason could not complete it. From these results, the reason(s) for the failure of the two innominates to fully tilt opposite is unknown. Nevertheless, the results of the current study demonstrate that movement likely develops from both left and right sacroiliac joints, and that although presenting unilaterally,
SIJP is not just a one-sided problem, as often suggested. Previous Osteopathic concepts regarding innominate tilt suggest that a single innominate can tilt unilaterally, where one side tilts independent (anterior or posterior) of the other side. However, for this to occur the symphysis pubis would have to move much more than is anatomically possible. The symphysis pubis is reported to only have 1.0-2.0 mm of motion. In those without SIJP, the amount of antagonistic tilt of the left and right innominate during reciprocal stance was nearly symmetrical suggesting that the left and right innominate tils equal yet opposite of each other. The kind of movement allows the two innominate bones to rotate together as a single unit around the sacrum, moving simultaneously at both sacroiliac joints, thus sparing the amphiarthrodial symphysis pubis joint from excessive shearing movement.

The finding of pelvic obliquity (uneven ASIS or PSIS) is common in patients with SIJP. When in a neutral stance for the subjects with SIJP the two innominate bones were always tilted opposite of each other, while those without SIJP were almost always nearly symmetrical. The mean of pelvic obliquity (pelvic tilt) found in patients with SIJP was 6.6°, when considering both sides (joints) are moving opposite of each other (thus summing both sides), this amount of movement is similar to previous studies. Previous authors who have conducted studies attempting to identify SIJP patients using innominate asymmetry have had significant design problems, including assessing the reliability of individual tests by themselves (yes/no) and not using information from complementary tests for feedback, as well as not integrating test results that supply the putative direction of innominate tilt (direction and side of tilt). For example, finding of a short leg that lengthens with the supine-long-sitting test suggests a posterior innominate tilt, while the long leg suggests an anterior innominate tilt, which should also agree with a finding of a lower PSIS on the same side of the shortened leg when in a seated position. If the test results don’t agree, there is a likely a problem, suggesting the need for additional re-testing to confirm. So far, none of the previous SIJP studies which reported poor test reliability used this kind of recursive method. As clinicians, using the diagnostic process, the sum of information is weighed from the patient's history as well as all of the clinical tests performed, not just information from a single test.

It is well understood that the pelvic girdle responds to muscle actions from above and below. Sacroiliac problems are often the result of asymmetrical muscle imbalances in the pelvis/hip. Asymmetrical muscle imbalances have been shown to be related to SIJP. Asymmetrical hip rotation, where hip rotation on one side (e.g. external rotation) is different (greater or lesser) than the opposite side, has been associated with SIJP, and those with asymmetrical hip rotation have hip rotator muscle imbalances. van Wingerden et al. showed that the forces from the biceps femoris muscle could influence the sacroiliac joint and thus low back kinematics. Vleeming et al. suggest the piriformis, gluteus maximus, and biceps femoris muscles all may influence the movement of the sacroiliac joint through their attachment to the posterior sacroiliac joint ligaments. Also, the active straight leg raise test, as suggested by Mens et al., lends further support to the concept that muscle action(s) can affect sacroiliac joint kinematics. Mens et al. noted an asymmetrical straight leg raise (signifying unilateral weakness of the hip flexors) on one side in peri-partum women with SIJP, may result in an anterior “hip” rotation. Similar to Mens et al. concept, a new method for assessing SIJP assessment relies on identifying pelvic muscle imbalances as a means to determine the presence and direction of innominate tilt. Many different combinations of muscle length or strength imbalances between the left and right sides of the hip/pelvis that possibly can produce an asymmetrical “pull” on the innominate bones. According to Kendall, asymmetrical muscle forces can create (strong or short muscles) or allow (weak or long muscles) a dysfunction. Thus, clinically a number of different muscle imbalances scenarios may exist creating or allowing a concomitant anterior tilt of one innominate and a posterior tilt of the opposite innominate. Thus, in clinical practice it is usually identifying the asymmetrical hip/pelvic muscle imbalance patterns that gives therapists the best information on the direction of left and right innominate tilt and therefore how to treat patients with SIJP.
Limitations
In this study, the PSIS's were palpated by only one examiner with 40 plus years of orthopedic clinic experience, and high inter-examiner reliability was demonstrated. Clinicians with less experience may produce different results. Also, all of the participants BMI were all fairly low, making palpation of the PSIS easy. If the BMI of the participants had been higher in this study, the results could have been different. Also, the population used in this study was relatively young, thus the results cannot be generalized to an older population. Finally, using pelvic calipers only captures simple differences between the left and right side, and the innominate bones move in a much more complex manner. Much more research is needed to explore how these joints move.

CONCLUSION
The innominate bones tilt in an equal and opposite fashion when measured in a reciprocal stance position, depending on whether the hip is flexed or extended, but not on the amount of hip motion (length of the stance). In SIJP a coupling failure may occur where the left and right innominate bones fail to fully tilt opposite of each other and remain in a neutral (anatomic) position. Understanding how innominate motion is altered in patients with SIJP will likely improve therapist’s ability to identify and treat patients with LBP from SIJP.

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ABSTRACT

Outcomes after long-term injuries such as anterior cruciate ligament reconstruction (ACLR) need improving. One area which has received limited research attention is the use of aquatic therapy to optimize the functional recovery process after injury. There is still limited understanding of what the benefits of the pool can bring for rehabilitation and particularly what and when can be done in the pool after injury. This clinical commentary describes how the application of the properties of water can support the functional recovery process after ACLR. Here it is proposed that the main properties (density, hydrostatic pressure, buoyancy and viscosity) of aquatic therapy, if applied correctly to rehabilitation practices, can be used to achieve six primary goals after ACLR: 1) assist in the reduction of pain and swelling; 2) support the recovery of gait; 3) support the maintenance and/or development of cardiovascular fitness; 4) help accelerate and optimize motor pattern retraining; 5) allow for earlier introduction of plyometrics and power training and 6) support the between session recovery and optimal load management, particularly in the later phases of rehabilitation. If implemented correctly, the presented phased protocol can support practitioners in implementing or delivering aquatic therapy rehabilitation services to their injured athletes. To support implementation, the authors have provided a specific protocol and supplementary videos for the use of aquatic therapy after ACLR.

Level of Evidence: 5

Key Words: Anterior cruciate ligament, aquatic therapy, rehabilitation, research translation

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BACKGROUND AND PURPOSE

Despite being perhaps the most discussed rehabilitation topic, there is no consensus on the best way to rehabilitate a patient after anterior cruciate ligament reconstruction (ACLR). It is well established that outcomes after ACLR are not perfect, with 35-45% of patients not returning to sport.\(^1\)\(^2\) Of those who do return to sport (RTS), 15% can expect a secondary ACL injury, with 30% of young athletes experiencing a re-injury within the first two years after RTS.\(^3\)\(^4\) Furthermore, there are associated long-term complications such as accelerated onset of knee osteoarthritis.\(^5\)

Recently, it has been suggested there is a need to optimize the rehabilitation process after ACLR in order to optimize patient outcomes.\(^6\) One area which has received limited research attention and may be potentially beneficial in optimizing the ACL rehabilitation process is aquatic therapy. Aquatic therapy does not refer to only different styles of swimming in rehabilitation (e.g., crawl, breaststroke etc.), rather, it includes all utilization of a water-based environment for therapeutic purposes during the rehabilitation process. The aquatic environment can be extremely beneficial for the rehabilitation of athletes after sports injury, if the properties of water are understood and maximized. The biological effects of immersion in water are related to the fundamental principles of hydrodynamics. Understanding these effects and the physical properties of water, such as density and specific gravity, hydrostatic pressure, viscosity and buoyancy, may help the sports medicine team maximize these properties to contribute to an optimized functional recovery program after ACLR. The main advantage of aquatic therapy in the functional recovery process is that activities or exercises can be introduced earlier in the functional recovery process than on land, potentially accelerating the recovery process and reducing the overall recovery time. This includes specific targeted exercises for development or maintenance of the neuromuscular and cardiovascular (CV) systems, at a low risk of injury.

Despite good theoretical relevance, there is a lack of actual research assessing whether aquatic therapy could support enhanced rehabilitation outcomes after ACLR. Research has assessed the short and long term benefits of exercise in water in both young and old individuals,\(^8\)\(^9\) assessing the benefits for CV training,\(^10\)\(^11\) and muscle strengthening.\(^12\)\(^13\) In addition, a systematic review comparing the effects of aquatic therapy and land-based exercise for people with arthritis found that aquatic therapy was comparable to land-based exercise in terms of functional outcomes.\(^14\) The authors recommended that aquatic physical therapy be used as an alternative to land-based physical therapy when people are unable to exercise comfortably on land.\(^15\) Given the range of limitations seen in athletes after ACLR, there are many benefits of aquatic therapy, which could support improved patient outcomes. Aquatic therapy is used regularly during the rehabilitation process after ACLR, however, there is a lack of published research demonstrating its clinical applicability. As such, this clinical commentary will attempt to bridge the gap between theory and research (based mostly on other injuries besides ACL as well as in un-injured participants) and rehabilitative practice. This commentary will specifically discuss the application and benefits of aquatic therapy to the functional recovery process following ACLR. In addition, the authors will share how aquatic therapy can be applied to the functional recovery of injured athletes, particularly after ACLR, providing a phased aquatic therapy protocol for use during the functional recovery process after ACLR through to RTS.

SIX-APPLICATIONS OF AQUATIC THERAPY
PRINCIPLES APPLIED TO THE FUNCTIONAL
RECOVERY PROCESS FOLLOWING ACLR

Utilization of the unique properties of water can facilitate optimal planning of rehabilitation sessions to support and optimize a functional recovery program. The six major applied benefits of aquatic therapy include:

1. Reduction of pain and swelling and restoration of joint range of motion
2. Recovery of normal gait cycle
3. Maintenance and/ or development of cardiovascular (CV) fitness
4. Movement pattern/ coordination training
5. Early introduction of plyometric training
6. Between-session recovery and optimal load management

**Reduction of pain and swelling and restoration of joint range of motion**

Early joint motion is beneficial when it comes to avoiding capsular contractions, reducing swelling and pain, and gaining early full passive and active extension appears to have no adverse effect on joint laxity. Unsatisfactory recovery of joint range of motion appears to adversely affect subjective and objective outcome markers in late-stage rehabilitation. Use of aquatic therapy can support the improvement in both joint swelling and passive and active range of motion. When an individual is submerged in water they are subjected to hydrostatic pressure. This pressure is directly proportional to the density of the liquid (e.g., gravity and depth to which the body is immersed). As such, this means it does not depend on the individuals body shape or the size or shape of the container (e.g., swimming or aquatic therapy pool), or the volume of water, but primarily on the depth of immersion. Water exerts a pressure of 22.4 mm Hg/ft of water depth, which translates to 1 mm Hg/1.36 cm (0.54 in.) of water depth. If an individual is immersed to a depth of 120 cm they are subjected to a force equal to nearly 90 mm Hg, which is slightly higher than the normal diastolic blood pressure.

If the water pressure is higher than diastolic blood pressure this will result in fluid shifts forcing fluid out of the joint and supporting optimized venous return and lymphatic system drainage (return). This could thus help with resolution of inflammation/swelling, facilitate reduced swelling and positively influence (increase) joint range of motion. Normal or optimal gait biomechanics cannot occur without normal or optimal joint motion, so resolving impairments as early as possible after surgery is important to target early gait restoration.

Immersion in water also desensitizes the injured area, as pain perception is diminished, due to an elevated pain threshold, which may be due to the stimulation of sensory nerve endings in the skin and sensory overflow. As such, this may facilitate (alongside the reduction in joint swelling) greater possible joint range of motion than possible at the same time-point on land, again facilitating the recovery of both passive and active range of motion.

**Recovery of normal gait cycle**

Following ACLR, a patient cannot typically fully weight bear or walk without crutches for a period of time, often around four weeks. Patients often can develop faulty gait patterns after injury, due to movement compensations to protect the injured joint. Abnormal gait patterns have been associated with joint weakness, decreased functional performance, low patient satisfaction with outcome after surgery and post-operative complications, including osteoarthritis. Re-establishing normal gait early after surgery is a key priority of the functional recovery process.

The properties of water, specifically density and buoyancy, can support maintenance and early normalization of optimal walking gait in ACLR patients, due to reducing the effects of gravity and allowing the practice of walking at lower body weights and joint loads. Density is the ratio between the mass of a substance (kg) and the space in which it occupies (m³). The density of water at 1 atmospheric pressure and 4 degrees C is 1000 kg/m³. The mean density of the human body is less than water at 950 kg/m³, although this varies person to person, with men averaging higher than women. Lean body mass, which includes bone, muscle, connective tissue, and organs, has a typical density near 1.1, whereas fat mass, which includes both essential body fat plus fat in excess of essential needs, has a density of about 0.9. The relationship between the density of water and human body (with the latter being less) means an individual can float in water (although more muscular athletes may have a tendency to sink). Buoyancy is defined as the upward thrust acting in the opposite direction to the force of gravity. A human with specific gravity of 0.97 reaches floating equilibrium when 97% of his or her total body volume is submerged. As the body is gradually immersed, water is displaced, creating the force of buoyancy, progressively off-loading immersed joints. The greater amount of the body immersed in water, the greater the off-load of body weight. A person immersed to the symphysis pubis has effectively offloaded 40% of his or her body weight; 50% when immersed at the umbilicus and 60% at the Xiphoid
depending on if the arms are in or out of the water. Immersion to neck height, would leave only around a 7kg weight (off-load of around 90% body-weight) of compressive force (e.g., the weight of the head), which would be exerted on the body.

Thus, during the early stages of the functional recovery period after ACLR, walking gait should be first trained in the pool at various water depths (progressing from deeper to shallower), in order to enable the removal of a proportion of body weight to facilitate optimal gait patterns, as needed. Furthermore, walking in water can present a challenge to dynamic stability and support the retraining of dynamic movement control in a safe environment. The walking gait re-education program should include selective movement retraining exercises to support the motor re-training process (e.g. standing marches in place, with optimal lumbar pelvic control and hip, knee and ankle flexion).

**Maintenance and/or development of cardiovascular fitness**

Preserving CV fitness parameters such as maximal aerobic capacity, lactate thresholds and running economy during the rehabilitation process is important for endurance and game sport athletes (e.g. football players) following long-term injuries such as ACLR. Recent research indicates that professional football players report deficits in aerobic fitness still six-months following ACLR, indicating a greater need to incorporate CV conditioning during the functional recovery process. It has also been suggested that exercise based CV training can be a useful tool that can allow injured athletes to maintain CV fitness and ultimately running performance. For example, over a 22-month period, Burns and Lauder examined the effects of deep-water running on 181 active-duty army soldiers with injuries that prevented them from undertaking their regular weight-bearing exercise and suggested that VO\textsubscript{2} max and running performance can be maintained while soldiers are restricted from weight-bearing aerobic training.

Water creates a resistance greater than that experienced during locomotion on land. This greater resistance is not only due to the water density but also its dynamic viscosity. Viscosity refers to the magnitude of internal friction specific to a fluid during motion. A limb moving relative to water is subjected to the resistive effects of the fluid called drag force and turbulence when present. Viscosity, as well as buoyancy and density of water mean that exercises such as deep water running or treadmill running (if carried at sufficient speeds/intensities and the right depth of water) can allow for the performance of CV exercise, which can result in similar CV responses to running on land. There are numerous studies which have analyzed the effects of water-based training, which suggest that improvements in maximal aerobic capacity (VO\textsubscript{2} max) from 12-40% in sedentary or lower physically fit individuals, while it can support the maintenance of CV fitness parameters (running performance, VO\textsubscript{2} max, lactate threshold) in trained athletes.

It is essential to ensure similar intensities that are used during land-based training to ensure an optimal workout and ensure optimal technique during exercises such as deep water running. A period of time to focus on technique during deep water running is recommended as part of the rehabilitation process, prior to focusing on CV responses/intensity. Optimal technique during deep water running would also support the maintenance/retraining of running gait. Monitoring the athlete with appropriate heart rate monitoring systems can facilitate the analysis of the CV responses (and as such desired exercise intensity). The value of this type of work would support the maintenance of CV fitness in a non-or low-load bearing manner. Cardiac output has been reported to increase by 30–35% when an individual is at rest, immersed in water. This increase has been attributed to an elevated stroke volume, which in turn is due to an enhanced diastolic filling. During exercise in water, an increase stroke volume has been reported to be higher at any given submaximal or maximal exercise intensity in water when compared with values obtained on land. As such, there is typically a reduction in heart rate at equivalent exercise intensities in water versus on land, of around 10-15 beats per minute which should be accounted for when monitoring and reporting exercise intensity and volume in water based training. Thus, it is advised to implement deep water running, while simultaneously monitoring heart rate of
the athlete, adjusting the HR parameters (e.g., if the training goal on land is 80% maximum heart rate at 160 beats per minute, then the equivalent intensities in the water would be 150 beats per minute for the same relative intensity) to achieve equivalent intensities in the water as on land to preserve CV fitness during the functional recovery period.

Movement patterns/ coordination training
Targeted movement re-training is important after injury to correct at risk biomechanics which may have either been prospectively linked to the initial injury, have occurred secondary due to changes associated with the injury or a combination of both. Altered movement biomechanics and postural control deficits are associated with heightened risk of re-injury upon RTS after ACLR. Conventional rehabilitation practices appear to be ineffective at restoring movement quality prior to RTS. Individualized movement re-training programs targeted at factors which contribute to movement dysfunction such as neuromuscular and biomechanical factors (arthrokinetic dysfunction, synergetic dominance, muscle imbalances, reciprocal muscle inhibition), as well as neurocognitive and sensorimotor factors are required. Failure to correct movement impairments could be linked to insufficient quality, intensity or volume of movement based training. In particular relevance to this commentary, it appears that neuromuscular retraining to develop strength (e.g. use of isolated exercises such as knee extension) is insufficient at optimizing movement quality, and there is a need to allow for movement practice following or during neuromuscular training in order to relearn appropriate movement patterning and optimize coordination. It is necessary to undergo a comprehensive movement retraining and coordination program to retrain optimal motor control and ‘integrate’ newly achieved muscle strength into the motor patterns. Thus, stressing the need for a balance between strength and movement training to optimize movement quality. This movement retraining process after ACLR, without the use of aquatic therapy is typically done in systematic manner in which the patient has a period of strength training to resolve muscle imbalances, followed by coordination training to relearn optimal movements. This is because during the early and middle periods of the functional recovery process after ACLR the patient is typically load compromised and cannot tolerate the loading parameters which accompany many functional sporting type tasks. The fact that water acts as a counterbalance to gravity, means that functional strengthening/ movement exercises (e.g., squat, step up, lunge) can be introduced earlier than possible on land. This can facilitate earlier introduction of motor training allowing for the simultaneous training of muscle strength (largely in the gym) and motor control (in the pool) during the early and middle stages of rehabilitation. The same holds true for the earlier introduction of running (using buoyancy devices and at various pool depths), jumping, landing and plyometric techniques, which can all be introduced at lower loading parameters than possible on land, thus accelerating the motor relearning process. This would be expected to maximize the progress through mid-stage rehabilitation, allowing for more appropriate restoration of functional performance, and provide a superior movement quality foundation on which to commence late-stage rehabilitation. Exercises such as jumping and single leg balance training in water have been shown to result in similar functional improvements, to the same exercises performed on land. The benefit of been able to perform them in water at lower body weight/impact forces means they can be introduced safely and earlier in the rehabilitation program.

Early introduction of plyometric training
The ability of the neuromuscular system to develop force is important to provide dynamic stability to a joint, as well as for optimal force propulsion. Typically, there is an over-reliance on isolated maximal muscle strength after ACLR, with less consideration of the ability to develop force rapidly. It is typically limited time to develop force during explosive sporting movements such as sprint running (80-120 ms), or rapid joint stabilization to prevent joint injury after mechanical perturbation (< 50 ms). It takes around 300 ms for the neuromuscular system to generate peak force. Hence, the capability to produce force during rapid sporting tasks (i.e. explosive efforts) may be more dependent upon the ability to increase force quickly from low levels,
termed rate of force development (RFD), than on maximal muscle strength. As such, RFD appears to be an important aspect of neuromuscular function and may require additional consideration in late-stage rehabilitation programs. From the available evidence, it appears that RFD is not effectively restored after injury prior to RTS. Angelozzi et al. identified deficits of RFD of 30% in ACLR patients at six months, despite almost full (97%) restoration of maximal concentric knee extensor strength. RFD was restored at 12 months following the incorporation of a program based on power development.

As well as RFD, the ability to generate maximal power during complex motor skills is also of major importance to successful athletic performance across many sports. Mechanical power is typically referred to as the rate of doing work and is determined by multiplying force by velocity. Based upon this equation, it is evident that the two central components that impact the athlete’s ability to generate high power outputs are the ability to apply high levels of force rapidly and express high contraction velocities. As such, maximal strength, RFD and high velocity strength are important elements of neuromuscular performance which need to be restored following injury. Power is influenced by numerous factors including slow velocity muscle strength, fast velocity muscle strength, RFD, ability to maximize the stretch-shortening cycle, and intra and intermuscular coordination. It is important that the rehabilitation process utilize a mixed methods approach to developing power, which should include the use of strength training, but also plyometric training, in order to target all the factors which may contribute to explosive power capabilities.

Lower extremity plyometric exercises are commonly used by athletes to develop explosive speed, strength, and power. They involve stretch-shortening cycle activity, where eccentric muscle contraction is quickly followed by concentric contraction of the same muscle (or muscles). During the eccentric phase (pre-stretch), the musculotendinous unit is stretched, which stores elastic energy, and the muscle spindles activate the stretch reflex. Plyometric training has been reported to be superior to more traditional resistance training for development of explosive lower limb performance and can contribute to improvements in lower limb strength and power, increased joint awareness, and overall proprioception. Performance of high-intensity plyometric exercise often produces muscle damage, due mainly to the eccentric component of the muscle action, and excessive joint loading (ligament, joint structures, tendon), which could result in injury. Typical impact forces during plyometric exercise on land is between two to six times body mass depending upon the specific plyometric task. Deficits in functional eccentric muscle strength of the lower limbs would mean insufficient neuromuscular capacity to eccentrically absorb these forces, with greater reliance on joint complexes (tendon, ligament and joint structures) for force absorption. This could result in increased injury risk or an overload response to the joint. Plyometric training often forms an important aspect of late-stage rehabilitation/ RTS training, once the necessary functional capacity to tolerate these high forces has been restored. However, in water, the buoyancy force controls the downward (landing) movement of the body, thus generating higher upward (concentric) and lower downward (eccentric) forces. There appears to be a reduction of around 45-60% in peak ground reaction forces recorded from plyometric exercise in water versus on land. Furthermore, plyometric training in water versus land appears to result in reduced joint inflammation and perceived pain in the subsequent hours and days after training. Additionally, similar characteristics in terms of power and explosive force production during the concentric phase have been reported during plyometrics in water versus land, thus, mimicking the neuromuscular stimulus for adaptation in power at a lower level of impact forces and muscle soreness/ joint overload. Plyometric exercise in water can offer an alternative to land based plyometrics which can be both introduced earlier in the program, with lower risk of joint injury and/or overload and use as a supplement to land based exercise to limit the impact forces and overall training load while maximizing neuromuscular training benefits (e.g., introduction to sport-specific on-field training and elevated body loading demands).

There appears to be a large individual variation in terms of the load reduction in water versus land,
which can partly be attributed to water depth, participant height, body composition, and landing techniques. Koury and Miller et al. recommended performing aquatic plyometrics in waist height water. They suggest that deeper water may impair movement control and coordination, making it more difficult to maintain stability in an upright position, whilst also decreasing the stretch-shortening cycle reaction time, and increasing drag due to arm swing through the water. Clearly, there is a need to use appropriate coaching techniques, observation and where possible filming (with underwater cameras) and providing appropriate feedback (real-time or delayed) on technique. Furthermore, having optimal complexity and load progression as part of a structured program (e.g., squat jump – countermovement jump – drop jump) is essential to ensure optimal learning and adaptation, as well as safe loading progressions.

The typical ground reaction forces during land-based running range from 2-3 times body mass meaning plyometrics in water may be used prior to (e.g. use of bilateral plyometrics) and during (e.g. bilateral and unilateral plyometrics) the implementation of return to running program, and as preparation for plyometric training on land.

**Between session recovery and optimized load management**

Deep water running has been recommended for players to accelerate the recovery process between matches. It also has relevance for recovery during the rehabilitation process, where patient athletes are reconditioning their bodies for athletic activity. Reilly et al. investigated the benefits of deep water running in accelerating the recovery process after a strenuous bout of plyometric exercise. Deep water running failed to prevent delayed-onset muscle soreness, but appeared to speed the process of recovery for leg strength and perceived muscle soreness. Leg strength was reduced by 20% on average for other groups (rest and treadmill runs) after 48 hours, but only by 7% for the deep water running group, while soreness was also reduced by 40% in the deep water running group.

Optimal loading may be defined as the load applied to structures that maximizes physiological adaptation. Rehabilitative exercise stimulates a series of homeostatic responses and accompanying adaptations of the human body system. It is essential that the rehabilitation program incorporates progressive optimal loading to facilitate functional recovery without overloading the muscle, ligament, tendon or joint and as such potentially compromising the regeneration process. Pool based exercise such as CV training, movement practice including ballistic and plyometric training can allow for a higher volume of training at lower relative loads to if performed on land. Therefore, the pool can be used for supplementary exercise on recovery days (e.g., a non-strength or on-field training day), even during the late-stage and RTS training stage of the functional recovery process after injury. This concept applies especially to the elite athlete or professional player after long-term injury such as after ACLR.

**Implementation into practice: Practical use of aquatic therapy during the functional recovery process after ACLR in professional athletes**

The properties of water (buoyancy, density, hydrostatic pressure and viscosity) can be utilized to implement an aquatic rehabilitation program which if planned correctly may help optimize patient outcomes after ACLR. The six discussed benefits of aquatic therapy 1) Reduction of pain and swelling and restoration of joint range of motion; 2) recovery of normal gait cycle; 3) maintenance and/or development of CV fitness; 4) movement patterns/coordination training; 5) early introduction of plyometric training and 6) between-session recovery and optimized load management should be utilized effectively to complement an existing functional recovery process.

**The functional recovery process:** To be able to effectively design the right aquatic therapy program after ACLR, it is important to have a well-structured functional recovery process in place. There is no gold standard ACL rehabilitation approach, but having criterion-based rehabilitation with specific criteria to progress through stages or phases is regarded as best practice. The functional recovery process described here can be broadly defined as a series of phases or stages, including:
1. Early stage rehabilitation which is focused on resolving pain and swelling, recovering sufficient knee joint range of motion, recovery of activities of daily living including the ability to walk without crutches, and minimization of muscle atrophy.

2. Mid-stage rehabilitation which is focused on restoring strength imbalances (to within 20% of the contralateral limb), basic motor patterning (e.g., functional exercises such as squat and running gait) and physical re-conditioning.

3. Late-stage rehabilitation which is focused on optimising neuromuscular and movement performance.

4. Sport-specific re-training and RTS (consisting of on-field rehabilitation, return to training and return to competition).\(^{83}\)

It is important that the aquatic therapy program be aligned to this functional recovery approach and the specific activity fit with the functional recovery stage to optimize its implementation and improved clarity amongst all members of the sports medicine/ rehabilitation team. This ideal program should always be considered as part of a functional recovery approach comprising gym-based, pool-based and on-field rehabilitation.\(^{22}\) The aquatic therapy program is an important element of the process, and should not be considered in isolation. It is essential to ensure that the correct work is undertaken at the correct time and aligned with the activity of the gym based (or field) rehabilitation program. As such, considering the specific activity outside the pool and the functional limitations are needed to prioritize the activity within the pool (see Table 1). Of note although this program can be utilized for all ACLR patients, it is important to recognize that aquatic therapy stages 2-4 are an adjunct to land-based rehabilitative training and a minimum volume of land-based work is needed prior to considering the addition of aquatic therapy. For example, if a patient can only undertake two to three sessions per week then this time should be better prioritized on land-based gym and/or on-field activity, at least within stages 2-4. For these individuals, aquatic therapy may be particularly beneficial in the early stage of recovery (e.g., stage 1- ‘post-op pool’). Those involved in professional athlete schedules, can have good benefit from the incorporation of aquatic therapy throughout their functional recovery programs (Figure 1).

Below it is shown how the aquatic therapy program can be aligned with this recovery process with discussion on important concepts for each stage, providing prescriptive advice for the professional athlete after ACLR for each stage. The authors also share supplementary video of the type of activity which can be undertaken within the aquatic therapy pool.

1. ‘Post-op pool’ (early-stage rehabilitation)

Post-operative pool typically commences around two weeks after ACLR, when a patient is safe to enter the water. The main contraindications to its use in

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**Figure 1.** The use of hydrotherapy in the recovery process after ACLR. Two standard stages have been identified and applied on all the ACLR patients in the first phases of recovery. Two other distinct stages may be applied to the elite athletes to optimize late phase rehabilitation and return to sport training. ACLR: anterior cruciate ligament reconstruction; ROM: range of motion; CV: cardiovascular; OFR: On Field Rehabilitation.
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this stage are wound healing and risk of infection so stitches have to be removed and surgery scars should be free from the phlogosis signs (Table 1). Early post-op aquatic therapy is mainly concerned with overcoming the effects of surgery and complementing the activity in the gym. It is focused predominantly on supporting the resolution of pain, swelling, joint range of motion and recovery of walking gait. During this stage, the athlete often has restricted range of motion, is using crutches on land when walking and is limited in their movement/ability to perform activities of daily living. It is important to incorporate active range of motion exercises to facilitate active range of motion and avoid joint stiffness. The desensitization in the pool and swelling can facilitate greater active and passive range of motion than possible on land. During this early period, the patient may not be able to use devices such as the stationary bike due to range of motion limitations and thus active range of motion on land may be difficult. The

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<tr>
<td><strong>Typical duration</strong></td>
<td>- Weeks 2-4 after surgery</td>
<td>- Weeks 5-12 after surgery</td>
<td>- Weeks 13-18 after surgery</td>
</tr>
<tr>
<td><strong>Entry criteria</strong></td>
<td>- Medical clearance to commence hydrotherapy</td>
<td>- Ready to transition to mid-stage rehabilitation:</td>
<td>- No pain/swelling</td>
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**Table 1. A staged aquatic therapy rehabilitation approach for the athlete after ACL reconstruction.** The program involves four stages aligned with the functional recovery status of the athlete after ACL reconstruction. The particular goal, strategy and approach are outlined. The program outlines a typical approach (and allocated time) for a professional athlete, who was able to return to team training at six months after ACL reconstruction. Time lines are dependent upon the injury (e.g., concomitant injury, such as cartilage, medial collateral ligament), and individual healing and progressions. Criteria and not time should be used to transition between phases ensuring entry and exit criteria are achieved. Importantly, aligning the activity in the pool to the activity on land is important.

**Typical duration**
- Weeks 2-4 after surgery
- Weeks 5-12 after surgery
- Weeks 13-18 after surgery
- Weeks 19+ after surgery

**Entry criteria**
- Medical clearance to commence hydrotherapy
- Surgical wounds: no signs of inflammation (swelling, redness, increased temperature swelling)
- Surgical wounds: stitches removed by medical staff
- Ready to transition to mid-stage rehabilitation:
  - Minimal pain (0-1 NPRS)
  - Minimal swelling (zero to trace effusion)
  - Knee extension to 110°
  - Sufficiently normalized gait outside the water with no side (e.g., no crotches)
  - No evidence of quadriceps dysfunction (e.g., quadriceps lag test)
- No pain/swelling
- Symmetrical 90° ROM
- Knee flexor and extensor LST > 80°
- Good subjective movement quality on land-based foundation tasks (e.g., bilateral and unilateral squat, step-up, lunges and hip hinge)
- Ability to run on the treadmill at 6 km/h for 10 minutes with good mechanics
- Be undertaking return to sport training

**Goals for the phase**
- Support the resolution of swelling
- Aid the recovery of ROM
- Support the recovery of correct gait cycle
- Enhance early recovery of flexibility
- Restoration of basic motor patterning
- Introduction and utilization of DWR for motor patterning and subsequent use for CV conditioning
- Late recovery of flexibility
- Continued fluidity exercises to support active range of motion
- Progressive introduction of BL and then UL landing and jumping work to develop biomechanical control (10 weeks+)
- Sport-specific neuromuscular exercises (healing, catching, throwing)
- High intensity plyometric exercises
- Sport technical gestures
- Physical conditioning
- Accurate recovery between on-field and gym land based sessions
- Allow for reduced loading training such as plyometric exercise and CV conditioning at a lower body loads

**Pool exercises**
- Walking, cycling, stretching, basic motor patterning (e.g., standing marching exercises) and gait re-training (see supplementary video 1)
- First half (weeks 5-8): DWR, squat, step up, standing balance and neuromuscular control exercises, functional strength exercises using additional modalities (e.g., standing press against rubber ring)
- Second half (weeks 9-12): Introduction of landing and jumping exercises for neuromuscular control

<table>
<thead>
<tr>
<th>Activity outside the pool</th>
<th>Rehabilitation gym</th>
<th>Rehabilitation gym</th>
<th>Rehabilitation gym / Movement environment</th>
<th>Rehabilitation gym / Movement environment</th>
</tr>
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<tbody>
<tr>
<td>- Hip-based eccentric strengthening</td>
<td>- Resisted training exercises using low-loads for muscle endurance training (12-20 RM range)</td>
<td>- Resisted training exercises using low-loads for muscle endurance training (5-8 RM range)</td>
<td>- LB high load isolated strength training (3-5 RM)</td>
<td>- LB high load isolated strength training</td>
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<tr>
<td>- ROM exercises</td>
<td>- Off feet core corrective training (e.g., transverse abdominis, bridges, clam, side leg raises etc.)</td>
<td>- Off feet core corrective training (e.g., transverse abdominis, bridges, clam, side leg raises etc.)</td>
<td>- Bilateral plyometrics</td>
<td>- Bilateral plyometrics</td>
</tr>
<tr>
<td>- Treatment modalities (TENS, electrical stimulation, ICE, massage)</td>
<td>- Basic motor control drills (BL squat, marching exercises, gait, walking on treadmill)</td>
<td>- Basic motor control drills (BL squat, marching exercises, gait, walking on treadmill)</td>
<td>- Landing drills, jumping drills</td>
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<td>- Progression to land based functional exercises (single leg squat, hip hinges, step-up, split squat)</td>
<td>- Off feet CV conditioning (bike, cross-trainer)</td>
<td>- Off feet CV conditioning (bike, cross-trainer)</td>
<td>- Core strength/ stability (load transfer)</td>
<td>- Core strength/ stability (load transfer)</td>
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<tr>
<td>- Standing humeral strengthening exercises (standing clam, lateral band walks)</td>
<td>Second half (weeks 9-12)</td>
<td>Second half (weeks 9-12)</td>
<td>- LB strength, core endurance and aerobic fitness on recovery days</td>
<td>- LB strength, core endurance and aerobic fitness on recovery days</td>
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<tr>
<td>- Moderate load resistance training for hypertrophy and strength development in open and closed kinetic chain exercises (8-12 RM range)</td>
<td>- Multidirectional running drills (pre-planned)</td>
<td>- Multidirectional running drills (pre-planned)</td>
<td>- On-field</td>
<td>- On-field</td>
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<td>- Running re-education with axial/45° transverse/treadmill</td>
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<td>- Multidirectional agility drills</td>
<td>- Multidirectional agility drills</td>
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<td>- Technical based sports re-training</td>
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<td>- Fitness training</td>
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<td>- Plyometric training</td>
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CV, cardiovascular; NPRS, Numeric pain rating scale; ROM, range of motion; LST, limb symmetry index; DWR, deep water running; BL, bilateral; UL, unilateral; TENS, transcutaneous electrical nerve stimulation; ICE, ice, compression, elevation; RM, repetition maximum; LB, lower body; UB, upper body
motor pattern re-training. For example, deep water running can be used to support CV fitness training and restoration/development of aerobic endurance, but also support running gait re-education with the impacts associated with running on land. This holds true for other exercises such as important functional tasks such as squat and lunging, and high load landing control (jumping and landing exercises). This is highly beneficial psychologically for the athlete as they can commence ‘performance-based training’ in the pool. Introduction of neuroplasticity exercises that can mimic the sport-specific movements (without loading the knee joint) can commence at this stage. These include exercises such as heading a football while seated on a floating device (e.g. rubber ring) to challenge postural control (Figure 2).

Given the range of complexity of exercises within stage 2, the phase as a whole and the pool program are typically broken down into two sub-phases (stage 2.1, stage 2.2). The first half is when the athlete is undertaking basic muscle endurance in the gym, as well as core corrective exercises performed in a non-load bearing position (e.g., exercises on the bed) due to being too load compromised to practice weight bearing functional exercises (e.g., not strong enough to commence unilateral functional exercises such as single leg squat). During this stage it is highly beneficial to incorporate corrective movement training using foundation exercises (e.g., lunging, squatting etc.) in the pool, as well as deep water running. As

![Figure 2. Neuroplasticity exercise in the pool.](image)
the athlete becomes stronger and overcomes many of the aspects of neuromuscular dysfunction following surgery, they can generally commence higher load strengthening in the gym (e.g. transition to moderate load resistance training to restore muscle hypertrophy and strength), and weight-bearing exercises on land (generally the second half of this stage), including progressions towards treadmill running. Thus, when they are able to perform these tasks on land, there is less need to perform them in the water. Therefore, during the second half of this stage, patients can practice higher loading impact exercises in the pool (allowing for around a 50% reduction in impact forces), such as two-leg and one-leg landing exercises (also using the trampoline as a progression, Figure 3), bilateral jumping exercises to support the development of lower body power (Figure 4), and treadmill running at the appropriate depth. These movements can be performed once the patient is sufficiently strong enough and has the desired level of neuromuscular control (the tasks can still involve around 1.5-2

Figure 3. Running in place (A), and single leg landing on trampoline (B).

Figure 4. Bilateral jumping for power development with A, countermovement phase, B, flight phase and C, landing phase.
as a useful adjunct to the program to enable some of the exercises which cannot be done initially on land to be performed in the pool. For example, initially in this stage, the patient can run on land and begin a landing and jumping progression program, but unilateral plyometrics are typically done towards the end of this stage (therefore minimizing the opportunities to train explosive neuromuscular control and power under sport-specific movement demands).

Thus, during the initial period of the stage, the patient can perform some of the high load exercises on land (e.g., bilateral plyometrics and unilateral landing drills) and the remainder in the pool (e.g., unilateral plyometrics, Figure 5). Practicing these unilateral plyometric exercises in the pool can support technique learning which can then be applied on land. It can also be used to manage the loading of the athlete when they commence high load exercise on land and support athletic conditioning on land by providing an opportunity to perform some of the work in the pool at lower loads (the pool will reduce impacts loading by around 50%).

Aquatic therapy is typically used more sporadically in this phase to complement existing programs in conjunction with times body mass). Importantly, the athlete should not perform unilateral plyometrics in this stage, as they involve potentially dangerous knee joint loads, even if in water (ground reaction forces of 2-4 times body mass). See Table 1 for specific exercise content in this stage. Also see supplementary video 1 demonstrating movement-based re-training in the pool.

3. ‘Intense conditioning and field preparation’ (late-stage rehabilitation)

Late-stage rehabilitation and pool training is an intense program designed to simulate sport-specific training on land to prepare for beginning sporting type movement training on the field. In addition, the athlete transitions to high load movements on land such as running, deceleration, jumping and landing exercises, prior to being able to perform unilateral plyometrics and multi-directional coordination exercises on the field. As such, the benefits of the pool are less dramatic as the majority of activity can be performed on land during this stage and aquatic therapy is less essential in this stage than during previous stages (and generally not required in non-professional athletes). However, the pool can used as a useful adjunct to the program to enable some of the exercises which cannot be done initially on land to be performed in the pool. For example, initially in this stage, the patient can run on land and begin a landing and jumping progression program, but unilateral plyometrics are typically done towards the end of this stage (therefore minimizing the opportunities to train explosive neuromuscular control and power under sport-specific movement demands).

Thus, during the initial period of the stage, the patient can perform some of the high load exercises on land (e.g., bilateral plyometrics and unilateral landing drills) and the remainder in the pool (e.g., unilateral plyometrics, Figure 5). Practicing these unilateral plyometric exercises in the pool can support technique learning which can then be applied on land. It can also be used to manage the loading of the athlete when they commence high load exercise on land and support athletic conditioning on land by providing an opportunity to perform some of the work in the pool at lower loads (the pool will reduce impacts loading by around 50%).

Aquatic therapy is typically used more sporadically in this phase to complement existing programs in conjunction with

Figure 5. Unilateral plyometric exercise involving forward A, step off from step, B, landing followed by immediate jump and C, single leg stabilisation on box and lateral drop jumps (D, step off, E, landing and jumping transition and F, lateral landing on step).
land based movement training (e.g., a short aquatic therapy session after a land based movement session for specific work, some deep water running and unilateral plyometric tasks). See Table 1 for example activity in this stage.

4. Recovery pool - (RTS training)

During the on-field rehabilitation process athletes are practicing sport-specific training on the field and are typically involved in re-conditioning work in the gym (e.g., strength and power training, neuromuscular control). During the on-field rehabilitation process, the pool can be used as a useful adjunct to the standard program to support accelerated recovery and low load conditioning between on-field sessions. During on-field rehabilitation, managing the workloads of the athlete is particularly important, as he/she is introduced to training type activity to prepare them to return to their team environment. As such, there is typically a rapid increase in training load. Optimizing recovery between sessions similar to general athlete training is important. As such, the pool can be used as a recovery tool to support low load conditioning and accelerated recovery between rehabilitation sessions. This is particularly relevant following intense training days on the field and/or in the gym, which designed to load the athlete to develop their tolerance to increased training demands. See table 1 for example activity in this stage.

SUMMARY

The properties of water (buoyancy, density, hydrostatic pressure and viscosity) can be utilized to implement an aquatic therapy program, which if planned correctly can facilitate the development of an optimized functional recovery program following injury. The six discussed benefits of aquatic therapy 1) reduction of pain and swelling; 2) recovery of gait; 3) maintenance and/or development of CV fitness; 4) motor pattern/ coordination training; 5) earlier introduction of plyometric training and 6) between-session recovery and optimized load management should be used effectively to complement an existing functional recovery process. It is essential to ensure that the aquatic therapy program is aligned with the ACLR functional recovery approach as a whole. The authors have provided a four-stage aquatic therapy program to complement existing land based ACL functional recovery programs that consists of 1) post-operative pool; 2) movement and CV conditioning; 3) intense conditioning and field preparation and 4) recovery pool.

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ABSTRACT

Flywheel training is a relatively new method used to train the human body with continuous resistance and eccentric overload. The performed exercises result in improvements of strength and power, hypertrophy, muscle activation, muscle length, and tendon stiffness. Other positive effects of flywheel training are athletically relevant improvements in things such as speed, jump height and change of direction. The positive results can be explained by the eccentric and power characteristics of the training, making flywheel training ideal for use in musculoskeletal rehabilitation. Flywheel training can be used for injury prevention, training after a period of unloading, tendon and muscle rehabilitation, as part of post-operative rehabilitation, during late stage sport specific rehabilitation as well as for fall prevention and treatment of sarcopenia among elderly. The purpose of this commentary is to inform physical therapists about the use of flywheel training in musculoskeletal rehabilitation.

Keywords: eccentric overload, flywheel training, power training, rehabilitation, tendinosis, movement system

Level of evidence: 5
INTRODUCTION

Flywheel training is a relatively new training method used by physical therapists. The positive effects of flywheel training in fitness and training are well documented and multiple reviews have been written.\(^4\) However, flywheel training has received scant attention in the rehabilitation and sports physical therapy literature. This clinical commentary will address the value of flywheel training in musculoskeletal rehabilitation.

A flywheel is a heavy wheel, measured in inertia, that needs externally applied force to spin around. The force required to set it spinning is also needed to make it stop. When a flywheel is spinning at high speed, it will keep spinning because of the angular momentum it has. This means it can store kinetic energy like a battery. The heavier and larger the flywheel, the more energy it can store. Speed is key in flywheel training. A flywheel that spins faster stores much more energy than one that spins slower. A variety of different flywheel devices are used in training settings, for instance boxes and pulleys (Figure 1). It is important that those devices have minimal friction by the rope to maintain high speed. The axis of the device has to be relatively big and light to keep the kinetic energy stored. The athlete or patient needs to move to keep the flywheel spinning and will do so by using his or her strength and power. Power training using a flywheel is an explosive way of training by which muscles will contract at maximum force in minimum time.

The use of a flywheel device for muscle training goes back to 1913 when Swedish researchers published regarding the physiology of muscles using a bicycle ergometer with a flywheel for resistance.\(^1\) In 1994 other exercise physiology scholars from

Figure 1. Flywheel pulley (above) and flywheel box (below).
Sweden developed and validated a flywheel ergometer to prevent muscle atrophy and loss of strength by astronauts in space. Because flywheel training is gravity independent, it has been used for resistance training by astronauts in space ever since. The gravity-independent character of flywheel exercises results in continuous resistance and eccentric overload. This isoinertial type of resistance facilitates optimal muscle force generation throughout all the angles of a movement. Improvements in muscle strength are experienced throughout the full range of motion. In addition, greater eccentric muscle activation occurs during flywheel training compared with normal weight training. The purpose of this commentary is to inform physical therapists about the use of flywheel training in musculoskeletal rehabilitation. To this end, the effects of flywheel training and the physiology behind these positive effects are summarized. Second, the use of a flywheel in prevention and rehabilitation of musculoskeletal injuries will be discussed.

**TRAINING EFFECTS**

A vast amount of research has shown that flywheel training is effective in increasing strength, hypertrophy, muscle activation, muscle length, tendon stiffness and power. In addition to these physiological benefits, flywheel training results in athletically relevant improvements. Increases in speed, jump height and change of direction are documented in a number of scientific articles. A review by Tesch et al. described the benefits of flywheel training for healthy individuals, athletes, astronauts, elderly, musculoskeletal and neurological patients as well as how it can assist in injury prevention among athletes. One of those benefits is that compared with weight training, flywheel training has demonstrated greater global EMG activity and greater muscle use, as measured by functional magnetic resonance imaging (fMRI). Another benefit identified in the review is the improvement of the post-activation potentiation (PAP) phenomenon, which refers to athletes improving in speed during their sports activity shortly after performing a bout of flywheel exercise. A systematic review and meta-analysis by Maroto-Izquierdo et al. provides more detailed information regarding the adaptations that occur in muscle tissue of healthy and trained individuals after performing flywheel training. According to Maroto-Izquierdo et al., compared with weight resistance training, flywheel training results in greater improvements in muscle power, muscle hypertrophy, and athletically relevant elements such as vertical jump height and running speed.

When using flywheel training in musculoskeletal rehabilitation, it is important for the therapist to know the physiology behind the exercises in order to optimize the benefits. This way the therapist can make better informed decisions, resulting in improved outcomes for the patient. So why does flywheel training give good results? Power training and eccentric overload training are two characteristics of flywheel training that can explain the positive results found in scientific research. The ability to train with high speed and high power implies that the exercises closely resemble many functional and athletically relevant movements. Flywheel training makes use of the stretch-shortening cycle, leading to, compared with weight resistance training, greater efficiency in the stretch-shortening cycle, higher specificity and enhanced adaptation during rehabilitation. Another noteworthy physiological change that has been documented after flywheel training is the hypertrophy of type II muscle fibers. Importantly, the described effects occur without triggering pain in patients with a musculoskeletal injury. Skeletal muscle shows increased peak torque during eccentric movement compared with concentric movement. The explanation for the increased peak torque during eccentric movement can be found in the two-state cross bridge model. Actin and myosin cross bridges will quickly detach and reattach and thick filaments will rearrange. The giant titin protein, an additional filament in muscles, plays an important role during eccentric contraction by creating stiffness in the muscles. This eccentric action is highlighted during flywheel training, resulting in an eccentric overload when performing exercises.

Exercises with eccentric overload activate various genes that trigger protein functions, for instance protein synthesis and sarcomerogenesis. Higher intra-muscular pressure during eccentric movements (compared to concentric movements) leads to hypoxia, which enhances gene expression. The
activated protein functions result in changes at the cellular level like membrane biosynthesis, stress management by stress-responsive genes, repair, growth and remodeling. Additionally, there will be less activation of myostatin and more activation of the IGF-growth factor. Gene activation followed by enhanced protein and cellular functions leads to recovery and adaptation of the trained muscles. Muscles will become stronger, thicker, faster and more powerful. Eccentric contractions produce high forces with low energy costs and result in positive outcomes, making them well suited for training and rehabilitation.

REHABILITATION
Flywheel training is used by astronauts in space to prevent muscle atrophy and loss of strength, as mentioned earlier. Other researchers have shown that flywheel training is effective to mitigate the negative effects of unloading, for instance after a period of bed rest or casting.

Prevention of musculoskeletal and sports injuries is another potential objective of flywheel training. The main goal of the use of this type of training is to decrease injury risk factors. Several studies have shown the positive effects of flywheel training on injury prevention. In two different studies, soccer players performed a ten-week program of flywheel exercises (squat and leg-curl) and experienced a significant decrease in lower limb muscle injuries during the season. Another study, which compared volleyball players who performed a six-week program of flywheel training compared with those who performed body weight exercises showed that flywheel training group experienced positive adaptations (improved tuck jump assessment and valgus scores, improved hamstring concentric and eccentric peak torque, and improved repeated shuttle sprint ability) that can decrease the risk of hamstring and Anterior Cruciate Ligament (ACL) injuries.

A variety of training methods have been proven to be effective in the treatment of tendon injuries and are commonly used by therapists. Eccentric training for injured tendons leads to a reduction in pain, decreased stiffness in the tendon, increased neovascularization, enhanced neuroplasticity, and increased shielding of muscles. For example, Achilles tendon and patellar tendon both react positively to eccentric training. Shoulder rotation eccentric training is effective for subacromial pain syndrome, and eccentric training improves outcomes in patients with lateral and medial epicondylitis. Although the majority of studies focus on the benefits of eccentric training on tendinosis, heavy-slow resistance training and a combination of eccentric and concentric training have also been shown to have positive effects. According to the findings of Maliaras et al. in their systematic review, there is not enough evidence for isolating the eccentric component during the rehabilitation of tendinosis, therefore, it has been suggested to use exercises with both a concentric and eccentric component. This makes flywheel training that has both concentric action and eccentric overload an ideal choice for tendinosis rehabilitation. The positive outcomes occur without triggering complaints caused by the tendinosis. For example, flywheel squats improve the quality of patellar tendon and Achilles tendon, indicated by an increase in the cross-sectional area of the tendon.

When examining the positive training effects of flywheel training, it is evident that it is an effective tool for muscle injury rehabilitation. The gains in strength, hypertrophy, muscle activation and muscle length will lead to positive adaptations and muscle healing. To use the example of rehabilitation after a calf muscle strain, flywheel training can be used by performing squats and lunges in the second week after the onset of the injury. Flywheel squats have been shown to lead to structural adaptations in the gastrocnemius muscle. Calf raises as a flywheel exercise can be performed in the proliferation and reorganization stages of the healing process for calf muscles. Thus, traditional early rehabilitation and flywheel training in combination with strength training and functional exercises could result in enhanced outcomes in patients after calf strain.

Another group of patients that can benefit from flywheel training are those after surgery, when atrophy and loss of muscle strength occurs rapidly. For example, in rehabilitation after anterior cruciate ligament reconstruction, patients need quadriceps strength and muscle power to be able to walk, run
reactivity. Strength, power and reactivity are all important for the elderly to keep them moving functionally, prevent them from falling, and maintain muscle health.26

It is recommended that flywheel training with the elderly and patients with musculoskeletal injuries be conducted once or twice a week with low intensity, low speed and medium inertia in the beginning of the rehabilitation and training.4,26 When elderly and patients perform the exercises in a well-coordinated manner and hardly experience any pain, intensity and speed can be increased.4,26 As inertia is increased, the training focuses more on strength and hypertrophy, while lower inertia and higher speed results in more explosive training sessions with higher power outputs. Four sets of eight to twelve repetitions with 90 to 120 seconds of rest between sets is preferable.4,26 The therapist can choose to change these training variables depending on the site of the injury, phase of rehabilitation, amount of pain, and objectives of the training.4,26

CONCLUSION
This clinical commentary provides an overview for physical therapists regarding the scientific evidence and practical implications of flywheel training in musculoskeletal rehabilitation. Flywheel training results in numerous and varied improvements in muscles, tendons and other connective tissue. Improvements in strength, hypertrophy, muscle activation, muscle length, tendon stiffness, power, and athletically relevant performance have all been documented. Such outcomes make flywheel training ideal for musculoskeletal rehabilitation. This commentary underscores the important role that flywheel training can
play in tendon rehabilitation. Prevention and rehabilitation of muscle and joint injuries and training of fragile elderly are other applications for which flywheel training can be used. Additional studies are required to draw definite conclusions about the use of flywheel training in general musculoskeletal and post-operative rehabilitation.

REFERENCES


for prizes during an oral presentation session. Dr. Carolyn Emery (#104) won the oral presentation competition; Mr. Henrik Riel (#103) and Mr. Chris Bramah (#102) were awarded the 2nd and 3rd positions, respectively. The remaining 67 abstracts (abstract numbers starting with 0) were presented during poster sessions.

Each abstract presents only a brief summary of a research project / presentation and does not permit full assessment of the scientific rigor with which the work was conducted. While the abstracts offer only preliminary results that may require further refinement and future validation, they do serve an important role of sharing new research ideas from around the world. This sharing of ideas helps to encourage worldwide dialogue among researchers, clinicians, and educators that will ultimately contribute to the sports physical therapy body of knowledge.

Notice: The abstracts below are presented as prepared by the authors. The accuracy and content of each abstract remain the responsibility of the authors. Minor edits for language were made to some abstracts.
Use of a novel, individualized running journal to guide return to competition in collegiate runners with running-related injuries: a case series

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Objective: Collegiate distance runners often train year-round with high acute and chronic running loads in order to maintain a competitive level throughout the entire competition year. It is common for these runners to exceed weekly running volumes of 40 miles per week. For injured runners, following traditional return to run protocols that adhere to the ‘10% rule’ of weekly progression can take up to 16 weeks to reach their competitive training volumes. Yet, there is a lack of evidence to support expedited running progression programs for injured runners. The objective of this report is to describe positive outcomes in injured, collegiate distance runners who adhered to expedited running progressions using a patient-centered running journal.

Methods: This study utilized a case series design. One physical therapist (PT) with five years of clinical experience, including one year of sports PT residency training, evaluated and treated all runners. Four collegiate Division I distance runners with persistent running-related injuries (RRIs) progressed weekly running volumes using the Running Individualized Progression with Evaluative Modification (RIPEM) journal. The PT used the RIPEM to evaluate individual responses while guiding acute and chronic workload progression.

Results: Runners increased running volumes by 24.8 ± 16.4% per week (excluding deload weeks). All runners successfully returned to weekly running volumes of 33-50 miles per week in 6-12 weeks, including return to competition in their respective events.

Conclusion: Guided, expedited running progressions using the RIPEM allowed collegiate distance runners to progress running volumes and return to competition at a faster rate than traditional running progressions using the ‘10% rule.’

Clinical implications: Sports PTs should consider using the RIPEM to guide collegiate distance runners in expedited return to run protocols.

Results: Both male and female ITBS runners demonstrated significantly greater contralateral pelvic drop when compared to controls. Female ITBS runners also demonstrated significantly greater hip adduction and transverse plane pelvis rotation during stance phase of running when compared to the male ITBS and control group. Male ITBS runners demonstrated a significantly more extended knee at initial contact when compared to the female ITBS and control group.

Conclusion: Males and female runners with ITBS demonstrate differences in running kinematics. In particular female runners with ITBS demonstrate greater kinematic deficits at the hip and pelvis when compared to male runners with ITBS and controls while male runners demonstrate differences in knee kinematics at initial contact.

Clinical implications: Based on these results, clinicians should consider potentially different mechanical patterns influencing ITBS development amongst male and female runners. Management and rehabilitation strategies may need to be varied according to sex and the associated kinematic patterns.

Self-dosed versus pre-determined progressive heavy-duty resistance exercise training for individuals with planter fasciopathy: a randomised clinical trial

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Objective: The aim was to compare the efficacy of a self-dosed versus a pre-determined heavy-duty resistance training (HSR) programme in improving the Foot Health Status Questionnaire (FHSQ) pain score in individuals with plantar fasciopathy.

Methods: We recruited 70 participants with plantar fasciopathy for this prospectively-registered (NCT03304353), participant-blinded, superiority trial. Participants were randomised to a self-dosed or pre-determined 12-week HSR programme of heel raises. The self-dosed group performed as many sets as possible at 8RM guided by perception of symptoms, whereas the pre-determined group followed a standardised protocol. Primary outcome was FHSQ pain. Secondary outcomes included a 7-point Global Rating of Change (GROC) dichotomised to “improved” or “not improved”, Patient Acceptable Symptom State (PASS), and training sessions performed.

Results: There was no between-group difference in FHSQ pain after 12 weeks (adjusted mean difference: -6.9 points, 95%CI: -15.5, 1.7, P = 0.115) and both groups had similar clinically important improvements. According to GROC, 24/33 (72.7%) in the self-dosed group and 20/32 (62.5%) in the pre-determined group achieved improvement. 3/35 (8.6%) in the self-dosed group and 1/35 (2.9%) in the pre-determined group achieved PASS. Both groups performed an equal number of trainings sessions (P = 0.412).

Conclusion: There was no significant or clinically relevant difference between self-dosed and pre-determined HSR programmes. Both were associated with similar response over 12 weeks, which was not sufficient to achieve acceptable symptom state.
Clinical implications: Loading programmes for tendinopathies are usually pre-determined, but our findings suggest there is no need for a standardised programme in patients with plantar fasciopathy. HSR provides clinicians with an alternative to other conservative treatments, but the effect compared to wait-and-see and less time-consuming treatments need to be established.

Implementing a school prevention program to reduce injuries through neuromuscular training (isprint): a cluster-randomized controlled trial

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Objectives: To evaluate the effectiveness of iSPRINT, a school-based program to reduce injury rates (IR) through neuromuscular training (NMT), in junior high school physical education (PE), in reducing the rate of sport and recreational (S&R) injuries.

Methods: This is a cluster-randomized controlled trial. Students were recruited from 12 Calgary junior high schools (2014-2017). iSPRINT is a 15-min NMT warm-up including aerobic, agility, strength, and balance exercises. Following a teacher workshop, teachers were asked to implement iSPRINT (N=6) or a standard-of-practice warm-up (N=6) at the beginning of PE classes for 12 weeks. Injuries included those that resulted in the inability to complete a session, time loss and/or medical attention. Incidence rate ratios (IRR) were estimated based on multivariable Poisson regression analyses (adjusting for sex (considering effect modification), previous injury, and clustering by class, offset by S&R participation hours) for intent to treat analyses.

Results: 1,067 students (ages 11-16) were recruited across 12 schools (53.7% female, 46.3% male). The iSPRINT program was protective of all S&R injury for females (IRR = 0.53, 95% CI; 0.32-0.89) but not males (IRR = 0.85, 95% CI; 0.42-1.71). The iSPRINT program was also protective of lower extremity (LE) injuries (IRR = 0.38, 95%CI; 0.22-0.66) and medical attention injuries (IRR = 0.28, 95% CI; 0.14-0.53) for females but not males for LE injuries (IRR = 0.16, 95% CI; 0.47-2.38) or medical attention injuries (IRR = 0.63, 95% CI; 0.25-1.62).

Conclusion: The iSPRINT NMT warm-up was effective in preventing all injury, lower extremity injury, and medically treated S&R injuries in female junior high school students but not males.

Clinical implications: A NMT warm-up program is recommended as best practice for injury prevention in youth S&R. Physical therapists are ideally positioned to provide leadership in delivering teacher/coach NMT injury prevention workshops that will have significant impact.
Effects of deep hopping training on ankle sprain in junior high school basketball players: a clustered randomized control trial

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Objective: In Japan, about 70,000 ankle sprains per year occurred in junior high and high school basketball players, which numbers exceeded those in soccer and baseball. In recent years, neuromuscular training using a deep hopping training (DHT) has become a common form of exercise to prevent ankle sprain. The purpose of this study was to clarify the effect of the DHT upon ankle injury in junior high school basketball players.

Methods: 105 junior high school basketball players without concurrent injuries were recruited. All players were randomly assigned as a cluster by school to a control group and the DHT group. 40 players at 3 schools were allocated to a control group and 65 at 4 schools were to the DHT group. Subjects in the DHT group completed an ankle injury prevention program including jump squats, front hopping, back hopping, right side hopping, left side hopping on the floor for 8 weeks. Ankle injury rates were calculated and compared by occurrence of injury per 1000 athlete hours (1000AH) and relative risk in the control and the DHT groups.

Results: There was no significant between-group difference in age, height, weight, and years of competition. The number of ankle sprain were 17 in the control group and 17 in the DHT group. Practice time was 4122 hours for control group, while 6867 hours for DHT group. The 1000 AHs calculated by the total practice time and the number of injuries were 4.21 (95%CI: 2.7, 6.0) in the control group and 2.47 (95%CI: 1.4, 3.5) in the DHT group. The relative risk compared to the control group was 0.61 in the DHT group. The number of injuries occurring at Chi-squared test (one tailed) was P = 0.045.

Conclusion: Our study showed that DHT for 8 weeks would reduce the occurrence of ankle sprain in junior high school basketball players.

Clinical implications: Our study suggests that high school basketball players should participate in DHT to reduce the occurrence of ankle sprain.

003 Injury prevalence and CrossFit movements: an epidemiological study

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Objective: CrossFit is a sporting practice that is growing worldwide, with a lot of supporters and followers. There are some ideas that this modality brings a lot of injuries and pain. However, the CrossFit movement probably can be related to injuries. Our objective was to investigate the prevalence of injury and CrossFit movement. Furthermore, verify which CrossFit movement is the most injurious.

Methods: Seventeen questions concerning training (frequency, length of practice, movement injury during CrossFit practice and location of injury) and demographics (gender, age, affiliation) were asked. Data were collected from September 2018 to February 2019 through an electronic questionnaire, which was created and hosted using an online questionnaire and survey software (SurveyMonkey; www.surveymonkey.com). The study was approved by the ethics committee of State University of São Paulo (UNESP- Botucatu Campus).

Results: 5,189 Brazilian athletes (51.9% woman; 47.7% aged between 21-29 years and 36.7% aged between 30-39 years) answered the questionnaire. 1,528 athletes (29%) had no injury with CrossFit. Deadlift was the main injury movement in 576 athletes (11%), Snatch in 322 athletes (6%) and Box Jump in 201 athletes (4%). There were 49 more movements with lower injury prevalence. Shoulder, low back and knee were the most injured body parts.
Correlation between shoulder functional assessment and thermography analysis in volleyball athletes with shoulder pain: a comparative study

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Objective: To perform a correlation between shoulder functional assessment and thermography analysis in volleyball players with and without pain.

Methods: Nine volleyball players with shoulder pain and 9 matched controls were evaluated with a thermography camera (TermoCam C2 Educational Kit, Flir Systems, Estonia) and they performed SPADI score and Score Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) to compare functional inter group. The pictures were analyzed on software VisionFy® (v.1.1, 2019, Thermofy Corp.,Brazil), to range of interest’s (ROI) quantification. The athletes were compared on maximal temperature (Max ºC), minimal temperature (Min ºC), average temperature (Average º C), amplitude (Ampl ºC), deviation of the thermal center (DTFC ºC) and delta difference. Kolmogorov-Smirnov was used to identify normality distribution and Mann-Whitney test was applied to compare the groups.

Results: Symptomatic volleyball players had a mean age of 26.9 ± 6.7 years, body mass of 83.2 ± 15.9 kg and height of 182.7 ± 9.9 cm. Non-symptomatic athletes had a mean age of 27.1 ± 5.5 years, weight of 75.6 ± 9.3 kg and height of 175.9 ± 4.1 cm. Pearson’s correlation showed stronger correlation (0.730 p=0.026) between CKCUEST and delta ROI mean in volleyball players with shoulder pain.

Conclusion: The functional movement pattern by CKCUEST, alteration of temperature by thermography analysis and SPADI scores are different in volleyball athletes with shoulder pain and there is stronger correlation with the functional movement pattern by CKCUEST and alteration of temperature between groups.

Clinical implications: This research shows one more assessment method to identify the parameters of pain and dysfunctions through thermography without risks for musculoskeletal structures.

005

Injuries surveillance in Brazilian male elite youth soccer athletes: a retrospective study

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Objective: To describe the injury incidence in an elite youth male soccer team over a season.

Methods: A retrospective analysis of 2018 injuries data of 246 Brazilian elite male youth soccer athletes were performed. The athletes were divided in two groups: under 11 to under 15 (group A, n=149) and under 17 to under 20 (group B, n=107). Descriptive and Chi-Square statistical analysis were used to characterize the sample and compare groups A and B.

Results: A total of one hundred and eleven injuries were recorded over the season. Athletes of group A had ten trauma injuries, eighteen non-contact acute injuries and thirteen overuse injuries. In group B, twenty-five athletes had trauma injuries, twenty-five had non-contact acute injuries and twenty had overuse injuries, with significant differences between groups for all types of injuries (p=0.01, p=0.17 and p=0.19 respectively). Eighty-eight training injuries and twenty-one during game injuries were identified, but only during game injuries showed differences between groups (p=0.01). Hip, knee and overuse injuries were more frequent in artificial grass field compared to natural grass field (p=0.01) in both groups. Athletes of group A had an injury-time loss of ten days, while group B had twenty-four days of absence.

Conclusion: Elite youth soccer athletes under 17 to under 20 had suffered more total and during game injuries, and more injury-days loss than under 11 to under 15 players. Moreover, hip, knee and overuse injuries were more frequent on artificial grass field in both groups.

Clinical implications: This research shows injury incidence in elite youth soccer players and can contribute to future researches on injury incidence and development of injuries risk patterns and preventive programs for these athletes.

006

Lower limb joint mechanical work during the single leg drop jump: a cross-sectional comparison of women with and without hip-related pain

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Objective: Women with hip-related pain (HRP) are underrepresented in the literature. As such, the movement strategies of women with HRP are not well understood. Therefore, the aim of the study was to compare the mechanical work completed by the lower limb joints during the single leg drop jump (SLDJ) in women with and without HRP.

Methods: Female football players, aged 18-50 years, with and without HRP were eligible to participate. Twenty-three women
with HRP and 13 controls participated. Biomechanical data on the SLDJ were collected using a three-dimensional motion capture system and force plates. Total lower limb work was calculated as well as the relative contributions of the hip, knee and ankle. Differences between group were assessed using t-tests.

**Results:** The relative contribution to negative work done at the knee was significantly less in the women with HRP compared with the control group (mean difference -4.7%, 95% CI -9.1, -0.3; P = 0.04). When comparing contributions across the three joints, the ankle provided the largest contribution to positive work for the HRP group (36.8%), with the hip being the largest contributor in the controls (35.4%).

**Conclusions:** Women with HRP absorbed significantly less energy at the knee compared to healthy controls. The reason why women with HRP do not use a knee dominant strategy for absorbing energy during the SLDJ requires further scrutiny. Despite no difference in total positive work between groups, we did observe some subtle differences amongst the joints in the relative contributions to positive work done. The ankle was the dominant source of positive work during the SLDJ for women with HRP, whereas the hip was for controls. This strategy adopted by women with HRP may be an attempt to 'offload' the symptomatic hip.

**Clinical implications:** The study demonstrates potential impairments that can be addressed in rehabilitation programs to normalise force attenuation and propulsive strategies in women with HRP.

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**Objective:** People with hip-related pain (HRP) walk with different biomechanics compared with people without HRP. However, study conclusions are often drawn from mixed cohorts, ignoring the potential for the effect of pain on biomechanics to be sex dependent. Therefore, we aimed to investigate the differences between men and women with HRP in lower limb biomechanics during walking and the single leg drop jump (SLDJ).

**Methods:** Football players aged 18-50 years with HRP were eligible to participate. Symptoms were quantified using the Copenhagen Hip and Groin Outcome Score (HAGOS). Biomechanical data were collected via a three-dimensional motion capture system during walking and SLDJ. Lower limb kinematics and kinetics were calculated at the hip, knee and ankle. Differences between men and women were analysed using statistical parametric mapping and t-tests.

**Results:** Sixty-five men and 23 women participated with no difference between groups for HAGOS scores (P>0.07). Walking: During stance, men with HRP walked with less hip flexion (P<0.01) and internal rotation (P<0.01), as well as a greater ankle dorsiflexion moment (P<0.01) and impulse (P<0.01) compared with women. SLDJ: During early stance, men with HRP completed the SLDJ with less hip flexion (P=0.03) and a greater external knee flexion moment (P<0.01). In addition, men produced a greater ankle dorsiflexion moment (P<0.01) and impulse (P=0.01) compared with women.

**Conclusion:** Differences observed were task specific at the hip and knee and joint specific at the ankle. These results demonstrate that sex may be an effect modifier in people with HRP. The use of mixed cohorts without appropriate between sex considerations should be strongly discouraged in biomechanical evaluations of HRP.

**Clinical implication:** Evaluations and knowledge into the potential modifiable risk factors of HRP are in its infancy, however this research demonstrates that sex dependent prevention and intervention strategies may be required.

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**Objective:** The purpose of this study was to attain consensus among international shoulder experts for the early and appropriate assessment and management strategies of PSI based on classification, recovery timelines, outcome measures and risk.

**Methods:** A three round e-Delphi survey was released over a series of consecutive months to 70 clinical shoulder experts (physiotherapists, orthopaedic surgeons, sport medicine physicians and researchers). Phase 1 consisted of a structured literature review which was integrated with expert input to create 50 items on definitions, classification, assessments, prognosis, and management. The draft Delphi survey was revised through iterative consultation and pilot testing Phase 2 consisted of three rounds of questions; with analysis and survey revision after each round. Consensus was defined as 70% agreement. Descriptive statistics were used to describe the characteristics of the respondents, the response rate of the experts per round and the consensus for PSI classification, assessment, and management.

**Results:** The response rate from each round ranged from 81% in Round 1 to a high of 94% in Round 3. The final survey was completed by 47 individuals from 5 different countries with Canada having the largest representations at 24 (51.1%). Three subgroups of PSI were identified: Traumatic (100% agreement), Microtraumatic (98% agreement) and Atraumatic (98% agreement). After 3 Delphi rounds the agreement of the clinical experts and researchers). Phase 1 consisted of a structured literature review which was integrated with expert input to create 50 items on definitions, classification, assessments, prognosis, and management. The draft Delphi survey was revised through iterative consultation and pilot testing Phase 2 consisted of three rounds of questions; with analysis and survey revision after each round. Consensus was defined as 70% agreement. Descriptive statistics were used to describe the characteristics of the respondents, the response rate of the experts per round and the consensus for PSI classification, assessment, and management.

**Conclusion:** This Delphi helps to streamline diagnostic subgroups and management strategies for PSI. This may in turn provide framework for future research in the field including randomized-controlled or prospective cohort studies with evidence-informed interventions.

**Clinical implications:** A shoulder expert consensus study on PSI will establish earlier recognition and management strategies for health care providers.
Initial foot contact affects dynamic parameters in running.

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Objective: This study aims to clarify the relationships between foot strike patterns and dynamic parameters during running.
Methods: The study included 25 participants (17 males and 4 females; mean ± SD age, 21.1 ± 0.3 years; weight, 60.0 ± 6.6 kg; and height, 166.7 ± 7.4 cm) who had no reported foot or ankle injuries in the past 6 months. Dynamic parameters were collected with a 9-camera motion capture system using a Plug-in Gait full-body marker set, dynamic navicular drop marker set, and 3 force plates (sampling rate, 200 Hz). The participants each completed five running trials. Dorsiflexion angle during initial contact (IC) and ankle moment (AM) and dynamic dorsiflexion range of motion (DDR) peak values were calculated. Furthermore, dynamic navicular drop (DND) was determined by calculating the difference between the navicular height at heel contact and minimum navicular height during the stance phase. Pearson correlation coefficients were calculated between the IC and other variables, with p-value of <0.05 considered as statistically significant. This study was approved by the Ethics Committee for Human Research, Gunma Paz University, Takasaki, Japan.
Results: A significant positive correlation was found between IC and DDR during running (p = 0.026, r = 0.444). There were no significant correlations between IC and AM (p = 0.609, r = -0.018) or DND (p = 0.165, r = -0.285).
Conclusion: A relationship was found between IC and DDR, indicating that further the IC occurs into plantar flexion, the greater the decrease in dorsiflexion. However, IC was not associated with AM or arch.
Clinical implications: It may be possible to determine dynamic dorsiflexion during the stance phase in running based on IC. It should be determined whether this variable is a risk factor, taking the other physiotherapy assessments into consideration.

A single session of gait retraining improves pain, function and running kinematics in runners with patellofemoral pain

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Objective: To investigate whether running kinematics differ between male runners with a history of recurrent calf muscle strain injury (CMSI) and injury free controls.
Methods: Three-dimensional running kinematics were compared between 14 male runners with a history of CMSI and 28 male controls. A 12-camera Qualysis Oqus system recorded 3D running kinematics as participants ran on a treadmill at 3.2m/s. Independent t-tests were used to compare differences in select kinematic patterns during the stance phase of running.
Results: Several kinematic differences were observed between groups. The CMSI group demonstrated significantly longer stance times (p = 0.02), increased hip adduction (p = 0.03), contralateral pelvic drop (p = 0.04) and anterior pelvic tilt (p = 0.03) during mid stance. These differences highlight potential neuromuscular impairments of the calf muscle complex while also implicating altered hip neuromuscular control as a contributor to CMSI.
Conclusion: Runners with a history of recurrent CMSI demonstrate differences in stance phase running kinematics when compared to injury free controls. These differences may represent impairments to the stretch shortening function of the calf complex during running and reduced neuromuscular control at the hip and pelvis.
Clinical implications: The observed differences provide insight into potential kinematic mechanisms and consequences of recurrent CMSI. Based on the current results we suggest rehabilitation should focus on the restoration of stretch shorten function of the calf complex and improving neuromuscular control at the hip and pelvis.
A survey of acute injury in wheelchair basketball players: relation to the functional classification

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Objective: Wheelchair basketball (WB) players are classified into eight groups depending on their degree of physical ability. The risk of acute injury is higher than chronic injury in WB. The intensity of shoulder pain has been reported to differ depending on the functional classification. Similarly, the type and cause of injury might be different. However, there is no research from this point of view. This study aimed to investigate the injury in WB players focused on the functional classification.

Methods: A questionnaire survey was conducted for 96 WB players in Japan. The question items were the basic information about the injury (type, cause, etc.). The definition of injury was “injury caused by a single impact, having left the game for a day or more, or having consulted a medical institution”. According to the classification system, the players were grouped into four classes: Class 1 (most severe disability), 1.0 and 1.5 point; Class 2, 2.0 and 2.5 point; Class 3, 3.0 and 3.5 point; Class 4, 4.0 and 4.5 point.

Results: Valid answers were obtained from 85 people (89%). The incidence of injury for Class 1, 2, 3, and 4 were 36%, 20%, 19%, and 25%, respectively. The most common injury types were as follows: in Class 1, 2, and 4, soft tissue injury (41%, 50%, and 41%, respectively); in Class 3, fracture (53%). The cause of injury ranked in descending order was as follows: in Class 1, 3, and 4, fall (31%, 53%, and 91%, respectively), rebound (22%, 24%, and 5%, respectively); in Class 2, fall (44%), shooting (28%).

Conclusion: The tendency of the cause of injury differed from each class. Most injuries in Class 4 were caused by falls. Injuries in Class 1 were caused not only by falls but by WB play. It was suggested that WB players with severe disability are often injured by a minor impact.

Clinical implications: This study might provide information for injury prevention in consideration of the functional classification to reduce the risk of acute injury in WB players.

Injuries tendency during fall league match in the Japanese Chushikoku area collegiate American Football league match, past 7 seasons (2012–2018)

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Objective: American Football (AF) is a sport with intense physical contact, and there are many injuries. According to the surveys on injuries in collegiate AF in Japan, ligament injuries were the most frequent (37–39%). These studies were conducted in the Kanto or Kansai leagues, which have sufficient players. However, no surveys on injuries has been conducted in leagues with a small number of players, such as in the Chushikoku league. Therefore, this study aimed to investigate the occurrence of injury in the Chushikoku Collegiate AF league.

Methods: The survey period spanned 103 games played over 7 seasons. The survey subjects had described in the injury report of the Japan AF Association. The injury report was described when a “timeout for the injured” was called by the referee. The survey items included the player’s position, injury type, injury location, the quarter (Q) during which the injury occurred, and the number of injuries per game.

Results: The total number of injuries was 424. The number of injuries per games was 4.1 per game. The most frequent type of injury was bruising in 138 cases (32.5%). In addition, there were 114 cases (26.9%) of muscle cramps and 74 cases (17.5%) of ligament injuries. There were 189 cases among offensive players and 235 cases among defensive players. The timing of the injury was the 3Q in 127 cases and 4Q in 183 cases. Overall, 73.1% of injuries occurred late in the game.

Conclusion: Previous studies reported the number of injuries for the Kanto Collegiate AF league to be 1.3 per game. In contrast, the number of injuries in Chushikoku league was 4.3 per game, and the prevalence of bruises and muscle cramps was overwhelmingly large. This high number could be due to several factors, such as few players per team (few opportunities for substitution), and the participation of students with lower skills.

Clinical implications: The injury rates in the Chushikoku league tended to differ from those of other leagues.
placement of the sesamoid at weight bearing on the forefoot.

It is thought that the progression of HV angle is promoted by the reduction of the abduction torque of the ABH by the large outward displacement of the sesamoid at weight bearing on the forefoot.

Clinical implications: We concluded the SRA in the HV group increased more during weight bearing on the forefoot.

015

What do the stories of experienced sports physiotherapists’ tell us about their continuing professional learning

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Objective: To gain understanding of the continuing professional learning of experienced sports physiotherapists in the United Kingdom. Currently there is a paucity of knowledge about sports physiotherapists’ continuing professional learning.

Methods: Narrative Inquiry. Narrative interviews were conducted with 4 female experienced sports physiotherapists purposively recruited (19-34 years’ experience) in the United Kingdom. A narrative thematic analysis was applied to the transcribed data to search for emerging themes.

Results: 3 main themes were identified; 1) intrinsic motivation and skills to continue to learn and succeed, with sub themes of seeking and taking learning opportunities, overcoming and rising to challenges and identifying learning needs and setting development goals, 2) patients and practice drive learning…the need for a big tool kit, with sub themes of formal learning and informal learning, 3) developing contextual intelligence.

Conclusion: This study provides insight into how sports physiotherapists continue to learn, supporting previous literature which identifies that both formal and informal learning are utilised by physiotherapists. The participants used both types of learning with formal learning activities dominating early, and informal dominating later in their careers. High levels of intrinsic motivation, in combination with identifying key required learning and methods to learn were evident. The ability to develop a large sports physiotherapy tool kit (skills and knowledge) was viewed as a requirement to be successful. However, this needed to be supplemented with developing contextual intelligence to cope with the pressures and required behaviours in the sporting environment.

Clinical implications: These insights into sports physiotherapists’ continuing professional learning will assist appropriate support to be provided for future learning; acknowledging the variety of ways sports physiotherapists need to learn to be successful.

016

Female sports physiotherapists’ experiences of their work in the context of a Gulf Cooperation Council (GCC) country

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Objective: To explore the female sports physiotherapists’ experiences of their work in the context of a Gulf Cooperation Council (GCC) country, the role of gender in this experience, and the factors that the GCC region may play in it.

Methods: The experiences of three expatriate sports physiotherapists working in GCC countries were explored. In-depth semi-structured interviews collected data which was analysed by adopting the principles of Interpretative Phenomenological Analysis (IPA).

Results: Three super-ordinate themes emerged; the move to the unknown, professional paradigm shift and adapting to succeed. The study highlighted the varying career opportunities in the GCC for female sports physiotherapists and the participants’ frustrations about the national attitude and commitment towards sports participation. The professional shift in attitude and expectation was the most challenging and the most crucial for the participant’s professional success in the GCC. A negative attitude towards the use of physical contact when treating males stemmed from unease related to the sports physiotherapists gender rather than her aptitude or skill. There was a limited understanding and lack of professional clarity of a sports physiotherapist’s role among some GCC nationals which influenced demands and expectation’s relating to the role.

Conclusion: The findings in the study have not been addressed before, providing new information on how some female sports physiotherapists experience their work in the context of a GCC country. Cultural adaptability and sensitivity along with cross-cultural communication skills were the most crucial skills for success of the expatriate female sports physiotherapist in the GCC.

Clinical implications: The study allows for female sports physiotherapists, interested in working in the GCC, to learn about its sports scene and its frustrations, the opportunities it provides, alongside the skills needed to succeed.

018

The effectiveness of blood flow restriction vs. heavy load resistance training during post-surgery rehabilitation of anterior cruciate ligament reconstruction patients: a UK National Health Service randomised controlled trial.


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Objective: To compare the effectiveness of light load personalised blood flow restriction resistance training (PBFR-RT) and standard care heavy load resistance training (HLRT) in the post-surgery rehabilitation of patients undergoing anterior cruciate ligament reconstruction (ACLR) in the National Health Service (NHS).

Methods: Twenty-eight patients with hamstring autograft were recruited for this single assessor blinded trial. Participants were block randomised to HLRT (n = 14) at 70% of one repetition maximum (1RM) or PBFR-RT (n = 14) at 30% 1RM and completed 8 weeks of biweekly unilateral leg press training alongside standard hospital rehabilitation, beginning at 3 weeks post-surgery. Isotonic strength (10RM), muscle morphology of the vastus lateralis, self-reported function, Y-balance test perfor-
Objective: To validate the use of an inertial measurement unit (IMU) system compared to a camera-based 3D motion analysis system, for high speed running assessment of lower limb kinematics.

Methods: One runner had three IMUs (Noraxon Myomotion) secured on their pelvis, left shank and thigh, and 24 retro-reflective markers generating left shank, left thigh and pelvis segments with a 16 infrared camera 3D motion analysis system (Cortex Motion Analysis). The runner completed two treadmill trials (T1, T2) involving incremental running from 12 to 18km/hr within 1 min, on two separate days. Point of contact (POC) was identified by IMU vertical acceleration and compared to POC identified via force plate. Agreement in the sagittal shank, knee, hip and pelvic angles between the systems was evaluated using root mean square error (RMSE) and at POC using intraclass coefficients (ICC) and Pearson's correlation.

Results: The IMU was highly accurate in determining time of POC (RMSE T1:0.0044s T2:0.0053s), hip angle (RMSE T1:4.0° ± 2.3°, ICC T1:0.89 T2:0.79, r T1:0.90 T2:0.93), pelvic tilt (RMSE T1:2.1° ± 2.5°, ICC T1:0.94 T2:0.74, r T1:0.96 T2:0.87), but was inconsistent for knee (RMSE T1:7.3° ± 2.9°, ICC T1:0.07 T2:0.02, r T1:0.62 T2:0.38) and shank angle (RMSE T1:7.3° ± 2.6°, ICC T1:0.05 T2:0.05, r T1:0.65 T2:0.56).

Conclusion: Noraxon IMUs are suitable for use in high speed running for determination of POC and evaluation of sagittal hip and pelvic angles.

Clinical implications: Valid and reliable portable testing methods are integral for accuracy of on field testing. This study provides confidence in certain lower limb biomechanical variables for risk assessment, allowing for evidence-based injury prevention programs. It may offer a valuable feedback tool for clinical rehab/gait retraining. However, the findings need to be interpreted in light of the limitations (e.g. inertial marker movement) of 3D motion analysis systems.
The potential primary outcomes.

Methods: Searches were performed in MEDLINE, Embase, Cochrane, PEDro, SPORTDiscus, CINAHL and AMED databases. All randomised trials that evaluated CT in individuals with PT were included. Two reviewers screened studies, extracted data, and assessed risk of bias of all included studies. Meta-analyses were conducted and we assessed certainty of the evidence using GRADE methodology.

Objective: To determine the effectiveness of conservative treatment (CT) on pain and function in patients with patellar tendinopathy (PT) compared with minimal (MI) or other invasive interventions (OI), or in addition to decline eccentric squat.

Results: When compared to MI, CT did not improve pain (mean difference = -0.2, 95% CI -1.5 to 1.1) or function (mean difference = -0.2, 95% CI -1.8 to 7.4) at medium/long-term follow-up. When compared with OI, CT did not improve pain (mean difference = -0.4, 95% CI -2.6 to 1.8) or function (mean difference = 5.9, 95% CI -17.1 to 29.0) at medium/long-term follow-up. No overall effects were found for combined CT (when a conservative intervention was added to decline eccentric squat) on pain (mean difference = -0.5, 95% CI -1.4 to 0.4) or function (mean difference = -2.3, 95% -9.1 to 4.6) at short-term follow-up. Single studies showed an effect on pain with iontophoresis at short-term follow-up (d=2.42) or dry-needling at medium/long-term follow-up (d=1.17) and function with exercise intervention at medium/long-term follow-up (d=0.83). Conclusions: The estimates of treatment effect have only low-to-very-low-certainty evidence to support them.

Clinical implications: There is low to very low certainty evidence to support the short- and long-term effects of exercise, dry needling and iontophoresis as treatments for PT. This field of sports medicine/sports physiotherapy urgently needs larger, high quality studies with pain and function considered among the potential primary outcomes.

Objective: To investigate the association of hip external rotators (ER) strength, hip ER passive stiffness and shank-forefoot alignment with hip adduction and internal rotation (IR) during single-leg squat.

Methods: Forty-six participants had shank-forefoot alignment, hip ER isometric torque, hip ER passive stiffness and hip kinematics during single-leg squat assessed. Multiple linear regressions were performed to identify the factors which predicted hip adduction and IR mean and peak movement during single-leg squat.

Results: Participants were aged 23.47 years (Standard Deviation [SD] = 4.29); had a mean body mass of 60.40 kg (SD = 11.28), mean height of 1.67 m (SD = 0.89), mean shank-forefoot alignment of 12.82 degrees (SD = 12.8), mean passive hip IR range of motion (ROM) of 33.36 degrees (SD = 12.18) and hip ER torque of 0.44 Nm/kg (SD = 0.14). The results showed that passive hip IR ROM predicted only mean (R² = -0.405 (95% C.I. = -0.250, -0.048), p=0.005) and peak (R² = -0.341 (95% C.I. = -0.223, -0.210); p = 0.019) hip transverse plane during single-leg squat.

Conclusion: Hip ER passive stiffness influences hip movement in the transverse plane during the single-leg squat. Further prospective studies are necessary to establish the causative relationship between these two variables.

Objective: To analyze direct and indirect costs of musculoskeletal injuries in Brazilian female volleyball players.

Methods: A retrospective cohort study was performed over two seasons, analyzing one elite female volleyball team database. The direct costs are related to the injury rehabilitation (number of physiotherapy visits per injury) and indirect costs are related to the low productivity or work absence and were calculated by time loss (number of time loss per injury x athlete’s salary per day) and matches lost (the number of official matches lost x athlete’s salary per match). Descriptive data were organized in Microsoft Office® Excel® 2016-2017.

Results: A total of 24 elite female volleyball players who participated in 2015-2016 and 2016-2017 seasons were considered in the analysis. Both seasons had the same coach and physiotherapist. The direct cost was 27,994.40 USD and the average cost per injury was 243.43 USD. Considering injuries without time loss the total cost was 2,549.50 USD and 25,144.96 USD for time-loss injuries. Indirect cost was 12,320.29 USD, which was a result of 249 days lost because of injuries. Fifteen official matches were lost as a result of musculoskeletal injuries, and the club spent 27,518.01 USD because of athlete absence.
Analyzing the physiotherapy department budget to female volleyball, 45% represented the direct costs to injuries rehabilitation.

**Conclusion:** The results of the present study showed the financial impact of musculoskeletal injuries in one elite female volleyball team with a high infrastructure. Future research should be done with all the Super League teams to represent the Brazilian Volleyball costs.

**Clinical implication:** The direct costs were higher than the indirect costs, showing the importance of the sports physiotherapist in the team monitoring, since most of the injuries did not lead to time loss from training and games.

**025**
The prevalence and incidence of injuries in Brazilian elite volleyball players

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**Objective:** To analyze the prevalence and incidence of musculoskeletal injuries in Brazilian elite female volleyball players.

**Methods:** A retrospective study was performed with an elite female volleyball team database from 2015 to 2017. Injuries were any musculoskeletal complaint that occurred as a result of training or competition that required medical assistance. Injury incidence was calculated by the number of injuries per 1,000 hours of exposure in total and also in matches, training and competition that required medical assistance. Injury incidence was 1.97/1,000h, considering all matches, training and performance, Universidade Federal dos Vales do Jequitinhonha e Mucuri, Diamantina, Brazil.

**Results:** A total of 24 elite female volleyball players with mean age of 24.63 years old (±5.22), mean body mass of 71.15kg (±8.51) and mean height of 182.83cm (±6.15) were considered in the analysis. A total of 115 injuries were observed during all seasons (5.48 injuries per athlete). Acute injuries were 79% and 21% were overuse injuries. A total of 35% were time-loss injuries and only 2 injuries were severe (greater than 21 days lost). The injury incidence was 5.65/1,000h and the time-loss injuries incidence was 1.97/1,000h, considering all matches, training and strength conditioning training. Most injuries occurred during training (73%), followed by matches (21%) and strength conditioning training (6%). Knee joint and cervical spine injuries were the most prevalent followed by ankle, lumbar spine and shin.

**Conclusion:** The most prevalent injuries were in the knee joint and cervical spine. The results could guide strategies for the prevention and rehabilitation of injuries.

**Clinical implications:** Effective prevention strategies should be implemented targeting the sports demand and injury prevalence. The prevalence of overuse injuries was lower than acute injuries, showing relevance of the entire sports staff job in load management.

**026**
Preventive effect of tailored exercises on patellar tendinopathy in youth athletes

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**Objective:** To analyze the effect of tailored exercises on patellar tendinopathy (PT) in Brazilian young athletes.

**Methods:** A prospective cohort study was performed during the 2016 and 2017 seasons. The incidence rates of PT injuries were registered from male basketball and volleyball players. In the first year, 277 players were tracked (mean age of 14.2 ± 1.9 years, mean height of 181.2 ± 1.2 meters and mean body mass of 71.1 ± 16.4 kilograms) and the eligibility criteria for PT were: 1) have tendon pain on jumping/landing, running or changing directions; and 2) have pain during tendon palpation. Tailored exercises were applied in the second year, which 269 athletes (mean age of 14.4 ± 1.13 years; height of 182.2 ± 5.8 cm; weight of 72.3 ± 12.7 kg) participated in the intervention period. The program was implemented for 10 months and all participants were part of regular training sessions 3 or 5 times a week during the second year. Cox regression for survival analysis was used to indicate the effect of tailored exercises on PT.

**Results:** Thirty-two athletes had PT in the first season, whereas only 12 athletes had PT in the second season. Patellar tendinopathy has decreased significantly in the intervention group (HR 2.388, 95%CI 1.30, 4.37, p=0.05) compared to the athletes of the first season.

**Conclusion:** Athletes that did not participate in the intervention season had 2.38 times more chance to have PT. Little is known about the development of tendinopathy in childhood and adolescence. PT prevention needs future studies to enhance new possibilities and strategies adopted.

**Clinical implications:** Tailored exercises could prevent PT injuries which is an overload injury that could lead to months of treatment and sport absence. Adding a weekly eccentric load squat training to a regular basketball and volleyball exercise routine enhances lower limb muscle power without triggering patellar tendon complaints.

**027**
Heavy-slow resistance training in addition to an ultrasound-guided corticosteroid injection for individuals with plantar fasciopathy: a feasibility study

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Objective: We aimed to evaluate the feasibility of combining heavy-slow resistance training with a corticosteroid injection for individuals with plantar fasciopathy.

Methods: We recruited 20 participants with plantar fasciopathy for this prospectively-registered feasibility study (clinicaltrials.gov: NCT03535896). Participants received an ultrasound-guided injection and performed heel raises on a step every second day for 8 weeks. To assess participant acceptability of the combined interventions and exercise compliance, we used a 7-point Likert scale dichotomised to “unacceptable” (categories 1-2) or “acceptable” (categories 3-7) and training diaries. ≥10/20 had to rate the combination “acceptable”, ≥15/20 had to perform ≥20 training sessions, and ≥15/20 had to start exercising ≤7 days after injection to confirm feasibility.

Results: 18/20 rated the combination acceptable. 5 training diaries could not be retrieved. 10/15 participants performed ≥20 training sessions and 15/15 started exercising ≤7 days after injection.

Conclusion: Based on participant acceptability and time to exercise start, combining heavy-slow resistance training with a corticosteroid injection is feasible. Due to loss of 5/20 training diaries, firm conclusions regarding exercise compliance could not be drawn.

Clinical implications: As patients found this combination to be acceptable, it may be a relevant treatment modality in patients with refractory symptoms who do not respond to first-line treatment. However, the efficacy of this combination compared to other treatments remains to be investigated in future studies.

Clinical implications: In order to reduce throwing injuries, therapists should increase opportunities to provide more information to baseball players about the significance and method of performing self-care.

Objective: The purpose of this study was to investigate the correlation between foot sole sensitivity and postural control in single-leg stance as well as muscle activity during single-leg jump landing.

Methods: Twenty-two healthy subjects (24.2 ± 6 years) participated. Plantar cutaneous thresholds to light touch were determined at three locations of the foot sole using Semmes-Weinstein monofilaments. The center of pressure (COP) displacement during single-leg stance was measured using a force plate (Bertec, 1000 Hz). Vertical ground reaction forces (vGRF) and muscle activity of six muscles were recorded during a single-leg jump landing task using a force plate (Bertec, 1000 Hz) and surface electromyography (EMG, Noraxon, 1500 Hz). Correlations between plantar sensitivity, COP displacements, vGRF and EMG-data were determined using Spearman’s rank correlation coefficient rho or Pearson’s correlation coefficient (p<0.05).

Results: Plantar sensitivity at the metatarsal head I was negatively correlated to the activity of the vastus lateralis muscle at peak vGRF (r = -0.51; p = 0.02) and during the stabilization phase after jump landing (r = -0.54; p = 0.014). The medio-lateral COP displacement was positively correlated to the activity of the peroneus longus muscle during the stabilization phase after jump landing (r = 0.53; p = 0.018).

Conclusion: A low cutaneous threshold at metatarsal head I seems to moderately correlate to an increased activity of the vastus lateralis muscle during single-leg jump landing. An increased medio-lateral COP displacement appears to relate to an increased peroneus longus muscle activation during the stabilization phase of jump landing.

Clinical implications: The findings of the study may be relevant for the prevention and rehabilitation of injuries to the lower extremity. Furthermore, results may be interesting for companies producing athletic shoes or therapeutic insoles.
Sticking to it: a scoping review of adherence to exercise therapy interventions in children and adolescents with musculoskeletal disorders

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\textbf{Objective:} Improving exercise therapy adherence after youth sport-related musculoskeletal injury is crucial for recovery and reducing long-term consequences. This scoping review consolidates reported barriers, facilitators, and strategies to boost exercise therapy adherence in youth musculoskeletal injuries to inform future research and clinical practice.

\textbf{Methods:} Arksey and O’Malley’s framework and the PRISMA Extension for Scoping Reviews were followed. Six databases were searched using predetermined keywords and subject headings. English studies with original data featuring an adherence barrier, facilitator, or boosting strategy and youth (0-19 years) with musculoskeletal disorders treated with exercise therapy were included. Two authors independently conducted title/abstract and full-text reviews, and assessed study quality with the Mixed Methods Appraisal Tool. Descriptive consolidation and inductive thematic analysis were completed.

\textbf{Results:} Of 4,930 records, 34 studies representing 1,563 participants (65% female, 2-19 years old), 11 musculoskeletal disorders and multiple exercise interventions were included. Time constraints, physical environment (e.g., location), and negative exercise experiences were commonly identified barriers. Social support and positive exercise experiences were frequently identified facilitators. Reinforcement, exercise program modification, and education were recurring boosting strategies, despite being infrequent barriers or facilitators. Exercise experience, time, and environment (physical and social) emerged as key themes related to youth exercise therapy adherence.

\textbf{Conclusion:} A diversity of barriers and facilitators to exercise therapy for youth musculoskeletal disorders exist. Strategies to boost adherence are not consistent with identified barriers or facilitators.

\textbf{Clinical implications:} Making exercise enjoyable, social, and convenient may be important to maximizing adherence to exercise therapy in young injured athletes.

Relationship between mechanical stress and injury around the hip joint due to kicking action in football.

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\textbf{Objective:} In this study, we analyzed the association between kick-induced stress distribution and the clinical findings of injuries around the hip joint.

\textbf{Methods:} We selected 5 healthy football players. They performed the inside, instep, and infront kick 3 times each with right foot. 3D motion analysis device was used to record their motion. The motion analysis software was used to calculate stress between hip joints and the angle of the hip joint. In addition, the bone strength analysis software was used to analyze the CT and MRI data of each subject to develop a finite-element (FE) model. Then, hip joints calculated in dynamics analysis was input as a load value into the FE model for the stress analysis.

\textbf{Results:} At the time of BI, kicking motions produced a high-stress area in the pubic ramus compared with other areas. Stress generated in the superior and inferior rami of the pubic bone was 3.52 and 2.94 MPa for the inside kick, 7.15 and 5.40 Mpa for the instep kick, and 4.47 and 3.33 Mpa for the infront kick, respectively. Compared to the static posture, the stress distribution at the superior and inferior pubic rami was 3-fold and 2-fold, respectively.

\textbf{Conclusions:} The high-stress area was the same area where groin pain syndrome occurs in the clinical examination of football-related hip joint injury and where fatigue fractures occur in pubic bone rami. Then, the values of equivalent stress generated by the inside kick, instep kick, and infront kick in the superior and inferior rami were approximately 3-fold, 5-fold, and 3-fold. We revealed the relationship between the clinical symptoms of the hip joint and previously reported kick-related injuries around the hip joint.

\textbf{Clinical implications:} It was found that the kicking motion in football includes not only muscle stress but also bone stress confirmed by clinical findings. It should be taken into consideration that not only the muscle tightness but also the kicking motion itself affects the bone.

Niseko resort changes Japanese ski safety

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\textbf{Objective:} Niseko is a town in Hokkaido which is located north of Japan. In Niseko, high quality powder snow is falling for many days in winter. There is famous for the best powder snow called “JAPOW”. Therefore, Niseko is visited by many tourists from all over the world and English is used more frequently than Japanese. In the past, number of accidents in Niseko increased because of backcountry skiing’s popularity. However, no severe accident has occurred in Niseko in recent years. We conducted a field work at Niseko for skiing safety. We investigated the frequency and severity of backcountry skiing injuries in Japan and Niseko.

\textbf{Methods:} Interview survey was carried out in Niseko. We investigated the number of injuries in Niseko ski resort and the situation of severe ski accidents in Japan.

\textbf{Results:} About 50 severe backcountry skiing injuries occur every year in Japan, and 20 of them were fatal. The severe injury means head, back injury and suffocation. 1985 to 2000, there were 9 skiing fatalities in Niseko every year. All fatalities were caused by avalanches. 8 fatalities were backcountry skiing.
These Niseko ski resorts prohibited out of bounds skiing. These were called “Niseko Rule”. “Niseko Rule” was promulgated in 2001. No fatalities have occurred since 2001.

Conclusion: The important point of “Niseko Rule” is that Niseko resorts and the local community respect the freedom of mountain users and place a strong emphasis on the sage usage of the mountain. Ski Patrol checks the conditions of each ski resort for the boundaries of the “Niseko Rule”. The helmet wearing rate of users of Niseko resorts has increased due to the influence of foreign tourists. It will contribute to skiing safety.

Clinical implications: The number of skiers in Japan is one third of the peak period. Previously, many ski resorts closed during this contraction. Recently, new resorts opened and the skier population has stabilized. Niseko provides an opportunity to expand the skier population, further.

036
Guided load management for female soccer athletes: a case series using global positioning system technology (GPS) during return to sport

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Objective: Player availability post-surgery can be challenging, however, implementing a GPS guided load management program can maximise readiness.

Methods: In Fall 2017, Patient A (20 yrs, Centre Back) underwent patellofemoral realignment and Patient B (21 yrs, Centre Midfielder) underwent ACL reconstruction. Both players were cleared medically to play in the 2018 season and seventy-six sessions were monitored during the season. Modification of total distance (TD) and high-speed running (HSR) quantified by GPS was implemented with the medical staff to manage ongoing injury site symptoms. Training loads were based on absolute and relative values of individual match TD and HSR. TD and HSR (velocity >14.4km/h) were measured in metres (m).

Results: Patient A's average match duration was 84±23 minutes (min) and Patient B's average match duration was 90±12min. Overall team match duration was 95±8min. Patient A match loads were TD 8763±3826m and HSR 1039±509m. Patient B match loads were TD 8652±2281m and HSR 981±307m. Team match loads were TD 7431±1430m and HSR 1090±235m. Patient A training loads were TD 5201±1048m and HSR 463±352m; which was 59.3% of TD and 44.5% of HSR match load. Athlete B training loads were TD 4415±1650m and HSR 333±209m, which was 51% of TD and 33.9% of HSR match load. Team training loads were TD 4612±1296m and HSR 474±301m. This was 62% of TD and 43.4% of HSR match load.

Conclusion: As a result of implementing a GPS guided load management program, both athletes were available for starter selection for all matches throughout the whole competitive season and were able to play the majority of match duration.

Clinical implications: Successful collaboration between the medical and sport science teams can ensure injured player readiness and availability for matches. The prioritisation of drills is paramount for ensuring that players are maximising training potential despite being restricted to lower loads compared to the team.

037
A comparison of scapular position and the Davies closed kinetic chain stability test

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Objective: Appropriate evaluation of scapular dyskinesia can help in developing strategies for improving strength and functional sport-specific abilities. The purpose of this study was to explore the relationship between the reliability of scapular positions in recreational collegiate athletes as a comparison to the athletes’ ability to perform the Davies Closed Kinetic Chain (CKC) Stability Test.

Methods: Data were collected to address the specific aims: evaluate the ability of a therapist and student physical therapist to identify Kibler types, and additionally to evaluate the association of Kibler types and performance on the Davies CKC Upper Extremity Stability Test. Inclusion criteria: 18-to-40 years and follow instructions in English. Exclusion criteria: no upper extremity injury in the last year, no history of head or neck injuries in the past year, and have not been diagnosed with hypertension.

Results: Seventy-four participants (36 males, 38 females; mean age 23.1±3.01 years) completed the study. Reliability between therapist and student physical therapist was excellent (Cronbach’s α = 0.96) for static and dynamic scapula positions: hands by side, hands on hips, and bilateral flexion. Kibler type I was the most frequent presentation in all 3 testing positions and those with a Kibler type I performed better on the Davies CKC Upper Extremity Stability Test (25.38 touches averaged over 3 trials). Performance of touches Standard Error of Measurement for Kibler types ranged from 1.03 to 1.54. Older participants did better on the Davies CKC Upper Extremity Stability Test than younger participants.

Conclusion: Kibler scapular identification between students and therapists has excellent reliability in recreational athletes. Recreational athletes with Kibler Type I performed better than Kibler Type IV classifications.

Clinical implications: Kibler classifications do not indicate performance on the Davies CKC Upper Extremity Stability Test for recreational athletes.

038
What is the domain-specific burden of hip-related pain in men and women who play competitive football?

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Objective: Describe the domain-specific burden of hip-related pain (HRP) in competitive football players and explore whether sex-based differences exist within this population.

Methods: A cross-sectional study design was used to compare sub-elite football (Australian Rules and soccer) players with and without HRP. Symptomatic participants (HRP) were eligible for participation if they had

Clinical implications: The number of skiers in Japan is one third of the peak period. Previously, many ski resorts closed during this contraction. Recently, new resorts opened and the skier population has stabilized. Niseko provides an opportunity to expand the skier population, further.
The roles of psychological, social, and contextual factors in recovery after a sport-related knee injury: a scoping review

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Objective: Rehabilitation of sport-related knee injuries predominantly focuses on physical impairments despite calls to address psychological, social, and contextual (non-physical) factors. This scoping review aimed to explore the role of non-physical factors across the acute, rehabilitation and return to sport (RTS) stages of recovery following a sport-related knee injury.

Methods: This review followed the PRISMA Extension for scoping reviews and Arksey and O’Malley framework. Six electronic databases were searched. Included studies contained original data that described a non-physical factor related to rehabilitation, recovery, or RTS after a traumatic sport-related knee injury. Two authors independently conducted title-abstract and full-text reviews. Study quality was assessed with the Mixed Methods Appraisal Tool. Thematic analysis was undertaken.

Results: Of 7,289 records, 77 studies representing 5,540 participants (37% females, 84% anterior cruciate ligament tears, aged 14-60 years) were included. Psychological factors were reported in all studies, while only 39% and 25% of studies reported on social and contextual factors, respectively. 84% of studies investigated non-physical factors during the rehabilitation or RTS stage with few considering them at time of injury. A cross-cutting concept of individualization was present across four psychological (barriers beyond fear, active coping, independence, recovery expectations), two social (social support, engagement in care), and two contextual (environmental influences, sport culture) themes.

Conclusion: Diverse psychological, social, and contextual factors are present across all stages of recovery following a traumatic sport-related knee injury. A better understanding of these factors at the time of injury could assist with optimizing injury management.

Clinical implications: It is essential that psychological, social, and contextual factors are prioritized in the management of sport-related knee injuries.

040
Early use of anti-gravity treadmill training for return to running following tibial stress fracture

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Objective: Anti-gravity treadmill training (ATT) has been proposed as an effective treatment in the rehabilitation of tibial stress fractures in runners. This case study highlights the use of ATT early in the rehabilitation resulting in pain free return to running within 14 sessions.

Methods: A 36-year-old female long-distance runner was diagnosed with a grade 2 stress reaction of the right distal tibial diaphysis. Primary intervention consisted of ambulation with a CAM boot for 6 weeks and complete cessation of running. At initial physical therapy evaluation, the patient scored a 3/6 on the step down test of her right leg and 69/80 on her Lower Extremity Functional Scale (LEFS). The patient's goal was to return to running at a pre-injury pace of 11 minutes per mile (min/mi) for 4 miles. Treatment included strength training, neuromuscular re-education and ATT with cadence training and verbal cues. The patient completed 7 sessions of ATT at a pace of 15 min/mi and body weight (BW) progressions of 10% weekly from 60% to 90%. Intermittent verbal cues of ‘forward trunk lean’ and ‘core activation’ were given. Cadence training was initiated at 90% BW running increasing from 163 steps per minute (spm) to 180 spm. Thereafter, through interval running on the treadmill she returned to steady running at her desired pace of 11 min/mi.

Results: The patient completed a total of 14 sessions over 8 weeks including ATT at visits 3 through 9. At last visit, the patient reported having run pain free for “4 miles at 9.5 min/mi at 180spm” exceeding her pre-morbid level of running. Scores on step down test improved to 0/6 and LEFS improved to 80/80.

Conclusion: ATT offered progressive tibial loading and greater specificity of exercise to allow for a successful return to running following tibial stress fracture.

Clinical implications: Future research may focus on comparing the use of ATT to other treatments in return to running following tibial stress fractures.
Objective: To investigate whether inter-subject differences in activity of the hip extensor muscles during running could explain differences in frontal pelvic angles.

Methods: A total of 25 healthy runners were tested during over ground running at 3.2m/s. Pelvic and lower limb kinematics were collected along with bilateral EMG data from three adductor muscles (longus, magnus and gracilis), gluteus medius, medial hamstrings and gluteus maximus. To eliminate potential crosstalk, an ultrasound-based protocol was used to place the adductor EMG electrodes. A maximal voluntary isometric contraction (MVIC) was collected for each muscle group and maximal isometric adductor strength assessed using a dynamometer. The timing and magnitude of the peak pelvic angle in the frontal plane was identified bilaterally for each subject. EMG activity, normalised to MVIC, was averaged across a window immediately preceding this peak angle. Univariate correlations were then investigated between muscle activity and peak pelvic angle.

Results: Significant positive correlations ($r=0.64$ to $0.65$) were observed between adductor magnus activity and peak pelvic angle. Conversely, moderate negative correlations were found between the other hip extensors (gluteus maximus and hamstrings) and peak pelvic angles ($r=-0.41$ to $-0.5$). There were no correlations between abductor strength and peak pelvic angle.

Conclusion: Altered coordination of the hip extensor muscles, characterised by increased adductor magnus activity and decreased hamstring/gluteus maximum activity, may underlie increased frontal plane pelvic movements.

Clinical implications: Increased frontal plane pelvic angles are associated with running injuries, such as patellofemoral pain and ITBS. Future clinical intervention studies could focus on improving muscle synergy rather than on hip abductor strengthening.

Between-day repeatability of lower limb muscles during running
Scared to move: kinesiophobia in the acute stages of youth sport-related knee injuries

**Objective:** Despite its association with poor long-term outcomes, little is known about the onset or physical manifestation of kinesiophobia early after youth sport-related knee injury. This research assesses the relationship between kinesiophobia and knee strength, balance, or moderate-to-vigorous physical activity (MVPA) in acutely injured compared to uninjured youth.

**Methods:** Participants included 44 youth (11-19 years) with an acute (<4 months) sport-related knee injury and 44 uninjured age-, sex-, and sport-matched controls. The outcome was the Tampa Scale for Kinesiophobia (TSK). Covariates included normalized bilateral knee extensor and flexor strength (isokinetic dynamometer; Nm/kg), bilateral Y-balance test (YBT), and average daily minutes of MVPA (ActiGraph). Descriptive statistics including matched-pair difference (95%CI) were calculated for all variables by study group. Unadjusted conditional (matched-pair) logistic regression assessed the odds of TSK score >37 by study group (odds ratio; 95%CI) and multivariable regression (95%CI) assessed the association between TSK score and each covariate, adjusting for injury history.

**Results:** Participant median age was 17 years (range 10-20) and 65% were female. The median time since injury was 1.5 months (range 0.4-4.2). The injured group had higher TSK scores [matched-pair difference (95%CI); 5 (3, 8)], demonstrated weaker index (injured) knee extensor [-1.42 Nm/kg (-2.00, -0.84)], index flexor strength [-1.02 Nm/kg (-1.53, -0.51)], and non-index knee extensor [-0.56 Nm/kg (-1.08, -0.05)]; and had a 4.75-fold (95%CI 1.62, 13.96) greater odds of TSK score >37 compared to uninjured controls. No associations were found between TSK and strength, YBT, or MVPA.

**Conclusion:** Injured youth have increased kinesiophobia early after injury, but this fear does not appear to be related to physical outcomes.

**Clinical implications:** Kinesiophobia should be managed in the acute stages of a youth sport-related injury.

Injury patterns and perceived risk factors among basketball players in Nigeria

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**Objective:** This study was designed to determine the prevalence, pattern of injury and perceived risk factors of basketball players in Nigeria.

**Methods:** The study was a cross-sectional survey involving 110 basketball players (96 males and 14 females) including amateur and professionals. The amateur players were recruited from various stadia in Lagos state and professional players were those who participated in the Dstv Basketball Premier League. The trainings and matches were watched and recording was done. Basketball-related injury data were collected during trainings and matches using a standardized basketball injury report questionnaire. Data was analysed using SPSS version 21.0 and was summarized with mean, standard deviation, frequency, percentage and tables.

**Results:** The 12-month prevalence of sport injury during training sessions for the basketball players was 80.8%. Sudden turn or twist (40.0%) was the most common cause of injury and the majority of injuries were to the lower extremities, especially at the ankle joint (39.1%). Ligament sprain (52.7%) was the most common type of injury and massage (41.8%) was the most frequently used modality for treatment. 81% of the players never made use of mouth guard and 83% always play on a concrete surface during training sessions.

**Conclusion:** The findings from this study show that the prevalence of basketball injury was relatively high compared with other studies. The major perceived risk factors were non-usage of mouth guard and playing on a concrete surface.

**Clinical implications:** As compared with previous studies, future research should further investigate on injury prevalence with regard to player’s position and prevention strategies. These basketball injury cases could be significantly more rapidly reduced by ensuring the use of protective equipment, trained coaches, good technique, proper training floor with provision of physical therapists and medical doctors working with teams.

Effectiveness of Dry Needling Combined with a Treatment Programme for Musculoskeletal-related Chronic Pain: A Systematic Review and Meta-analysis

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**Objective:** To examine the effectiveness of dry needling (DN) combined with a treatment programme (TP) in comparison with TP alone in patients presenting musculoskeletal chronic
pain, by analysing the differences in pain intensity from baseline to the last available follow-up.

**Methods:** A systematic review was performed according to the PRISMA guidelines. PubMed, PEDro, Cochrane Library, Science Direct, SportDiscus, Web of Science and Ovid databases were searched. To assess changes in pain intensity, the effect size was calculated using Hedge's g (CI = 95%). Considering the I-squared, the random effect model was adopted.

**Results:** 1,082 articles were identified. After assessing for relevance, six randomised controlled trails were included. Data was extracted from 581 participants. The Downs and Black quality assessment revealed that scores ranged from 20 to 27 (maximum score = 31; mean = 24). The heterogeneity between studies was significant (I² = 73.21%; p < 0.001), and no publication bias was identified. 11 meta-analyses were performed. Both DN+TP and TP showed a statistically significant decrease in pain, however the DN+TP presented higher decreases in the immediate period (Δ = 22.89%; g = -0.687; p < 0.001), three-month follow-up (Δ = 36.08%; g = 0.629; p = 0.005) and six-month follow-up (Δ = 27.03%; g = 0.706; p = 0.039) when compared to TP alone.

**Conclusion:** Moderate-low to moderate-high quality evidence suggest that DN+TP is more effective than TP for decreasing chronic pain in the immediate and long-term.

**Clinical implications:** DN has a potential effect on the reduction of chronic pain associated with myofascial pain syndrome, as it seems to act directly on the trigger point. Although previous reviews have pointed out that DN alone is as effective as commonly utilized physiotherapy interventions, this study suggests that including DN as part of a TP may be a more effective clinical strategy for the management of musculoskeletal-related chronic pain.

047

Sticking with it? Adherence to a neuromuscular training injury prevention warm-up program in youth basketball

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**Objectives:** To determine coach and player adherence and explore coach-related factors associated with adherence to the SHRED Injuries Basketball neuromuscular training (NMT) warm-up (SIB) in youth basketball.

**Methods:** This study is based on a cluster randomized controlled trial (RCT) investigating two different delivery methods for SIB. All teams were asked to perform the SIB before every practice and game sessions. Adherence was tracked prospectively, for 34 youth basketball teams, at the team level by team designates, through daily reports, and at the player level by study physiotherapist by random mid-season direct observation of six teams (three per RCT group). Team adherence was measured as utilization fidelity (UF, proportion of total number of expected exercises) and cumulative utilization (CU, proportion of total sessions possible); and player adherence as exercise fidelity (EF, proportion of player observations in which all aspects of exercise components were performed correctly). A cut-point of 80% was indicated as in optimal adherence based NMT dose-response literature. Factors explored included age, years of coaching experience, level of education and post-workshop intention to use SIB through the season.

**Results:** Overall, 31 teams with baseline coach information and all 63 observations from 45 players were analyzed. UF, CU and EF were 93.5%, 71.0% and 47.6%, respectively. Delivery methods for SIB had no impact on adherence. Among the factors evaluated, younger age (t = 2.40; p = 0.023) and less years of coaching experience (Z = 1.99; p = 0.047) were significantly associated with optimal adherence.

**Conclusion:** While adherence to the SIB program was high based on CU, proper program execution was suboptimal at both the team and player levels. Determinants of optimal adherence to NMT programs need further evaluation.

**Clinical implications:** Coaches and players need to be thoroughly educated on the importance of proper program execution for optimum injury risk mitigation.

048

Morphological features of deep cervical muscles between patients with poor posture and healthy controls: a high-frequency ultrasound imaging study

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**Objective:** This study aimed to observe the difference in morphologic characteristics of deep cervical muscles between young females with poor cervical posture and normal posture, and further evaluate the intervention effects of different methods.

**Methods:** 18 female patients with poor posture (forward head angle > 41°) were selected as the experimental groups (EG) and 10 healthy counterparts as the control group (CG). EG were divided randomly into two groups: Craniocervical Flexion Exercise (CFE) group and Isometric Resistance Exercise (IRE) group. Both groups were required to complete the training plan. There was no intervention in the CG. High-frequency ultrasound imaging was used to observe deep cervical flexors (DCF) and extensor muscles' morphology in all participants. The test equipment was a full digital color doppler ultrasound diagnostic system (Apogee 1000). All participants were required to complete the muscles' morphology measurement of deep cervical flexion and extension muscle including DCF and semispinalis capitis (SSC). The cross-sectional area (CSA) of muscles were measured.

**Results:** 1) Compared with CG, there was a significant difference in CSA of right DCF and muscle endurance in the poor posture group; 2) The result of the muscle morphology measurement revealed that there was a significant improvement in cross-sectional area of left DCF and the transverse dimension of left SSC in CCE group (P < 0.05). As for the IRE group, the cross-sectional area of left DCF had a significant improvement (P < 0.05), and further evaluate the intervention effects of different methods.

**Conclusion:** Compared with the normal posture people, there was a significant difference of morphologic characteristics of...
deep cervical muscles in the poor posture people. Both of the CFE and the IRE can improve the function of the DCF.

**Clinical implications:** The high-frequency ultrasound imaging technique could be applied to the evaluation of deep cervical muscles.

**049**
Clinical and Performance Assessments in Athletes with Anterior Cruciate Ligament Reconstruction after Return-to-Sports

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**Objective:** To compare and evaluate clinical and laboratory performance assessments in athletes with anterior cruciate ligament reconstruction (ACLR).

**Methods:** Thirty athletes (15 ACLR and 15 healthy) were recruited. In return-to-sports situation of athletes with ACLR, they were assessed using a single-leg hop test, knee extension and flexion isokinetic tests, and landing performance with the landing error score system (LESS). Limb symmetry index (LSI) between sides was reported. Independent t-test and Mann-Whitney test were used when the sampled data was normal and non-normal distribution, respectively. For further analysis, 16 athletes from our sample (8 ACLR and 8 healthy) were asked to perform a single-leg landing in various directions (forward, diagonal, and lateral directions). Lower limb moments were collected in the motion analysis laboratory. Two-ways mixed ANOVA was used to analyze. Knee joint coordination was also measured.

**Results:** Average time after ACLR was 19 months (SD 10, 95%CI 14, 25). We found that single hop distance and LSI of knee extension strength were significantly different (p < 0.006) between ACLR and healthy groups. No significant difference (p > 0.05) was observed in LESS score and LSI of knee flexion strength and single-leg hop distance. Directions significantly influenced joint moments of the lower limb at peak ground reaction force while group and interaction effect did not show.

**Conclusion:** Direction of jump landing influenced lower limb biomechanics in both groups. After return-to-sports, lower limb biomechanics of athletes with ACLR were similar to uninjured athletes during landing. However, athletes with ACLR still showed some deficits including single hop and knee muscle strength tests.

**Clinical implications:** After return-to-sports, risks of recurrent ACL injury should be monitored even in those who completed a rehabilitation program.

**050**
Tensor fascia latae muscle structure and activation in individuals with lower limb musculoskeletal conditions: a systematic review and meta-analysis

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**Objective:** To systematically review the literature of structure and activation of the tensor fascia latae muscle (TFL) in individuals with lower limb musculoskeletal conditions.

**Methods:** A comprehensive search in MEDLINE, EMBASE, CINHAL, and LILACS was undertaken from inception to 5 November 2018. Studies investigating the structure or activity of the TFL between individuals with a lower limb musculoskeletal condition and a pain-free control group were included.

**Results:** Sixteen studies were included (n = 524 participants), eight reporting structure and eight activation (electromyography [EMG]). Conditions included greater trochanteric pain syndrome (GTPS), hip joint pathology (including femoroacetabular impingement), ACL injury, iliotibial band syndrome (ITBS), and patellofemoral joint osteoarthritis (PFJ OA). Meta-analysis did not show significant differences in muscle size between groups. Moderate effect sizes were found for a higher cross-sectional area of the TFL/sartorius ratio (SMD = 0.74, 95%CI [0.05, 1.43]) in GTPS, and a smaller body mass normalized volume (SMD = 0.61, 95%CI [-1.23, 0.0]) in PFJ OA. EMG amplitude did not differ between groups, but some normalization methods precluded between-group comparisons. Some differences in the pattern of TFL activation were observed when EMG pattern was analysed as linear envelopes or synergies in GTPS.

**Clinical implications:** The TFL has often been proclaimed problematic in conditions such as ITBS, patellofemoral pain, and GTPS. There is currently little evidence to support these clinical assumptions. This suggests that rehabilitation exercises that aim to minimize TFL activity are not yet based on sound evidence.

**051**
Shear wave elastography of the iliotibial band: an exploratory study in pain-free runners

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**Objective:** To explore differences in the shear elastic modulus (SEM) of three anatomical regions of the iliotibial band (ITB) between different tasks/postures by sex, age and nutritional status (normal vs. overweight).

**Methods:** Fifteen recreational runners were recruited from the local community. SEM (as an index of tissue stiffness) was measured unilaterally using shear wave elastography in three regions of the ITB (proximal, middle, and distal), during different tasks/postures: rest and contraction (pre- and post-15 minutes of running), Ober test, standing and pelvic drop in standing.

**Results:** Runners had a median age of 31 (interquartile range 27-36), 11 were females, with a body mass index of 23.5 (± 2.3) kg/m². Compared to rest, the middle region was stiffer during contraction, Ober test, and standing; and the distal region during contraction (mean differences [MD] from 47.6-67.6 kPa). Other conditions did not differ for any region. Stiffness of the middle region was higher in females than males during contraction (MD 38.5; 95%CI 8.4, 68.5), and higher in males than females in the middle (MD 82.4 95% 28.5, 136.2) and proximal (MD 49.9; 95%CI 12.0, 87.9) regions during pelvic drop. Stiffness of the middle region was higher in runners with a normal weight than overweight (MD 38.3, 95%CI -3.0, 79.7).
Conclusions: Stiffness of the ITB was greater in conditions where the ITB is put into strain through passive or active tension. SEM was different by sex and nutritional status during specific conditions. Comparisons between groups need to be considered in light of the small sample size and poor repeatability of some regions/conditions.

Clinical implications: High tension/stiffness of the ITB has been proposed to be associated in the pathogenesis of common running-related injuries, such as ITB syndrome and patellofemoral pain. Assessment of the mechanical properties of the ITB could help determine the potential role of the ITB in these conditions.

052 Evaluation of sprinting force production capacities in athletes at 6th month after anterior cruciate ligament reconstruction: a pilot study

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Objective: After anterior cruciate ligament reconstruction (ACLR), a test battery is often performed to allow the 2nd step of return to sport (RTS-2) continuum: the return to play. Lower limb force production capacities assessment during sprinting could be interesting because it is safe for the graft, provides complementary information in addition to usual functional assessments, and carry out evaluation of athletes’ performance in line with sports reality. The aim of this study was to analyse the potential differences between the operated and healthy lower limbs in force production capacities during sprinting at the time of RTS-2 after ACLR.

Methods: Force-velocity relationship of each limb was assessed during a 6-s sprint on a motorized instrumented treadmill in 9 patients who practiced sports pivot/contact in competition (Marx:14.2±2.1; Tegner:8.4±1.1; 4 females; 173.6±10.1cm; 70.3±8.5kg) at the 6th postoperative month. Maximum power (Pmax), force (F0) and velocity (V0), and Fvprofile (Fv-slope) were calculated and compared between operated and healthy limbs.

Results: Pmax were higher for healthy than operated lower limbs (p=0.005, d=−1.3). For the FV relationships, Fv-slope (p=0.009, d=−1.1) and F0 (p=0.004, d=−1.3) were statistically different, but V0 was not (p=0.10, d=0.6).

Conclusions: At the time of advancing to RTS-2, it seems that an asymmetry in sprint mechanics exist. It appears that the ACLR affects force production at low velocities (F0), and so does Pmax, resulting in side-to-side differences in Fvprofile (operated vs. healthy). This showed an incomplete muscular recovery of the operated limb, which should be compared with specific muscular evaluations (isokinetic assessments).

Clinical implications: For RTS-2 tests batteries, it seems important to determine force capacities asymmetry objectively after ACLR from Fvprofile during functional movements as sprinting or pedaling. These values could be helping decision later for RTS-3: the return to competition.

053 Effect of pressure biofeedback in abdominal drawing-in maneuver on transversus abdominis activation level in patients with chronic low back pain

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Objective: To investigate the effect of abdominal drawing-in maneuver (ADIM) with pressure biofeedback on percentage change of transversus abdominis (TrA) in patients with chronic low back pain.

Methods: 20 patients with low back pain who are eligible for lumbar stabilization training were randomly divided into verbal instruction group (n=10) and pressure biofeedback group (n=10), and received ADIM with verbal instruction and pressure biofeedback respectively. Ultrasound imaging was used to measure the percentage change of TrA thickness during supine lower extremity movement (external rotation of the hip, hip and knee flexion and straight leg raising) and upright loaded tasks (lifting task, loaded forward reach activity, stair stepping) before and after intervention.

Results: During supine lower extremity movement and upright loaded lifting tasks, percentage change of TrA thickness increased significantly after ADIM training (P<0.01). During loaded forward reach activity and stepping tasks, percentage change of TrA thickness showed moderate increase after ADIM training (P<0.05). However, there were no significant differences between the two groups (P>0.05).

Conclusion: Chronic low back patients who meet the criteria of stabilization classification successfully performing ADIM in supine position could effectively increase TrA activation level during supine lower extremity movement and uprighted loaded tasks. Pressure biofeedback doesn’t enhance the ability to increase TrA activation level.

Clinical implications: For patients with chronic low back pain who belong to stabilization classification, ADIM is an effective method to activate TrA. This study shows that the addition of pressure biofeedback doesn’t enhance activation level when performing ADIM and verbal instruction remains effective in learning ADIM.

054 Effects of exposure to cold on stiffness of muscle tendon unit of ankle plantar flexors

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Objective: Exposure to cold is known to affect physiological reactions, such as decreasing tissue metabolic rates, neuromus-
Pain and articular cartilage response to a challenging dynamic loading stimulus in patients after traumatic knee injuries

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Objective: Traumatic knee injury is a substantial risk factor for osteoarthritis, with changes in articular cartilage often evident on MRI within 1 year. The purpose of this study was to compare the response to a dynamic loading stimulus, as measured by changes in pain and tibiofemoral cartilage MRI T2 relaxation, in patients with a history of knee injury and healthy controls.

Methods: We recruited 10 patients (7 ACL rupture, 2 traumatic meniscal tear, 1 cartilage lesion) and 10 healthy controls. We obtained T2 maps before and after the loading stimulus using 3T MRI. We segmented articular cartilage using 3D Slicer. Follow- ing the scan, all participants completed the loading stimulus, consisting of 25 minutes of walking on an instrumented, dual-belt treadmill, including changes in speed, inclines and declines, lateral sways, and random pre-specified perturbations. Patients were asked to report pain on a scale of 0-10 before and after the loading stimulus, as well as rating of perceived exertion (RPE, Borg Scale) at three points throughout.

Results: Mean RPE was 11.5 ± 1.6 for patients and 10.4 ± 2.3 for controls (mean difference 0.1, 95% CI 0.0, 2.1). The patients experienced a significant increase in pain (1.5, 95% CI 0.6, 2.4) following the loading stimulus, while all healthy controls reported no pain at all timepoints. T2 decreased by 1.9 ± 1.5 ms in patients and 1.9 ± 1.3 ms in controls (mean difference 0.0, 95% CI -1.3, 1.3).

Conclusion: Patients with a history of traumatic knee injury experience significant increases in pain with dynamic loading compared to healthy controls despite similar RPE and cartilage load response.

Clinical implications: Clinical guidelines suggest patients who experience knee pain exercise within limits that increase their pain score by no more than 2 points. These results suggest that moderate intensity exercise with changes in pain within those limits causes no additional stress to the articular cartilage compared to healthy controls.

057

The upper limb rotation test: reliability and validity study of a new upper extremity physical performance test

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Objective: Screening tests must be reliable, sensitive, specific, inexpensive, easy to perform and widely available. Physical performance tests (PPTs) meet these criteria and are routinely used for injury prediction, performance enhancement or post-rehabilitation outcome measures. The primary purpose was to evaluate the reliability of the Upper Limb Rotation Test (ULRT). The secondary objective was to evaluate the relationship between the ULRT and two PPTs (SMBT and CKCUEST), trunk rotation range of motion (STRT) and shoulder rotational isometric strength using the Self-Assessment Corner (SAC).

Methods: A sample of 91 healthy adults participated to establish the reliability and validity of the ULRT. We used a two-session measurement design separated by seven days to evaluate the reliability. We used the SMBT, CKCUEST, SAC and the STRT to determine relationships with the ULRT.

Results: Results showed good reliability ranging from 0.76 (DA) to 0.78 (NDA). The SEM95 varied from 1.14 touches (DA) to 1.18 touches (NDA). The MDC95 ranged from 3.15 touches (NDA) to 3.27 touches (DA). A moderate correlation was found between the ULRT and CKCUEST scores (r range = 0.505 – 0.553 for DA; r range = 0.566 – 0.615 for NDA). A moderate correlation was found between ULRT (NDA) and SMBT scores (r range = 0.544 – 0.556).

Conclusion: Results demonstrated good relative reliability and clinically acceptable absolute reliability values for the ULRT. Results showed that performances on the ULRT were moderately correlated with the CKCUEST and the SMBT (NDA).

Clinical implications: Results suggest that the ULRT may be valuable as a screening test to help athletic trainers and physical therapists to assess functional upper extremity performance in a field setting.
Effect of knee aspiration and intra-articular corticosteroid injection on gait biomechanics and strength in patients with knee osteoarthritis

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Objective: To evaluate the effect of knee aspiration and intra-articular corticosteroid injection on gait biomechanics and strength in patients with knee osteoarthritis (OA) and active inflammation.

Methods: Fifteen patients with knee OA, synovitis and effusion were tested before and 3 weeks after receiving a knee aspiration and triamcinolone injection. All patients’ ultrasound (US) exam revealed signs of inflammation that aligned with symptoms. A standard of care knee aspiration and injection was performed under US guidance. Three-dimensional quantitative gait analysis included peak knee angles and moments during walking. Muscular strength testing included isokinetic knee flexion and extension torque at 90 deg/s. Ultrasound, gait and strength tests were completed by the same examiner to reduce variability. Paired t-tests were used to assess changes.

Results: Pre minus post mean changes (95% CI) were: peak knee varus angle -0.11 deg (-1.97, 1.76), first peak knee adduction moment (KAM) -0.01 %BW*ht (-0.33, 0.35), second peak KAM -0.05 %BW*ht (-0.49, 0.39), peak knee flexion excursion angle -2.5 deg (-4.50, -0.59), peak knee flexion moment -0.57 %BW*ht (-1.06, -0.68), peak knee extension moment -0.06 %BW*ht (-0.64, 0.52), peak quadriceps strength -6.14 Nm (-16.92, -1.06), peak knee flexion moment -0.68 %BW*ht (-1.06, -0.68), peak knee flexion moment -0.57 %BW*ht (-1.06, -0.68), peak knee extension moment -0.06 %BW*ht (-0.64, 0.52), peak quadriceps strength -6.14 Nm (-16.92, 4.65) and peak hamstring strength -5.59 Nm (-11.14, -0.03).

Conclusion: Preliminary results suggest patients undergoing aspiration and injection for knee synovitis and effusion experience increased sagittal plane angles and moments during walking and increased maximal hamstring strength.

Clinical implications: Future work will categorize patients as responders and non-responders based on OARSI-OMERACT responder criteria to analyze between group differences.

Establishing normative benchmarks for strength and hop test measures in collegiate athletes

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Objective: To determine differences between limbs and sexes for quadriceps isometric peak torque, single leg forward hop, and the 30-second side hop test.

Methods: Eighty-six Division I collegiate student-athletes (27 males, 59 females) from six teams participated in this study. Primary outcome measures included quadriceps isometric peak torque normalized to body mass (Nm/kg), single leg forward hop distance normalized to height, and the number of successful repetitions during the 30 second side hop test. Paired t-tests were used to determine between limb differences and independent t-tests to determine differences between males and females. For descriptive purposes a limb symmetry index (LSI) was calculated for each measure with the best performance used as the denominator.

Results: There was no significant difference between limbs for quadriceps peak torque (LSI in males 88.4±8.8%; p = 0.96), single leg forward hop (LSI in males 96.0±3.2%; p = 0.48), or the 30-second side hop test (LSI in males 89.2±9.1%; p = 0.60). Males had significantly greater (p<0.001) performance for quadriceps peak torque (males 3.47±0.88 Nm/kg; females 2.90±0.57 Nm/kg), single leg forward hop (males 1.09±0.08; females 0.87±0.10), and the 30 second side hop (males 65±9 repetitions; females 46±12 repetitions).

Conclusion: Performance between limbs was not significantly different, but average LSI values for quadriceps peak torque and the 30 second side hop were below the typical 90% threshold used for rehabilitation progression and return to sport decisions. Males had significantly greater performance values across all three tests.

Clinical implications: Although there was not a significant performance difference between limbs, the degree of asymmetry (e.g. LSI values) should be considered when utilizing an LSI of 90% as a clinical threshold. Additionally, the inclusion of normative values for male and female Division I collegiate athletes can serve as another relevant clinical benchmark.

Effect of cold-water immersion on perceptions of recovery in swimming athletes: a randomized placebo-controlled clinical trial

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Objective: The aim of the study was to verify the acute effect of cold-water immersion on perceptions of recovery in swimming athletes compared to passive recovery and placebo condition.

Methods: 19 young athletes of both sexes performed nine days of physical training out of water followed by 12 minutes of a recovery intervention. Interventions were performed in a crossover design and were: passive recovery (CON), cold water immersion at 14±1°C (CWI) or neutral water immersion at 27±1°C with a skin cleansing solution as placebo condition (PLA). Well-being, heaviness, tiredness, discomfort and pain were measured immediately after the physical training and the intervention using a 5-point Likert scale. At the end of the trial, it was asked “With which of the interventions you felt more recovered?”. Mixed ANOVA was used to analyze the variables (Bonferroni post-hoc) and χ² to compare the preference of interventions (p<0.05).

Results: There was a significant effect for time (p<0.05) for all variables with medium and large effect size. However, post-hoc tests indicated a real improvement of well-being and heaviness only for CWI and PLA, and discomfort only for PLA. Tiredness also showed a significant effect for time*group indicating that CWI and PLA behaved differently from CON. χ² indicated a sig-
Effect of two massage protocols on clinical parameters of swimming athletes: a randomized controlled clinical trial

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Objective: The aim of this study was to analyse the acute effects of massage with different intensities on clinical parameters of swimming athletes compared to control.

Methods: This was a crossover clinical trial in which 21 young swimming athletes of competitive level undertook 12 minutes of deep massage (DM), superficial massage (SM) and passive recovery (PR) after exercise. The athletes performed ~40 minutes of general exercises including squats, push-ups, sit-ups, vertical jumps, burpee, mountain climbers and resisted upper arm exercises. The DM was applied in 3 different intensities for 3 minutes on the anterior thighs, 3 minutes on the upper arms and 6 minutes on the back. The SM was applied superficially with only one intensity at the same sites and duration. For the PR the athletes maintained their normal routine out of the water. Before the beginning of the study the athletes were asked about their perceptions during a normal training to consider the specificity of the modality. Then they rated these perceptions (well-being, heaviness, tiredness, discomfort and pain) by a specific scale. Those results were used for the analysis. The athletes were randomized to a sequence of three interventions (DM, SM and PR) and were blinded to the interventions.

Results: All clinical variables improved over time (p<0.05) for both massage groups. For pain there was a significant small group effect (p<0.05; ES=0.041) and post hoc analysis showed that SM and DM interventions differed from PR but not from each other.

Conclusion: Both massage interventions seem to improve clinical parameters after exercise when compared to PR, however there was no statistical difference between the two massage protocols.

Clinical implications: These results show that 12 minutes of massage may be an effective strategy for post-exercise recovery of swimming athletes.

Pain trajectories and perceived exertion during a 12-week neuromuscular exercise program in patients with knee osteoarthritis

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Objective: To evaluate trajectories of knee pain and perceived exertion during a neuromuscular exercise (NEMEX) program for patients with knee osteoarthritis (OA).

Methods: Fifty-two participants with knee OA underwent a 12-week NEMEX program. At baseline, patients received instructions for a NEMEX program, consisting of 12 visits with a physiotherapist plus home exercises. We assessed the Measure of Intermittent and Constant Osteoarthritis Pain (ICOAP) pre and post program and measured knee pain (pre, post to pre and acute pain flare up (PF; pre to max level) for each visit. We evaluated mean changes (with 95%CI) for the ICOAP from pre- to post-program. We performed linear regression to investigate pain trajectory over time, using the group mean of PC for each exercise visit as the outcome and time as the predictor. The analysis was repeated for PF and RPE.

Results: Fifty patients (96%) completed the program. Decreases in intermittent [12.2 (95%CI 5.1, 19.3)], constant [14.1 (95%CI 8.0, 20.1)] and total pain [13.2 (95%CI 7.3, 19.1)] over the 12-week program indicated substantial improvements. PC and PF levels decreased over time by 0.07 (95%CI 0.02, 0.12) and 0.07 (95%CI 0.02, 0.12) per exercise visit, respectively. RPE increased over time by 0.24 (95%CI 0.12, 0.34) per exercise visit. Time (i.e., number of exercise sessions) explained 36% of the change in PC level, 42% of the change in PF level and 73% of the change in RPE.

Conclusion: Exercise-induced pain decreased while perceived exertion while exercising increased during a 12-week NEMEX program for patients with knee OA.

Clinical implications: Patients with knee OA and their therapists should expect that exercise-induced knee pain during a neuromuscular exercise program will decrease progressively over time, enabling gradual increases in exertion and perhaps intensity.

Combat sports training programme enhances physical performance attributes in children

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Objective: Karate is a type of martial arts which are ancient forms of combat, modified for modern sport and exercise. Participation in karate in Nigeria is beginning to increase, particu-
larly among youth. The focus of this study was to investigate if a combat sports training programme can serve as a tool for improving physical performance attributes such as speed of movement, lower body muscle strength, coordination, and balance of male children.

**Methods:** The study was conducted in 27 male children, with age range between 6 and 12 years, who are registered participants in a karate training programme in Benin City. The participants were randomly assigned to the experimental and control groups with each group containing 13 and 14 participants respectively. Age range of participants in the experimental and control groups were 6 to 11 years (mean = 8.3) and 6 to 12 years (mean age = 9.1) respectively. The study employed experimental research design involving pretest-posttest randomized control group. The participants were subjected to pretesting before and after the combat sports training programme. Data generated from the study were analyzed using independent samples t-tests with alpha level set at 0.05.

**Results:** Findings from the study revealed that the combat sports training programme positively influenced lower body strength (p = 0.002), coordination (p<0.001), and level of balance (p<0.001) of participants. However, no significant improvement was observed in speed of movement (p = 0.117).

**Conclusion:** The outcomes of this study suggest that combat sports training program designed for children with appropriate modification for their ages, can improve physical performance attributes and foster healthy physical development in children.

**Clinical implications:** It is therefore recommended that inclusion of combat sports training programme should be considered in designing sports programmes for children in schools to foster a healthy, all-round development in the children.

**064**

A comparison of medical encounters of older and younger athletes participating at major games

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**Objective:** To identify and compare medical encounter data of older and younger athletes competing in similar events.

**Methods:** Medical encounters for athletes competing in four team sports (Basketball, Football, Hockey, and Netball) were recorded at the 2015 Australian University Games (AUG) and the 2016 Pan Pacific Masters Games (PPMG) using the same standardised medical encounter surveillance system. The de-identified encounter data was compared for injury types and rates between both groups and between the individual sports for each group.

**Results:** For the four sports a total of 1,756 medical encounters were recorded at PPMG and 1,650 at the AUG. Of those 81.04% were medical encounters for lower limb injuries at the PPMG and 72.73% at the AUG. Injuries to ligaments, muscles and tendons accounted for 75.11% of all encounters at the PPMG and 68.97% at AUG. Skin wounds were the next most common presentation at both events (PPMG 6.49%, AUG 11.15%), followed by fractures/dislocations (PPMG 1.94%, AUG 4.97%). There was a higher rate of muscle/tendon injuries at PPMG compared to AUG across all 4 sports (PPMG 36.31%, 29.31% AUG). The higher rate of encounters for muscle/tendon injuries at the PPMG was most evident for Football (PPMG 42.81%, AUG 27.27%).

**Conclusion:** Medical encounter data collected at both the PPMG and AUG demonstrated a higher percentage of lower limb musculoskeletal injuries in older compared to younger athletes participating in similar events. Also, older athletes sought attention for a higher percentage of muscle and tendon injuries compared to younger athletes.

**Clinical implications:** Injury prevention programs for older athletes should target the lower limb, and give particular attention to preventative strategies for muscle and tendon injuries. For planning purposes event medical program organisers should be aware of the likely differences in medical encounters between older and younger athletes.

**065**

Head and knee injuries cause the most missed work in US women playing Australian Rules Football

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**Objective:** The purpose of this study was to examine the injury burden in women playing Australian Rules Football (AFL) in the United States.

**Methods:** All women registered to play AFL in the US were emailed a survey after the 2018 season. Questions asked the number and type of time-loss injuries experienced during the 2018 season, as well as mechanism, severity, and missed work. Athletes who had multiple injuries to the same body part reported on the most severe.

**Results:** 175 of 315 (55%) women responded (mean age 31.8+/−5.8). 109 athletes experienced 248 injuries (2.3 injuries/player). Injury type and severity information was available for 190 injuries (77%). Sprains (n=75, 30%) and strains (n=49, 20%) were the most common injury types. The hand/finger (n=67, 27%), knee (n=38, 15%), ankle (n=31, 12.5%), and head (n=24, 10%) were the most commonly injured body parts. A contact mechanism was responsible for 87 (35%) injuries, most frequently to the head (n=17) and knee (n=17). Foul play resulted in 21 (8%) injuries. Thirty-nine (16%) injuries resulted in athletes missing work, most frequently head (n=10) and knee (n=10) injuries. Moderate severity injuries (8-28 days absence from AFL) were the most common (n=58, 23%), followed by slight (<3 days, n=52, 21%), severe (>28 days, n=41, 17%), and minor (4-7 days, n=38, 15%). Knee injuries caused the largest number of severe injuries (n=15).

**Conclusions:** The results of this study mirror the injury findings of the professional women’s AFL. Even though AFL is a contact sport, the number of contact injuries in this study were less than other women’s sports, such as soccer. Similar to soccer, though knee injuries seem to be the most severe.

**Clinical implications:** Given the impact on work, head and knee injury prevention must be a high priority given the health implications and amateur status of US AFL athletes. This study could also indicate that investigation into the injury burden of other adult amateur sports may be beneficial.
Landing kinetics in collegiate female athletes with and without a history of ACL injury

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Objective: To determine if female collegiate athletes who successfully return to sport following ACL injury (ACLI) differ from their previously uninjured teammates with regard to kinetics during a drop vertical jump (DVJ) task.

Methods: Collegiate female soccer and lacrosse players participated in this study. 18 athletes had at least 1 prior ACLI (age = 20.6 ± 1.3 yrs; height = 169.0 ± 6.0 cm; weight = 65.7 ± 6.1 kg), and 40 athletes had no prior ACLI (age = 19.5 ± 1.3 yrs; height = 166.4 ± 6.4 cm; weight = 64.4 ± 8.6 kg). Athletes completed 3 trials of a DVJ task. The involved limb was randomly assigned in those with no prior ACLI. Kinetics were collected via two inground force plates. Peak vertical ground reaction force (vGRF) of the involved limb, peak vGRF limb symmetry index (LSI), and time to peak vGRF of the involved limb were extracted and normalized to body weight (bw). Independent t-tests were calculated to compare each kinetic variable by ACLI history.

Results: Those with a prior ACLI had lower peak vGRF in their involved limb (1.92 ± 0.48 bw) than those without ACLI (2.24 ± 0.55 bw); p = 0.04. They had less limb symmetry of their peak vGRF (87.9 ± 25.8%) than those without (104.2 ± 21.8%; p = 0.02). They reached this peak later after ground contact (58.1 ± 33.7 ms) than those without (44.0 ± 19.3 ms; p = 0.049).

Conclusion: Females who play collegiate sports following ACLI have differences in their landing kinetics compared to their previously uninjured peers. They have a lesser peak vGRF on their involved limb and take longer to reach this peak. These factors, combined with a greater asymmetry of the magnitude of this peak between limbs, suggest that they continue to offload and delay loading of their involved limb during double limb jumping tasks.

Clinical implications: Even athletes who successfully play collegiate sports following ACLI have kinetic differences relative to their uninjured peers. Further research should explore how these differences affect future injury risk and long-term joint health.

Sensitivity of the MyotonPro to measure the changes in the viscoelastic properties of a trigger point on the infraspinatus in non-traumatic chronic shoulder pain after a dry needling intervention

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Objective: To investigate the sensitivity of the MyotonPro to detect changes in the viscoelastic properties of a trigger point (TP) in the infraspinatus muscle in participants with a non-traumatic chronic shoulder pain after a dry needling intervention.

Methods: Forty-eight individuals who presented non-traumatic chronic shoulder pain were recruited. The presence of a TP in the infraspinatus muscle of the painful side was confirmed by an experienced physiotherapist with a palpatory exam according to Travell and Simons criteria. The TP was marked and the viscoelastic properties including tone and stiffness were measured with the MyotonPro device by an evaluator. After the first set of measurements (T0), an experienced physiotherapist applied dry needling to the TP with an Optimed 40 x 0.30 mm single use acupuncture needle to obtain a twitch. The same set of measurements was repeated immediately after the dry needling (T1) and 30 minutes later (T2). Repeated measures ANOVA and post-hoc tests where used to assess changes in viscoelastic properties over time with a significant level set at 0.05.

Results: Significant decrease in stiffness and tone was found across time after the dry needling intervention. Post-hoc tests with Bonferroni corrections revealed significant differences in stiffness and tone between T0-T1 (Stiffness: T0 = 296.96±65.19 N/m; T1 = 277.25±62.14 N/m; p=0.001, Tone: T0 = 15.99±2.63 Hz; T1 = 15.08±2.89Hz, p=0.004) and T0-T2 (Stiffness: T2 = 283.73±57.32 N/m; Tone: T2 = 15.68±2.42Hz, p=0.013).

Conclusions: Findings of this study reveal that the MyotonPro can detect changes in the measurements of stiffness and tone of a trigger point after a dry needling intervention.

Perceptions about running footwear and assessment of an online educational module

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Objective: The objectives of this study were to (1) assess the perceptions of runners, footwear retailers and healthcare practitioners (HCP) on the effects of running shoes on injuries; (2) evaluate the role of an evidence-based online educational module.

Methods: Using an online survey, we collected information on demographics and beliefs about injury risk and different shoe features (e.g. cushioning, drop) or selection strategies (e.g. based on foot arch). Agreement with survey items was assessed using continuous scales (0: not important/useful, 10: very important/useful). Subsequently, an optional educational module was presented after which beliefs were reassessed. We ran one-way ANOVA between subgroups and paired t-tests to analyze the effects of the module.

Results: A total of 1,425 participants completed the baseline survey, of which 781 completed the educational module. Overall, footwear was perceived as important in preventing injury (7.2/10, 95% CI 7.1, 7.3). HCP perceived footwear as less important (6.3/10, 95% CI 6.1, 6.6) than runners (7.6/10, 95% CI 7.5, 7.7) and retailers (7.9/10, 95% CI 7.3, 8.5)(P<0.001); relevance of cushioning, drop and selection according to foot type were also lower in HCP than in other subgroups (P<0.001). The educational module was deemed useful (8.3/10, 95% CI 8.2, 8.5) and 58.6% of respondents said it changed their perceptions. Perceived importance of footwear in preventing injuries decreased after the module (-1.0/10, 95% CI -0.9, -1.2; P<0.001).
Conclusion: Running footwear is perceived as important in the prevention of running injuries; an evidence-based module can aid in educating individuals on the literature surrounding footwear allowing informed recommendations/choices.

Clinical implications: This online module can effectively be used to educate runners, retailers and HCP about the scientific research on running footwear and injuries. This could potentially translate into reduced injury rates among runners.

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SierraSil as an ergogenic aid to performance in athletes

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Objective: SierraSil (SS) is a unique mineral complex and a Health Canada licensed Natural Health Product (NPN 80039305). This study examined whether SS could improve anaerobic power in a group of well-trained athletes. A secondary purpose was to examine the effect of SS on the severity of delayed onset muscle soreness (DOMS).

Methods: This was a double-blind, cross-over design with 10 male varsity football players (mean age = 22 years; height = 183.6cm; weight = 90.3kg). The athletes performed three Wingate cycle ergometer tests 5 minutes apart as a test of peak power, average power and fatigue index. DOMS were recorded on a 0-10 visual analogue scale (VAS) at 24, 28, and 72 hours post exercise. Prior to exercise and 5 minutes following the last Wingate test, blood was taken for analysis of selected cytokines. The athletes were randomly assigned to SS or placebo groups for three weeks and, following a three-week washout period, the experimental treatments were reversed.

Results: Following SS supplementation, the peak power increased by 33.8 W (a 3% increase) and mean power by 6.7 W (a 1% increase). In the placebo group the peak power decreased by 11.2 W (-2.6%) and the mean power decreased by 17.2 W (-1%). DOMS values on the VAS were higher in the placebo group at 24, 48, and 72 hours post-exercise (P = 3.2, 2.2, 1.3 vs. SS = 2.5, 1.6, 0.6). There were no statistically significant changes in the performance measures between the two groups however (p > 0.05). There were no significant changes in the cytokine measures following supplementation with either SS or placebo.

Conclusion: All athletes completed the trial. SS was well tolerated and resulted in improvements in anaerobic power and in reducing the level of DOMS post-exercise. There were no adverse effects reported.

Clinical implications: SierraSil is safe to use in highly trained athletes and resulted in improvements in anaerobic power and in reducing the level of DOMS post-exercise in a ‘sport significant’ way.

071
The proprioception and postural stability characteristics of perceived instability subgroups in chronic ankle instability

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Objective: The purpose of this original investigation was to determine if selected proprioception and postural stability are different among perceived instability subgroups of chronic ankle instability (CAI) and healthy control participants.

Methods: Fifty-five participants volunteered and were categorized into perceived ankle instability (PI) alone (n = 11), PI in combination with recurrent ankle sprains (PI-RAS; n = 11), PI in combination with mechanical ankle instability (PI-MI; n = 11), PI in combination with mechanical ankle instability and recurrent ankle sprains (PI-MI-RAS; n = 11) and controls (n = 11). Participants completed assessments of proprioception and postural stability. The data between groups were statistically evaluated by one-way ANOVA.

Results: There were no significant differences in active closed chain proprioception and single-leg stance assessments between PI subgroups and healthy participants (p > 0.05), or between the four subgroups of PI (p > 0.05). There were significant differences in postero-medial and postero-lateral direction of star
The effect of sleep on explosive strength gains in female collegiate soccer players during off-season training: a pilot study

**Objective:** In athletes, sleep quantity and quality are imperative to effective physiological and cognitive functioning. In addition, sleep quantity and quality may affect the outcome of an off-season resistance training program. This study aimed to investigate the effect of sleep quality and quantity on explosive strength in NCAA D1 female collegiate soccer players during an off-season training program.

**Methods:** Eleven female collegiate soccer players (19.8±0.8 years) participated in an off-season resistance training program three days per week for five weeks. A jump mat and associated software was used to measure explosive strength (ES), defined as the maximum vertical jump height inches (in) in over three trials, prior to the start of the training program and at the end of a 5-week training program. Sleep quantity, in hours (h), was reported by each athlete at the initiation of the study and before the start of each resistance training session. Each athlete also reported sleep quality on a 5-point scale (1 = poor quality and 5 = great quality) at the same times as sleep quantity.

**Results:** No difference in ES was observed as a result of the 5-week resistance training program (initial = 17.8±2.3 vs final = 18.3±2.4). Initial average sleep quantity was 6.7±0.6 while at study conclusion was 6.8±0.9. The median sleep quality at the start of the program was 3.2±0.5, and 3.8±0.4 at study conclusion. A weak correlation between sleep quantity and ES (r = 0.11) was observed, while a moderate correlation between sleep quality and ES was noted (r = -0.37).

**Conclusion:** A weak correlation between sleep quantity and ES was observed, yet sleep quantity reported is more than one hour less than that recommended for college athletes. The moderate correlation between sleep quality and ES suggests improved sleep quality may benefit ES development.

**Clinical implications:** Practitioners should consider that sleep quality may mediate the development of ES during off-season resistance training.

Differences in muscle activities of the scapular muscles in open and closed kinetic chain exercises

**Objective:** To study the activation of the scapular muscles between healthy people and people with scapular dyskinesia (SD) in the open and close chain exercises (OKC & CKC), to explore the differences of these two exercises on the activation of scapular muscles, and to clarify the optimal strategy for shoulder injuries rehab.

**Methods:** 42 subjects were divided into SD group (n = 22) and C group (healthy, n = 20). The MVIC of target muscles were tested as well as 8 actions: CKC/OKC-flexion, CKC/OKC-extension, OKC/CKC-neutral external rotation and OKC/CKC-shoulder 90° abduction external rotation. We calculated the IEMG% and input% of the target muscles.

**Results:** Between groups, for the OKC, the activation of SD group was more optimized, SA-IEMG%, LT-IEMG% and infraspinatus (IS)-input% were higher than C group in flexion. Intra-group: (1) In SD group UT-IEMG% and input% of CKC-flexion were significantly lower than that of OKC (P<0.05), while the IEMG% and input% of SA were higher(P<0.05). (2) The activation of MT, SA and especially LT in CKC-extension was higher than that in OKC(P<0.01). (3) Under the external rotation, the IEMG% of IS and post deltoid is largest at neutral-CKC, but IS-input% is the highest at 90° CKC.

**Conclusions:** (1) OKC/CKC exercises have no difference in healthy people, but CKC-flexion can promote coordinated contraction of stabilizing muscles in SD. (2) The CKC-extension is conducive to the contraction of MT, LT and SA, especially the mobilization of LT. (3) CKC-shoulder 90° abduction external rotation exercise can safely and effectively activate IS, which is a good exercise for shoulder external rotation, especially for early rehabilitation of rotator cuff injuries involving IS.

**Clinical implications:** CKC exercise is beneficial to balance the scapular muscles. It is suggested that CKC training can be safely applied to shoulder injury patients’ early rehabilitation.
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May 30, 2019

Anthem, Aetna, Cigna Updates on TENS and Knee and Back Braces

UPDATE: T.E.N.S. & Anthem BC/BS FDA-approved T.E.N.S. units are considered medically necessary when prescribed as a treatment for pain for those who have not responded to other modalities, and

May 29, 2019

Cutting-Edge Rehab and Recovery System Backed by Research

NORMATEC PULSE PRO 2.0 The Ultimate Rehab and Recovery Experience The NormaTec PULSE PRO 2.0 is today’s most advanced athlete recovery system. It brings you cutting-edge connectivity and

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