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ABSTRACT

Background: Ankle injuries account for up to 40% of all sport related injuries. These injuries can result in weeks to months of missed sport or work. The PRICE (Protection, Rest, Ice, Compression, Elevation) treatment is standard care for most acute ankle sprains. Recently, early mobilization in adults has been shown to decrease time off from sport or work, and the likelihood of developing chronic instability. To date, no research has been performed assessing the effectiveness of early mobilization in pediatric patients (<18 years). Purpose: There were two objectives of this study: (1) to determine if early ankle joint mobilization using elastic band traction is effective and (2) assess the occurrence of adverse events with this technique in the pediatric population.

Methods: Patients with an acute ankle sprain of <7 days referred to physical therapy were randomly assigned to receive early mobilization or PRICE. Early mobilization was performed using a stretch band ankle traction technique. Both groups received a standardized rehabilitation program. Pain, edema, ankle strength using hand-held dynamometry, and Foot and Ankle Disability Index (FADI) were measured at both initial evaluation and at discharge. The number of days before return to sport and the number of treatment sessions were also variables of interest.

Results: Forty-one pediatric patients were recruited for participation (mean age 14.6 ± 1.9 years). Both treatment groups had clinically significant improvements in pain, edema, strength, and FADI scores. No significant differences in outcomes were noted between treatment groups. Mean number of days for return to sport for the PRICE group was 26.33 ± 7.14 and the early mobilization group was 26.63 ± 14.82, the difference between groups was not significant (p = 0.607). The number of total visits for the PRICE group of 8.07 ± 2.63 and the early mobilization groups of 8.5 ± 1.57, was also not statistically significantly different (p = 0.762). There were no reported adverse events with early mobilization.

Conclusion: Early mobilization appears to be a safe intervention in pediatric patients with an acute ankle sprain. Early mobilization resulted in similar outcomes when compared to traditional PRICE treatment. A high drop-out rate in both treatment groups was a limitation of this randomized trial.

Level of evidence: 1b

Key words: Ankle sprain, pediatric, mobilization
verses the traditional treatment PRICE, as well as use a technique that could be replicated at home independently in areas where access to physical therapy services may be limited. Therefore, the two objectives of this study were: (1) to determine if early ankle joint mobilization using elastic band traction is effective and (2) assess the occurrence of adverse events with this technique in the pediatric population.

**METHODS**

The design of this study was a single blinded randomized controlled trial using a sample of convenience. Patients presenting to Nationwide Children’s Hospital sports medicine or physical therapy clinics in Columbus, Ohio with an acute lateral ankle sprain were eligible for participation. Patients were diagnosed with acute lateral ankle sprains by the sports medicine physician. This study was registered at ClinicalTrials.gov (Identifier number NCT01134653). The institutional review board approved this study prior to recruitment and data collection. Inclusion criteria were: patients 8-18 years old, with an acute lateral ankle sprain of <3 days. The inclusion criteria of duration of ankle sprain was later modified from 3 days to 7 days due to recruitment difficulties. Patients were excluded if they had: latex allergy, syndesmotic ankle sprain, concurrent lower extremity injury, previous history of lower extremity surgery or fracture in the past year, inability to follow directions, and inability to attend follow-up appointments. After the parent or legal guardian and patient gave informed consent/assent and prior to randomization, the patients were evaluated by a physical therapist. Pre-treatment evaluation measures included clinical and self-report measures. These same evaluation measures were completed at discharge by a different blinded therapist.

**CLINICAL MEASURES**

**Figure Eight Tape Measurement of Ankle Edema**

Ankle and mid-foot edema was measured using the figure-of-eight procedure described by Esterson and modified by Petersen. This is performed by using a flexible tape measure with the zero point positioned in the groove at the edge of the lateral malleolus, approximately midway between the prominence of the tibialis anterior tendon and lateral malleolus. The
taped measure was then drawn medially across the instep, pulled toward the base of the fifth metatarsal, drawn toward the medial malleolus and across the Achilles tendon to the lateral malleolus, and finally brought around to meet the original zero. All measurements were rounded up to the next whole millimeter. The amount of edema was reported as the difference between the injured and uninjured figure-of-eight measurements.

**Numeric Pain Rating Scale (NPRS)**

The NPRS is an 11-point pain-rating scale ranging from 0 (no pain) to 10 (worst imaginable pain) used to verbally assess current pain intensity as well as the best and worst level of pain during the last 24 hours. A score of ± 2 represents the minimal clinically important difference.

**Ankle Range of Motion (ROM)**

Both active and passive motion of dorsiflexion, plantarflexion, inversion, and eversion was measured using a standard 8” goniometer with the patient in the supine position.

**Ankle Muscle Strength**

Strength was measured using a digital hand-held dynamometer for dorsiflexors, plantarflexors, invertors, and evertors. Testing was performed using a make-test, with the patient in the long sitting position. Repeated strength measurements were performed for three sequential tests, the highest of the trials for each motion was recorded.

**SELF-REPORT MEASURES OF FUNCTION**

**Foot and Ankle Disability Index (FADI) and FADI Sport Module**

The FADI is a 26-item questionnaire that uses a 5 point scale (“unable to do” through “no difficulties at all”) to rate the extent that the ankle injury in impacting everyday life. Items include a variety of activities from standing and sleeping through stair climbing and recreational activities. The FADI sport modules includes an additional 8 items related to specific athletic movements such as landing and cutting, questions about the technique and duration of participation. The FADI has been shown to have excellent construct validity (r = 0.64) and excellent intra-rater reliability. The FADI has a reported minimal detectable change (MDC) of 4.8 points.

**Interventions**

After the evaluation, the patients were randomly assigned to either traditional PRICE treatment or early mobilization. The therapist that completed the evaluation then performed the assigned treatment. The evaluation measures were performed before group assignment to maintain blinding during data collection.

**PRICE group**

Patients randomized to the PRICE group were instructed in ankle compression wrapping if they had not already been issued a lace-up ankle brace. If issued a lace up ankle brace by their physician, the brace provided compression. Patients were instructed to wear compression during weight-bearing activity and at least eight hours a day. During the first 72 hours these patients were instructed to rest, use intermittent ice and compression, as well as elevate their sprained ankle at least 12 inches while lying in supine. Patients were instructed to remove their brace to ice and elevate their ankle for 20 minutes, two times a day.

**Early Elastic Band Mobilization Group**

For the early elastic band mobilization group, the talocrural distraction technique described by Hartzell and Schimell was followed. Two mini Jump Stretch® bands (JumpStretch Inc. Stow, Ohio) were looped around the patient’s shoe, so that the center of distraction pull was directly inferior to the talocrural joint. (Figure 1) The therapist used these bands to put as much horizontal traction on the ankle joint as possible without creating pain. The patient then actively dorsiflexed and plantarflexed the ankle within pain free ROM for 30 seconds or until fatigue with the aim of increasing pain free talocrural motion. After a 30 second rest, the patient actively inverted and everted their ankle within pain free ROM for 30 seconds or until fatigue. The traction force was then released and the patient actively performed 10 clockwise and counter-clockwise circles. The band traction was then repeated in a vertical traction position, as this position is thought to help reduce edema. (Figure 2) After an additional 30 second rest, a third light Jump Stretch® band was
could continue to wear the brace as desired. The patients were instructed not to ice or perform compression or elevation in this treatment group.

**Standard physical therapy care**

A standard treatment program was administered for both groups according to prescribed progression criteria (Appendix 1). There were three Phases in the standardized treatment program and the patient transitioned through each Phase based on functional ability. All patients began with Phase 1 and transitioned to Phase 2 once they demonstrated: 1) no gross deviations with walking, 2) a report of <5/10 pain with ADLs on the NPRS, and 3) within 5 degrees of ROM to the contralateral ankle for all planes of motion. Patients transitioned from Phase 2 to Phase 3 once they were able to demonstrate: 1) single leg balance on the injured lower extremity >30 seconds, 2) up and down 12 stair steps using a reciprocal gait pattern without pain, 3) able to jog for 2 minutes on the treadmill with <2/10 pain and 4) no report of instability with gait.

Patients were discharged from physical therapy once they completed all 3 Phases of standard therapy and were able to meet the following functional criteria: 1) single leg hop test within 80% of the contralateral limb, 2) Ability to single leg balance within 2 seconds of uninvolved lower extremity on an inflated rubber hemisphere attached to a rigid platform (BOSU). The number of days from initial evaluation until the patient met the discharge criteria was recorded for the outcome of time in therapy.
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BLINDING AND RANDOMIZATION
The evaluating therapist was aware of treatment allocation, whereas the exercise therapist and discharge therapist were blinded to treatment group allocation. Due to the nature of the intervention, blinding patients to treatment allocation was not feasible. Randomization was determined by sealed envelopes which were opened by the evaluating therapist after the patient agreed to participate and evaluation measures had been completed. An individual not involved in the study filled 50 blank envelopes with a paper designating either Jump stretch or PRICE. The envelopes were shuffled and given a numeric number from 1-50. When patients were enrolled the next numeric envelope was opened and the patient received the treatment described on the paper.

SAFETY
To address the issue of safety, patients who experienced a clinically significant increase in pain (MCID of two points), which did not affect their ability to perform activity, during or after the elastic band traction were classified as having had a mild adverse reaction. Following the treatment, if patients reported or were observed to have a decrease in their ability to perform activity they were classified as having had a moderate adverse event. Patients were instructed that if they experienced pain or reduced function following the intervention to notify study staff. Patients who had an adverse reaction were re-evaluated by their therapist. The patient would be referred back to their physician if they demonstrated a significant injury or were deemed inappropriate to continue physical therapy.

SAMPLE SIZE
The calculations were based on detecting an 4.6% difference in the FADI index at the 4-week follow-up, assuming a standard deviation of 5.1, a 2-tailed test, and an alpha level equal to 0.05 and 80% power. This generated a sample size of 18 patients per group. Allowing for a conservative dropout rate of approximately 15%, we recruited 41 patients into the study.

DATA ANALYSIS
All analyses were conducted using SPSS 21 software. An intent-to-treat design with the multiple imputation model was used for any missing values. The first aim of the study was examined with a two-way repeated measures multivariate analysis of variance (MANOVA) with treatment group as the between-patient variable and time (baseline, and discharge) as the within-patient variable. The dependent variables were function (FADI and FADI sport score) and pain. The relative risk of having an adverse reaction from early mobilization was calculated to assess the second aim of this study. A Chi-square analysis was performed to determine if there were any differences between treatment groups for adverse reactions. Post-hoc repeated measure univariate analyses were performed to assess the individual effect of the intervention on FADI, FADI sport, and pain. Secondary outcomes including edema, range of motion, and strength were assessed using a t-test or Wilcoxon rank sums test depending on the nature of the data distribution.

RESULTS
Eligible participants were recruited from March 2010 to February 2014. Study staff screened 1,970 consecutive patients who presented to the sports medicine physicians or physical therapists with an ankle sprain for inclusion. Forty-one patients (aged 10-18 years) were enrolled after receiving written consent from the patients and their parent or legal guardian (Figure 4). All patients received the appropriate randomized treatment intervention (early elastic band mobilization or PRICE).

Baseline variables were similar between treatment groups. (Table 1) Eleven patients dropped out of physical therapy before discharge (eight in the early elastic band mobilization group and three in the PRICE group). All patients reported non-study related reasons for not continuing with physical therapy treatment (time and financial constraints). A grade II lateral ankle sprain was the most common referring diagnosis for patients participating in this study (71%), with grade I lateral ankle sprains accounting for 24% and Grade III 5% of injuries. There were no significant differences in grade of sprain between treatment groups (p = 0.89).

Patients in both groups were treated for an average of 7.7 ± 3.8 visits over the course of 25 days to meet all predetermined discharge criteria. (Table 2) Between-group comparisons revealed no significant differences in the number of visits or duration of
Dynamometer strength testing of the injured ankle showed significant weakness, <90% of compared to uninvolved limb, in all major motions (Table 3). Both groups demonstrated significant increases in strength at discharge (p < 0.01) but there were not significant differences between treatment groups.

Early elastic band mobilization group had a mean of 0 ± 0.6 cm of edema and PRICE had a mean of 0.1 ± 0.4 cm of edema compared to the non-injured ankle. There were no significant differences between treatment groups (p = 0.77). Dynamometer strength testing of the injured ankle showed significant weakness, <90% of compared to uninvolved limb, in all major motions (Table 3). Both groups demonstrated significant increases in strength at discharge (p < 0.01) but there were not significant differences between treatment groups.
The two-way treatment group x time interaction repeated measures MANOVA demonstrated no statistically significant between-group differences for function and pain (p = 0.79). Within-group differences showed that both groups had statistically and clinically significant improvement at discharge. Repeated measures univariate ANOVA demonstrated no differences between treatment groups for function or pain (Table 4). No patient in either group reported an adverse reaction with treatment. Relative risk and chi-square analyses were not performed since no adverse reactions were noted.

**DISCUSSION**
Joint mobilization has been shown to be effective for improving function and increasing motion in adults and older adolescents with ankle injuries. This study assessed the safety and efficacy of early manual joint mobilization after an acute inversion ankle sprain in pediatric patients as young as 10 years of age with a mean age significantly younger than subjects of any other study. No adverse events were noted with the use of elastic band ankle traction mobilization in this study. Although some authors have voiced concern over performing joint mobilization techniques in pediatric patients due to concern of growth plate injury there have been no documented cases of a growth plate injury as a result joint mobilization. Additionally, the forces imparted from mobilization are significantly lower than those that children experience during commonly performed activities.25-27 The results of this study offer preliminary evidence that early ankle joint mobilization is safe in this population. This finding is consistent with other research assessing joint mobilizations to the lumbar spine in pediatric patients.28,29

Many studies performed on adults have focused on short-term results of manual therapy with follow-up times from immediate to one-week.10,14,30,31 The authors chose to look at longer term outcomes, including time to recovery, and change in the function and pain at discharge from supervised therapy. Cleland et al.4 assessed the long-term outcomes (four-week and six-month) of joint mobilizations compared to a supervised home exercise program for acute lateral ankle sprains. Although significantly better outcomes were found with joint mobilization, Cleland's study assessed joint mobilization and supervised exercise compared to a supervised home exercise program. Due to their study design, it

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<td></td>
<td>Baseline</td>
<td>Discharge</td>
<td>Baseline</td>
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<tr>
<td>Dorsiflexion</td>
<td>7.7 ± 4.3</td>
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<td>Plantarflexion</td>
<td>15.5 ± 7.0</td>
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<td>16.6 ± 6.9</td>
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<tr>
<td>Inversion</td>
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<td>9.9 ± 3.5</td>
<td>5.0 ± 2.7</td>
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<tr>
<td>Eversion</td>
<td>4.3 ± 2.6</td>
<td>9.4 ± 2.6</td>
<td>4.4 ± 2.7</td>
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Table 3. Ankle strength, measured using handheld dynamometer (kg)

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<tr>
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<th>Discharge</th>
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<td>FADI</td>
<td>PRICE</td>
<td>63.4 ± 20.1</td>
<td>101.6 ± 2.8</td>
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<td>66.1 ± 25.5</td>
<td>102.1 ± 2.7</td>
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<tr>
<td>FADI Sport</td>
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<td>7.8 ± 9.8</td>
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<td>30.6 ± 2.0</td>
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<td>Pain (NPRS)</td>
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<td>0.1 ± 0.3</td>
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Table 4. Pairwise comparison of Function and Pain
is difficult to conclude the addition of joint mobilization was solely responsible for the positive long-term outcomes. The design of the current study allowed for the assessment of the mid-term efficacy of the addition of a manual therapy technique to a supervised exercise program. The results of the current study show, at least for the pediatric population, the addition of early joint mobilization to a supervised exercise program was not more beneficial than traditional PRICE recommendations.

The results of the current study indicate that the addition of talocrural distraction to a supervised PT program was not more effective than PRICE followed by supervised PT. These results contrast with findings from similar research in the adult population; there are several possible reasons for the conflicting evidence. The first possible reason is that children recover well following an acute ankle sprain and the addition of manual therapy may not be needed. Another reason for the conflicting results may be the lack of a short-term assessment in the current study. Studies of adults demonstrate positive short-term results, however, it is unknown if children might experience a similar short-term benefit. Finally, this study assessed elastic band ankle traction with movement at the talocrural joint, which is a different technique for joint mobilization than what has been previously shown to be effective in an older population. There were two reasons the authors chose this technique: 1) Distraction manipulation of the talocrural joint has been shown to have positive results in adult research, but a mobilization technique was chosen as the safer alternative for the pediatric population, and 2) with minor modification and instruction, the patient can perform the elastic band ankle traction technique independently (as a self-mobilization).

LIMITATIONS
There are a number of limitations to the current study that should be considered. First, there was a high drop-out rate noted in both treatment groups (24%). Second, there were difficulties recruiting patients who met the original strict acute injury inclusion criteria. The authors lengthened the time post-injury from 3 to 7 days in an attempt to increase the number of patients eligible for this study. By altering the inclusion criteria to improve recruitment, time to early joint mobilization was delayed. This delay in application of the joint mobilization may have altered its effectiveness for improving patient outcomes. Additionally, this study only assessed one distraction joint mobilization technique to the ankle, whereas positive responses in adults resulted from multiple joint mobilizations to both the ankle and knee. A more expansive joint mobilization approach may have produced different results.

CONCLUSIONS
Early mobilization appears to be a safe intervention in pediatric patients who have sustained an acute ankle sprain. Early mobilization resulted in similar outcomes in pain, range of motion, and self-reported function when compared to traditional PRICE treatment. A high drop-out rate in both treatment groups was a limitation of this randomized trial.

REFERENCES


### Appendix 1

#### Phase I

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<td>Ankle alphabet (A-Z x 1)</td>
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<td>Gastrocnemius stretch against wall (3 x 30 seconds)</td>
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<tr>
<td>Soleus stretch against wall (3 x 30 seconds)</td>
</tr>
<tr>
<td>BAPS® seated: Level 2 if children shoe size (up to size 13.5), Level 3 if adult shoe size (30 repetitions each)</td>
</tr>
<tr>
<td>-dorsiflexion/plantarflexion, inversion/eversion, clockwise and counter</td>
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<tr>
<td>-clockwise circles</td>
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<tr>
<td>Elastic Band 5-way ankle strengthening. (15-30 repetitions)</td>
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<td>-dorsiflexion, plantarflexion knee straight, plantarflexion knee bent, inversion, and eversion.</td>
</tr>
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<td>Straight leg raises abduction and extension (30 repetitions)</td>
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<tr>
<td>Seated heel and toe raises (30 repetitions)</td>
</tr>
<tr>
<td>Weight Shifts anterior/posterior (20 repetitions)</td>
</tr>
<tr>
<td>Weight Shifts Lateral (20 repetitions)</td>
</tr>
</tbody>
</table>

#### Phase II

<table>
<thead>
<tr>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treadmill walk at 2.5 mph (3-5 minutes based on tolerance)</td>
</tr>
<tr>
<td>Treadmill light jog at 5.5 mph (30 seconds -2 minutes based on tolerance)</td>
</tr>
<tr>
<td>Treadmill side step away from injury (3-5 minutes)</td>
</tr>
<tr>
<td>3-way medicine ball toss (1kg) at rebounder in single leg stance. (15 repetitions each direction facing with rebounder to the front, left and right)</td>
</tr>
<tr>
<td>Standing elastic band resisted hip three-way (hip flexion abduction and extension) (15-30 repetitions)</td>
</tr>
<tr>
<td>Functional Star: Stand on single leg. Opposite lower extremity reaches in five directions hold at the end of the reach for 2 seconds. Start with five repetition and progress to 10.</td>
</tr>
<tr>
<td>Calf raises (15-30 repetitions)</td>
</tr>
<tr>
<td>Squats (15-30 repetitions)</td>
</tr>
<tr>
<td>Half foam roll dorsiflexion (15-30 repetitions)</td>
</tr>
<tr>
<td>Lateral step downs (15-30 repetitions, step height based on patient)</td>
</tr>
<tr>
<td>4-way resisted walking: One inch medium elastic band placed around patients’ waist and the opposite end anchored to the wall. (x 5 repetitions each: Forward, Backward, Lateral Left, Lateral Right)</td>
</tr>
</tbody>
</table>
### Appendix 1 (continued)

<table>
<thead>
<tr>
<th>Phase III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treadmill running at 6 mph (up to 10 minutes -slow down or stop if Pain &gt; 3/10)</td>
</tr>
<tr>
<td>1 foot to 2 feet hops in place (20 repetitions)</td>
</tr>
<tr>
<td>2 feet to 1 foot hops in place (20 repetitions)</td>
</tr>
<tr>
<td>Line jumps forward/backwards and side to side (2-3 repetitions of 30 seconds each)</td>
</tr>
<tr>
<td>Carioca (4 repetitions of 30 feet)</td>
</tr>
<tr>
<td>Single leg diagonal hops for distance (5 repetitions)</td>
</tr>
<tr>
<td>Shuttle run drill (20 feet distance down and back, 5 repetitions)</td>
</tr>
<tr>
<td>BOSU® runs forward (2 repetitions of 30 seconds)</td>
</tr>
<tr>
<td>BOSU® runs lateral (2 repetitions of 30 seconds)</td>
</tr>
</tbody>
</table>
ABSTRACT

Background: Women's soccer has among the highest injury rates in collegiate sports, and lateral ankle sprains (LAS) are among the most commonly occurring injuries in that athletic population. However, no established LAS prediction model exists for collegiate women's soccer players.

The purpose of this study was to develop a prediction model for acute LAS injuries in collegiate women's soccer players utilizing previous ankle sprain history, height, mass, and BMI as potential predictors.

The authors' hypothesized that collegiate women's soccer players with greater height, mass, and body mass index (BMI), as well as a previous history of ankle sprain would have greater odds of sustaining a LAS.

Study Design: Prospective cohort study.

Methods: Forty-three NCAA Division I women's soccer players' (19.7±1.1yrs, 166.8±3.7cm, 60.8±4.4kg) height, mass, and BMI were measured one week before beginning preseason practices. Additionally, participants reported whether or not they had sustained a previous ankle sprain. The team athletic trainer tracked LASs over the competitive season. Independent t-tests, binary logistic regression analyses, receiver operating characteristic (ROC) curves, and diagnostic statistics assessed the ability of the variables to differentiate between those that did and did not sustain a LAS.

Results: Participants that sustained a LAS (n=8) were significantly taller than those that did not sustain a LAS (n=35) (t41 = -2.87, p = 0.01, d = 0.83[0.03,1.60]). A logistic regression analysis (odds ratio = 1.30[1.00,1.70]) and area under the ROC curve analysis (AUROC = 0.73[0.58,0.89], p = 0.04) further exhibited predictive value of height. A height cutoff score of 167.6cm demonstrated excellent sensitivity (0.88), moderate specificity (0.51), and a favorable diagnostic odds ratio (7.5). A logistic regression analysis (odds ratio = 1.87[1.22,1.98]) exhibited predictive value of previous ankle sprain history. That variable was also associated with good sensitivity (0.75) and specificity (0.71) within the model, as well as a favorable DOR (7.37). Mass and BMI demonstrated no predictive value for LAS.

Conclusion: Taller collegiate women's soccer players and those with previous ankle sprain history may have a greater predisposition to LAS.

Level of evidence: 1b

Key words: Ankle sprain, injury prediction, women's soccer

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The authors report no conflicts of interest
have demonstrated usefulness in LAS prediction models, likely due to their potential influence on LAS mechanisms of injury. Typically, a LAS is sustained when excessive ankle plantar flexion, subtalar inversion, and foot internal rotation are present while decelerating during a functional task. These combined movement patterns result in the center of pressure (COP) moving laterally on the plantar aspect of the foot, as well as medially relative to the ankle joint axis of rotation. In this position, an external load can create an external supination moment at the ankle. Greater body mass index (BMI), calculated from height and mass, likely increases the body's moments of inertia and reduces an individual's ability to resist external forces. Due to the potential influence on injury occurrence and simplicity of their measurement, anthropometrics are viable predictor variables for any injury prediction analysis. No previous investigators have developed a model of LAS risk for collegiate women's soccer players specifically, but anthropometrics may possess potential injury prediction value for that population. Therefore, the purpose of this study was to develop a prediction model for acute LAS injuries in collegiate women's soccer players utilizing previous ankle sprain history, height, mass, and BMI as potential predictors. The primary hypothesis was that athletes with a previous ankle sprain history, greater height, mass, and BMI would have greater odds of sustaining a LAS.

METHODS

Participants
A convenience sample of 43 NCAA Division I women's soccer players (19.7 ± 1.1 years, 166.8 ± 3.7 cm, 60.8 ± 4.4 kg) volunteered for participation in this prospective cohort study. Inclusion criteria consisted of team membership, full medical clearance for participation in sporting activities. Within one week prior to the beginning of pre-season practices, each participant reported for testing in the university athletic training facility. Each participant reviewed and signed an informed consent document approved by the university institutional review board.

Procedures
One week before the onset of pre-season practices, each participant's height (cm) and mass (kg) were
measured using a standard physician beam scale (Detecto 339 Eye Level Physician Scale; Detecto Scale Company; Webb City, MO) in the school’s athletic training facility. Body mass index (BMI) was calculated from height and mass measures (kg/m²). Additionally, participants reported whether or not they had ever sustained a previous ankle sprain of any type (lateral, medial, syndesmotic). Throughout the course of the subsequent soccer season, the certified and licensed athletic trainer responsible for providing care to the team recorded LAS injuries sustained by the participants. A LAS must have 1) occurred during a team practice or competition, 2) required care by medical personnel, and 3) resulted in at least one day of missed soccer activity.

### Statistical Analysis

Independent t-tests and Cohen’s d effect sizes with 95% confidence intervals (CIs) compared height, mass, and BMI between injured and uninjured participants. Effect sizes were interpreted as small: $d = 0.20 – 0.49$, moderate: $d = 0.50 – 0.79$, and large: $d ≥ 0.80$. Separate forward binary logistic regression analyses assessed the influence of each outcome on the estimated odds of sustaining a LAS. A Receiver Operating Characteristic (ROC) curve plotted the predictive utility (sensitivity vs. 1-specificity) of each value observed for each continuous outcome. The ROC curve analysis produced the area under the ROC curve (AUROC), a singular quantitative representation of the overall predictive value of each variable, with 95% confidence intervals. The AUROC can range from 0 to 1, with 0.5 representing an absence of predictive power, and 1 representing perfect predictive power. From ROC curves demonstrating predictive utility, cutoff scores that maximized sensitivity and specificity for the predictor variable were identified. Fisher’s exact test to determine the strength of association between the predicted group classification (based on the cutoff score for continuous variables) and the observed injury status. Sensitivity, specificity, positive and negative likelihood ratios (+LR, -LR), and the diagnostic odds ratio (DOR) were calculated from predicted and observed injury status. Statistical significance was set a priori at $p<0.05$. All statistical analyses were conducted using IBM SPSS version 22 (IBM Corporation, Armonk, NY).

**RESULTS**

During the competitive season, 8/43 (18.6%) participants sustained a LAS. A significant difference on the t-test and large effect size indicated the injured group was taller than the uninjured group (Table 1). No statistically significant group differences existed for mass or BMI. A history of previous ankle sprain was reported by 16/43 (37.2%) participants, with 6/8 (75%) players with a new LAS having a history of previous ankle sprain. Separate binary logistic regression analysis revealed that height and previous ankle sprain history were significant predictors of injury status (Table 2). A ROC curve analysis further demonstrated moderate predictive utility of height (AUROC = 0.73 [0.58, 0.89]; $p = 0.04$) (Figure 1). The ROC curve analyses further demonstrated poor predictive value for mass (AUROC = 0.52 [0.25, 0.79]; $p = 0.84$) (Figure 2) and BMI (AUROC = 0.65 [0.38, 0.91]; $p = 0.21$) (Figure 3). A cutoff score for height that maximized sensitivity and specificity (167.6 cm) within the ROC curve produced a significant Fisher’s exact test ($p = 0.04$) (Table 3). A Fisher’s exact test

### Table 1. Comparisons of Anthropometrics between Injured and Uninjured Participants.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Injured (n=8)</th>
<th>Uninjured (n=35)</th>
<th>Independent T-Test</th>
<th>Cohen’s d (95%CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>169.2 ± 2.3</td>
<td>166.3 ± 3.7</td>
<td>$t_{41} = -2.87, p = 0.01$</td>
<td>0.83 (0.03, 1.60)</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>60.7 ± 6.1</td>
<td>60.6 ± 4.1</td>
<td>$t_{41} = 0.05, p = 0.96$</td>
<td>0.02 (-0.75, 0.79)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>21.2 ± 2.2</td>
<td>22.0 ± 1.5</td>
<td>$t_{41} = 1.23, p = 0.22$</td>
<td>-0.49 (-1.25, 0.30)</td>
</tr>
</tbody>
</table>

BMI = body mass index; Bolded data indicate statistically significant differences ($p < 0.05$).

### Table 2. Separate Binary Logistic Regression Analyses.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Odds Ratio (95%CI)</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>1.30 (1.00, 1.70)</td>
<td>0.05</td>
</tr>
<tr>
<td>Mass</td>
<td>1.00 (0.84, 1.19)</td>
<td>0.95</td>
</tr>
<tr>
<td>BMI</td>
<td>0.74 (0.46, 1.20)</td>
<td>0.22</td>
</tr>
<tr>
<td>Previous Ankle Sprain History</td>
<td>1.87 (1.22, 1.98)</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Bolded data indicate statistically significant differences ($p < 0.05$).
Table 5. For height, excellent sensitivity (0.88) and moderate specificity (0.51) were identified within the model, as well as a favorable DOR (7.50). For previous ankle sprain history, we identified good sensitivity (0.75) and specificity (0.71) within the model, as well as a favorable DOR (7.37).

**DISCUSSION**

The primary finding of this study is that participant height and a history of previous ankle sprain were effective predictors of LAS among collegiate athletes. The results also demonstrated a significant association between previous ankle sprain history and sustaining a LAS in the current season (p = 0.02) (Table 4). Associated sensitivity, specificity, +LR, -LR, and DOR calculated from the 2-by-2 contingency tables are in line with the findings.
in agreement with a number of other authors who have reported similar findings in soccer players. Ekstrand and Gillquist found significantly higher rates of previous LAS in adult soccer players that sustained a LAS during one year of injury surveillance (47%) compared to those that did not sustain a LAS in the same time (25%). Kofotolis et al. also prospectively examined a large cohort of amateur soccer players and determined that those with a previous LAS had nearly two times greater odds of sustaining a LAS during two years of subsequent observation. In another study of amateur male soccer players, previous history of LAS was again the strongest predictor of LAS, increasing the odds of injury approximately 23%. This is the first study to assess the predictive value of previous ankle sprain history in a sample of collegiate women’s soccer players.

Clinically, the strength of height and previous ankle sprain history as LAS predictors is their ease of assessment, but they are clearly limited by their lack of modifiability. Although they are not changeable, these simple outcomes may be important catalysts for targeted intervention. For example, preventative measures such as prophylactic ankle supports and postural control training are viable options for LAS prevention, and perhaps may be particularly valuable for taller athletes and those with a previous ankle sprain. As a LAS in collegiate women’s soccer players occurs through a variety of mechanisms (~35% player contact, ~27% non-contact, ~25% surface contact, ~13% other), postural control training likely should be diversified to include static and dynamic balance exercises, dynamic stability following a landing or cutting task, and external perturbations. Future studies should examine

Table 5. Diagnostic Statistics of Height and Previous Ankle Sprain History

<table>
<thead>
<tr>
<th>Quantities</th>
<th>Formula</th>
<th>Height (167.6 cm)</th>
<th>Previous Ankle Sprain History</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>true positive/(true positive + false negative)</td>
<td>7/8 = 0.88</td>
<td>6/8 = 0.75</td>
</tr>
<tr>
<td>Specificity</td>
<td>true negative/(true negative + false positive)</td>
<td>17/35 = 0.51</td>
<td>25/35 = 0.71</td>
</tr>
<tr>
<td>+LR</td>
<td>sensitivity/(1-specificity)</td>
<td>0.88/0.49 = 1.80</td>
<td>0.75/0.29 = 2.58</td>
</tr>
<tr>
<td>-LR</td>
<td>(1-specificity)/specificity</td>
<td>0.12/0.51 = 0.24</td>
<td>0.25/0.71 = 0.35</td>
</tr>
<tr>
<td>DOR</td>
<td>+LR/-LR</td>
<td>1.89/0.21 = 7.50</td>
<td>2.58/0.35 = 7.37</td>
</tr>
</tbody>
</table>

+LR = positive likelihood ratio; -LR = negative likelihood ratio; DOR = diagnostic odds ratio

women's soccer players. Specifically, those athletes equal to or taller than 167.6 cm in height had 7.5 times greater odds of sustaining a LAS than those below 167.6 cm in height. Within the sample 24/43 (56%) participants were at least 167.6 cm tall, and thus, possessed an elevated predisposition to sustaining a LAS. This finding supports previous studies reporting participant height as an effective predictor of ankle injuries. Waterman et al. reported taller military academy cadets were at greater risk of sustaining an ankle sprain. Similarly, Milgrom et al. found that taller infantry recruits were more prone to LASs. They postulated that taller stature may contribute to larger moments of inertia in the lower extremity. Essentially, longer trunk and extremity segments may reduce the ability of an individual to resist external moments exerted on the body, potentially increasing injury risk. The aforementioned studies only found associations between height and injury in male participants, but the current findings suggest height may also be pertinent to LAS risk in females. The average height of the sample was similar to that of 64 Division I collegiate women’s soccer players (168.4 ± 5.9 cm) that underwent testing of physical and physiological performance characteristics, suggesting the results are likely relevant to other collegiate women’s soccer teams. Elevated body mass can also increase moments of inertia, but the lack of differences between injured and uninjured participants suggests body mass had little influence over injury risk in this population. Furthermore, the lack of body mass differences likely limited the ability of BMI to differentiate those that did and did not sustain a LAS.

Table 5. Diagnostic Statistics of Height and Previous Ankle Sprain History

<table>
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Not surprisingly, previous ankle sprain history was also a significant predictor of LAS. This result is
various forms of neuromuscular control training and attempt to find the most effective protocol for LAS prevention in this population. While prophylactic ankle supports and postural control training are associated with significant cost and time demands, respectively, identification of strong risk factors will allow clinicians to allocate preventative resources to those with the greatest predisposition to LAS. While the DORs suggest previous ankle sprain history and height were similar in their ability to predict a LAS, the small sample size inhibited the ability to examine these predictors in a multivariate logistic regression model. Future studies using larger samples should explore whether or not a combination of increased height and previous ankle sprain history can elevate LAS risk even further.

Limitations

Certain notable limitations are present within this study. First, this study was specific to NCAA Division I women’s soccer players and may not be applicable to those participating in other sports and levels of competition. Furthermore, the sample of convenience population was potentially small raising the possibility of type II error during comparisons of body mass and BMI. Lastly, this study focused on a limited collection of potential predictor variables. Future studies should continue to explore LAS prediction in collegiate women’s soccer players using a larger sample and other clinical tests that may be relevant to LAS injury mechanisms (i.e. postural control, flexibility, muscular strength, and self-reported function).

CONCLUSIONS

Participant height and previous ankle sprain history demonstrated predictive value for LAS among collegiate women’s soccer players. Longer trunk and segment lengths may impair an athlete’s ability to resist external forces, potentially increasing the likelihood of sustaining a LAS. Clinicians should consider collegiate women’s soccer players with increased height and previous history of ankle sprain for increased need for interventions designed to prevent LAS.

REFERENCES


ABSTRACT

Background: Ankle plantarflexion (PF) active range of motion (ROM) is traditionally assessed in a non-weight-bearing (NWB) position with a universal goniometer. However, a convenient, reliable, low-cost means of assessing functional PF active ROM in a weight-bearing (WB) position has yet to be established.

Purpose: To compare the intra- and interrater reliability of PF active ROM measurements obtained from a goniometric NWB assessment, and a functional heel-rise test (FHRT) performed in WB.

Study Design: Reliability study.

Methods: Two physical therapy student examiners, blinded to each other's measurements, assessed PF active ROM through a NWB goniometric technique and a FHRT on all subjects within the same test session. Intra- and interrater reliability values were calculated using an intraclass correlation coefficient (ICC2,1, ICC2,k) and 95% confidence intervals. Standard error of measurement (SEM) and minimal detectable change (MDC) were recorded for each method.

Results: 43 healthy participants (mean ± SD, age: 22.7 ± 1.7 years, height: 1.7 ± 0.1 m, mass: 77.8 ± 17.2 kg) completed testing procedures. The within-session intrarater reliability (ICC2,1) estimates were observed for goniometry (right: 0.96, left: 0.95 - 0.97) and FHRT (right: 0.99, left: 0.99), as well as the interrater reliability (ICC2,k) of goniometry (right: 0.79, left: 0.79) and FHRT (right: 0.79, left: 0.87). Goniometry SEM (3.3 - 3.6°) and MDC (9.2 - 9.8°) were observed, in addition to FHRT SEM (0.6 cm) and MDC (1.6 - 1.7 cm). A weak correlation was found between FHRT and goniometric measurements (r = -0.03 - 0.13).

Conclusions: The FHRT was found to have good to excellent intra- and interrater reliability, similar to goniometric measurement. The lack of agreement between these measurements requires further exploration of a WB assessment of ankle PF active ROM.

Level of Evidence: 2b

Key words: Ankle, functional, heel-rise, plantarflexion, range of motion

1 University of South Dakota, Vermillion, SD, USA

Financial Disclosures: The primary investigator (Brandon Ness) is in the process of commercializing a device to measure weight bearing plantarflexion active range of motion at the time of manuscript submission.

United States Provisional Application number 62/529,878
“Physical Therapy Measurement Device, Rehab Ruler”

Statement of the Institutional Review Board approval of the study protocol: “The study submission and informed consent for the proposal referenced above has been reviewed and approved via the procedures of the University of South Dakota Institutional Review Board.”

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INTRODUCTION
The ankle plantarflexors are a muscle group of the lower leg with the primary function of plantarflexion of the ankle joint. Additionally, the plantarflexors have an instrumental role in allowing the knee extensors to stabilize the knee when subjected to ground reaction forces. Ankle range of motion (ROM) is measured and monitored throughout the rehabilitation process to assess joint dysfunction and determine treatment effectiveness, in which ROM is typically assessed both passively and actively. Active ROM is defined as “movement of a segment within the unrestricted ROM that is produced by active contraction of the muscles crossing that joint.”

Abnormal ankle plantarflexion (PF) ROM can both contribute to, and result from, various foot and ankle pathologies. Posterior ankle impingement occurs in athletic populations due to forceful PF requirements during athletic activity (i.e., ballet dancers), where a hyperplantarflexion motion places extreme pressure on the structures between the calcaneus and the distal tibia. Excessive PF ROM has also been identified as an injury risk factor for development of medial tibial stress syndrome in military personnel and collegiate athletes. Distally, the typical mechanism for a turf toe injury involves hyperdorsiflexion of the first metatarsal phalangeal joint in combination with hyperplantarflexion of the ankle.

A number of lower extremity conditions are influenced by PF performance in weight-bearing (WB). Following an Achilles tendon repair, excessive tendon lengthening can occur due to separation of the tendon ends from early WB and aggressive rehabilitation. This lengthening can lead to an insufficiency of the tendon and decreased strength in end-range PF. Common ankle sprain sequelae, such as swelling and pain, do not fully explain PF mobility deficits. Miyamoto and colleagues evaluated a cohort of patients with a history of multiple inversion ankle sprains who were experiencing residual pain and restricted PF ROM. Arthroscopy revealed an anterior fibrous bundle running from the distal anterior tibia to the anterior edge of the dome of the talus, which became taut with PF in all cases; however, the study did not specify whether PF ROM measurements were recorded in a WB or non-weight bearing (NWB) position, making it difficult to assume whether the clinical presentation of PF ROM restrictions would be consistent across multiple testing positions. In such instances where PF ROM is deemed less than optimal, appropriate and reliable means of assessment are necessary.

Various methods have been used to evaluate ankle ROM, specifically at the talocrural joint. Measurement of ankle ROM in NWB with a universal goniometer is a common method of evaluating ankle mobility and provides feedback to the clinician in regards to rehabilitation progression and outcome. Despite the routine use of goniometry in physical therapist practice, its reliability has been questioned. Goniometric assessment of PF active ROM has demonstrated good intrarater (ICC = 0.64 – 0.98), but poor interrater reliability (ICC = 0.25), and has proven to be less precise when compared to ankle dorsiflexion (DF) active ROM. The variability in goniometric measurement reliability can be partly attributed to the goniometer’s physical construct, starting position, individual anatomy, and body region. Difficulties in finding the joint axis of rotation, as well as properly placing the distal arm of the goniometer along the forefoot, may influence measurement accuracy. These limitations may lead to varying measurement values for the same joint, contributing to error in the final ROM assessment. An incorrect reading may have physical, financial, social, and psychological ramifications for the patient.

Inclinometry is another method used to measure ankle ROM. When using an inclinometer, the device is set to zero degrees at the neutral position of the ankle and the degree of movement in the directions of both ankle DF and PF is assessed. Inclinometry has demonstrated good-excellent interrater reliability when measuring ankle PF in NWB positions with the knee flexed (ICC = 0.86) and extended (ICC = 0.72). Interestingly, it was also noted that intrarater reliability for PF ROM assessment was greater in clinicians with less experience. It was proposed that measuring ankle PF ROM is less common compared to DF; thus, less experienced clinicians may grasp the technique more quickly.

WB assessment of ankle ROM has been explored more recently, specifically for ankle DF. A WB lunge test for ankle DF ROM has been thought to
be a more functional test when compared to a NWB approach. The torque placed on the dorsiflexed ankle when in a lunge position is much greater than the NWB assessment, which is posited to be representative of daily function. The WB lunge test for ankle DF demonstrated excellent within-session intrarater reliability when assessed via tape measure (ICC = 0.98 – 0.99), digital inclinometer (ICC = 0.96 – 0.97), and goniometer (ICC = 0.85 – 0.96). The WB lunge test also demonstrated excellent interrater reliability when assessed through tape measure (ICC = 0.98) and inclinometry (ICC = 0.97) for raters of varying skill levels. However, a similar WB technique to assess ankle PF ROM has yet to be established.

Various methods of WB assessment of PF performance have traditionally focused on manual muscle testing and endurance, rather than reporting the resultant maximal vertical excursion. In reality, WB heel-rise performance requires adequate active ROM at the talocrural joint and sufficient strength of the gastroc-soleus complex to complete the motion, where muscle strength can be defined as “the ability of contractile tissue to produce tension and a resultant force based on the demands placed on the muscle.” Silbernagel and colleagues described a method used to assess PF endurance in those with Achilles tendon rupture through a device that included a spring-loaded string attached to the heel of a shoe. Individuals then completed a single leg heel-rise, and feedback regarding the distance achieved was provided through a digital sensor output. In those with a history of drug use, a more simple method of PF endurance assessment was conducted by performing a heel-rise relative to a five cm block of wood placed on the floor. Additional methods of assessing PF endurance included a laser-guided line positioned above the individual’s head placed at 50% of the heel-rise maximum vertical height, while another utilized an electrogoniometer to measure the angle of PF. A recent study investigating PF strength and endurance in aging adults employed a “calf-raise senior” test, which used a horizontal bar above the participant’s head to mark the maximum vertical height achieved when performing repetitions of a heel-rise, which demonstrated good intrarater (ICC = 0.79 – 0.84) and excellent interrater (ICC = 0.93-0.96) reliability.

Although the previously mentioned tests may be useful for examining PF strength and endurance as assessed during a traditional heel-rise test, various challenges are inherently present including efficiency, equipment required, and positioning/body mechanics of the examiner to visualize the measurement. Many of the previously mentioned methods did not report the maximal vertical excursion achieved or active ROM, as this was not the primary objective.

The proposed benefits of a WB assessment and the lack of an efficient, reliable, and inexpensive means to assess PF active ROM leaves clinicians with few options to assess this attribute. The purpose of this study was to explore the intra- and interrater reliability of a novel, functional heel-rise test (FHRT) performed in WB to examine active ROM when compared to a NWB technique with a universal goniometer. The authors hypothesized the FHRT would have greater interrater reliability than goniometry, while both tests would demonstrate similar intrarater reliability when measuring PF active ROM.

**METHODS**

**Research Design**

The study protocol was approved by the University of South Dakota Institutional Review Board. All subjects signed an approved informed consent form prior to participation. This was a reliability study design.

**Subjects**

Subjects were recruited from a sample of convenience. Subjects were included if they were between the ages of 18-35 and English-speaking, and were excluded if they reported any previous injury or surgery to the back or lower extremities within the prior six months, reported any balance problems, or were pregnant.

**Procedures**

The procedures utilized in this study were adapted from Konor and colleagues and summarized in Figure 1. Two second-year physical therapy doctoral students (novice raters) performed the measurements and underwent standardized training with an experienced physical therapist prior to data collection.
collection. With all participants barefoot, only PF active ROM was measured.

Prior to testing, participant’s height and body mass were gathered by one examiner. Ankle PF active ROM measurements were recorded by two other researchers during a single session. Examiners were blinded to each other’s test results. Testing order for examiner, limb, and active ROM assessment method were randomized with a computer algorithm for each subject. PF active ROM was measured with both the WB unilateral heel-rise and the NWB goniometric technique. Three separate active ROM measurements for each technique were obtained on both the right and left limbs and averaged for data analysis, respectively.

**Functional Heel-Rise Test (Weight-bearing)**

PF active ROM was assessed in WB using the FHRT (Figure 2). One standard measuring tape labeled in 0.5 cm increments was fixed vertically along a wall, while a second measuring tape was fixed to the floor, starting at the wall-floor interface. The heel-rise was performed on each limb with the participant in a standing position. The stance limb was positioned in relative extension and participants stood facing the wall with the tip of their great toe 15 cm from the wall. Balance was maintained by allowing the participant’s fingertips to touch the wall with elbows in 90 degrees of flexion. Participants were instructed to shift their weight onto the test limb and stand as erect as possible, which was monitored by the examiner. The non-stance limb was held in slight knee flexion to attain a NWB position. The examiner stood on a 12.5 inch elevated platform adjacent to the participant to record test results. A steel, 8-inch by 12-inch IRWIN carpenter square tool (Stanley Black & Decker, Inc., New Britain, CT, USA) was aligned vertically on the wall and rested atop the midline of the participant’s head to measure starting position (Figure 3). Participants were instructed to perform a maximal unilateral heel-rise by rising onto their toes, with the angle device maintained in position throughout the motion by the examiner. The participant was instructed to perform a simple up and down motion at a self-selected speed, without any prolonged hold. The participant’s maximum height was recorded at the completion of the movement. FHRT score was calculated by subtracting the starting height from the participant’s maximum height. Three FHRT measurements were recorded on each limb and averaged, respectively. Each participant underwent three practice trials followed by a 30-second rest period prior to three test trials on each limb. Test trials were recorded by the first examiner, and then the second examiner entered the room and the tests were repeated upon exit of the first examiner. Alternating blinded examiners was performed for both NWB and FHRT assessments.

**Gonioimetry Measurement (Non-Weight-bearing)**

PF active ROM was assessed in NWB using a universal goniometer with the participant supine with
their feet off the edge of the treatment table (Figure 4), as previously described. The measurements were taken with knees extended to maintain consistency with the position of the knee during the FHRT.

Initially, the examiner placed the participant’s foot in a position of neutral DF. The axis of the goniometer was aligned just distal to the lateral malleolus with the arms aligned with the fibula and fifth metatarsal. The participants were instructed to maximally perform a PF motion. Three measurements were documented and averaged for each participant on each limb and recorded in degrees.

Figure 2. Functional Heel-Rise Test of Plantarflexion Active Range of Motion (Weight-bearing).

Figure 3. Carpenter Square Tool.

Figure 4. Goniometer Assessment of Plantarflexion Active Range of Motion (Non Weight-bearing).

Statistical Methods
Analyses were conducted using R statistical software and included descriptive statistics, reliability coefficients, and Pearson correlations. Additionally, a paired t-test procedure was applied to compare the mean differences between goniometer and heel-rise variables. An alpha value was set at 0.05. Intraclass correlation coefficient (ICC) with a 95% confidence interval was used to determine intra- and interrater reliability, where the following criteria were applied: < 0.5 (poor), 0.5 – 0.75 (moderate), 0.75 – 0.9 (good), and > 0.9 (excellent). The standard error of measurement (SEM) and the minimal detectable change (MDC) values were calculated. The standard error of measurement (SEM) determines the error present in the examiner’s recorded measurements when attempting to estimate the true measurements; SEM = SD \sqrt{1-ICC} (SD = standard deviation). The 95% confidence interval value was used to calculate the MDC, which is the smallest amount of change that can be attributed to a true change rather than an error in the measurement, in which MDC = SEM * 1.96 * \sqrt{2}.25
Results
Forty-three healthy volunteers (23 females, 20 males) completed testing procedures (mean ± SD, age: 22.7 ± 1.7 years, height: 1.7 ± 0.1 m, mass: 77.8 ± 17.2 kg). Goniometric and FHRT interrater reliability coefficients (ICC_{2,k}), along with SEM and MDC values are described in Table 1 for the right and left limbs, respectively. Both measurement techniques demonstrated good to excellent interrater reliability (ICC = 0.79 – 0.87) across both limbs. Intrarater reliability (ICC_{2,1}), SEM, and MDC values for goniometry and the FHRT are summarized in Table 2, with excellent reliability reported for goniometry (ICC = 0.95 -0.97), as well as the FHRT (ICC = 0.99).

Table 1. Plantarflexion Active Range of Motion: Interrater Reliability (ICC_{2,k}), Standard Error of Measurement (SEM), and Minimal Detectable Change (MDC).

<table>
<thead>
<tr>
<th></th>
<th>Right</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC_{2,k} (95% CI)</td>
<td>SEM</td>
</tr>
<tr>
<td>Goniometer</td>
<td>0.79 (0.46, 0.91)</td>
<td>3.3°</td>
</tr>
<tr>
<td>Heel-Rise</td>
<td>0.79 (0.61, 0.88)</td>
<td>0.6 cm</td>
</tr>
</tbody>
</table>

Table 2. Plantarflexion Active Range of Motion: Intrarater Reliability (ICC_{2,1}), Standard Error of Measurement (SEM), and Minimal Detectable Change (MDC).

<table>
<thead>
<tr>
<th></th>
<th>Right</th>
<th>Left</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>ICC_{2,1} (95% CI)</td>
<td>SEM</td>
</tr>
<tr>
<td>Examiner 1 Goniometer</td>
<td>0.96 (0.90, 0.98)</td>
<td>1.7°</td>
</tr>
<tr>
<td>Heel-Rise</td>
<td>0.99 (0.97, 0.99)</td>
<td>0.2 cm</td>
</tr>
<tr>
<td>Examiner 2 Goniometer</td>
<td>0.96 (0.94, 0.98)</td>
<td>1.4°</td>
</tr>
<tr>
<td>Heel-Rise</td>
<td>0.99 (0.98, 0.99)</td>
<td>0.1 cm</td>
</tr>
</tbody>
</table>

Table 3. Paired T-Test Comparing Examiner Measurements of Goniometry and Heel-Rise.

<table>
<thead>
<tr>
<th></th>
<th>Examiner 1</th>
<th>Examiner 2</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goniometer Right</td>
<td>66.6 ± 8.39</td>
<td>62.97 ± 7.17</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Left</td>
<td>66.12 ± 8.97</td>
<td>62.95 ± 7.82</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>Heel-Rise Right</td>
<td>8.86 ± 1.52</td>
<td>9.08 ± 1.36</td>
<td>0.24</td>
</tr>
<tr>
<td>Left</td>
<td>8.64 ± 1.79</td>
<td>8.82 ± 1.58</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Values expressed as mean ± standard deviation; *Statistically significant difference at p ≤ 0.05

Descriptive data were calculated for each examiner according to measurement method. Paired t-test results are summarized in Table 3, which revealed significant differences between goniometric measurements among examiners on both limbs. A weak correlation (r = -0.03 - 0.13) existed between the goniometric and FHRT measurements.

Discussion
The FHRT demonstrated good to excellent intra- and interrater reliability. Previous investigations have noted that raters of varying levels of experience can reliably measure NWB\textsuperscript{13} and WB\textsuperscript{14} ankle ROM, which is further supported by the findings of the current study. Also, significant differences were found between examiners when measuring ankle PF active ROM with goniometry, but this trend was not observed for the FHRT. Contrary to some of the challenges previously mentioned with goniometry, as well as the conflicting evidence around the reliability of surface palpation in other body regions\textsuperscript{26-28} the FHRT does not require palpating bony landmarks nor aligning equipment with said landmarks, which may increase the ease of its use. This highlights the potential utility of the FHRT, which may lead to increased clinician confidence when WB measurements are recorded between multiple rehabilitation specialists, including those with minimal experience. This notion is especially important, given the relevance of a team-based approach to interdisciplinary patient care in contemporary clinical practice. Future research may wish to investigate the FHRT among clinicians of various healthcare disciplines and levels of experience.

The FHRT, as measured by vertical excursion distance, attempts to capture a more functional measure of PF active ROM compared to traditional NWB goniometry. Several components of motor control are required to execute a standing heel-rise including motor planning, unilateral weight support, balance, and coordination\textsuperscript{16,20} in addition to adequate mobility and muscle power of the foot and ankle complex. The authors posit the FHRT is a functional measure of PF active ROM requiring multiple links...
in the kinematic chain to work effectively (balance, motor control, mobility, etc.). This notion has been investigated in other single limb tasks, such as evaluating the influence of hip strength on frontal plane knee motion with a single leg squat,29 or the contributions of ankle DF ROM when performing a lateral step-down test.30 Additionally, the Star Excursion Balance Test’s evaluation of single limb dynamic balance requires varying degrees of hip strength31 and ankle DF ROM.32 In terms of WB assessment of ankle mobility, the WB lunge test for ankle DF ROM does not require the same degree of muscle power and balance in comparison to the FHRT – making the FHRT perhaps a more complex test with additional opportunities for movement variability. Future research should investigate the different contributions to FHRT performance along the kinematic chain.

The lack of correlation between goniometric and FHRT measurements may suggest these measure different constructs of ankle mobility. While goniometry may assess PF active ROM at the talocrural joint with contributions from the midfoot/forefoot, performance of the FHRT may also require adequate mobility of the great toe in order to complete the test. Locally at the ankle-foot region, adequate ankle and foot mobility, muscle power from the gastrosoleus complex, and a degree of dynamic stability are required to successfully maintain single limb stance in order to perform a heel-rise. The authors posit the discrepancy observed between NWB and WB active ROM may partly be due to individual differences in the use of available muscle power – highlighting the need for both a NWB and WB assessment of ankle PF active ROM, as measuring ankle mobility in only one position may lead to improper assumptions by the clinician and adversely affect patient outcomes.

It has been accepted that assessment of heel-rise performance can be evaluated at the foot and ankle region,18,19,21 or at the head by the amount of vertical excursion as determined by change in height.20,22 Measurements taken at the two body regions both have benefits and drawbacks. When evaluating a heel-rise through a measurement at the foot and ankle, the measurement is perhaps more accurate in terms of motion that is occurring locally at the heel relative to the ground. However, measurement through various techniques at the foot and ankle region can be challenging for the rehabilitation specialist, as it may require adequate visualization and palpation of bony landmarks in order to properly align equipment. Measurement of WB heel-rise performance at the head, as with the FHRT, offers the potential advantage of improved visualization and examiner/patient interaction, allowing for more meaningful patient feedback. The authors feel this method is also easier, and perhaps more efficient, for novice clinicians to perform, as palpation of body landmarks is not required. However, as previously mentioned, there is perhaps greater movement variability when performing the FHRT, which one may argue that ankle ROM is only one component assessed.

Although the current investigation included only healthy participants without a history of recent foot/ankle pathology or balance issues, the importance of heel-rise performance in clinical populations may justify further exploration of the FHRT. Deficits in heel-rise height were identified in patients who sustained an Achilles tendon rupture and experienced subsequent tendon elongation at 6 and 12 months post-injury.8 The measurement technique used a spring-loaded string attached to the heel of a shoe, where unilateral heel-rise height mean values for the uninjured (healthy) side were attained (12.9 – 14.7 cm), which were somewhat higher than FHRT mean values (8.6 – 9.1 cm). If exploring heel-rise performance in clinical populations, differences in testing methods should be taken into account when comparing outcomes.

Limitations
Blinding of the participants and researchers to the testing procedure and limb was not possible due to the nature of the data collection process. Also, examiners were not blinded to their own goniometer and FHRT measurements, which may have introduced a degree of examiner bias. In addition, generalizability of study outcomes is limited due to a sample of convenience including healthy, adult participants.

CONCLUSION
The FHRT demonstrated good to excellent intra- and interrater reliability among novice examiners,
similar to goniometric measurement. The lack of agreement between these measurements requires further exploration of a WB assessment for ankle PF active ROM.

REFERENCES


ABSTRACT

**Background:** World Rugby Union laws are constantly evolving towards stringent injury-prevention, particularly for contested scrums, since front row players are most at risk of cervical spine injuries. Recently, some countries have also introduced tailored training programs and minimum performance requirements for playing in the front row. Nevertheless, these approaches lack an objective assessment of each cervical muscle that would provide protective support.

**Objective:** Since front row players are the most at risk for cervical spine injuries due to the specific type of contact during scrums, the purpose of this study was to ascertain whether significant differences exist in neck muscle size and range of motion between front row players and players of other positions, across playing categories.

**Study Design:** Cross-sectional controlled laboratory study

**Methods:** 129 sub-elite male subjects from various first-team squads of Belgian Rugby clubs were recruited. Subjects were grouped according to age: Junior (J) < 19 years old, Senior (S) 19 to 35 years old and Veteran (V) > 35 years old; as well as playing position: Front row players (J=10, S=12, V=11 subjects), (Rest of the) pack (J=12, S=12, V=10), backs (J=10, S=11, V=11). An age-matched control group of non-rugby players was also recruited (J=10, S=10, V=10).

For each subject, the total neck circumference (NC) and the cervical range of motion (CROM) were measured. In addition, the thickness of the trapezius (T), splenius capitis (SCa), semispinalis capitis (SCb), semispinalis cervicis (SPC), sternocleidomastoid muscles (SCOM), and the total thickness of all four structures (TT), were measured using ultrasonography.

**Results:** In each age category, compared to controls, rugby players were found to have decreased CROM, an increase in neck circumference (NC), and increased total thickness (TT), trapezius (T), semispinalis capitis (SCb) and sternocleidomastoid muscles (SCOM) sizes. For junior players, the thickness of the semispinalis cervicis (SPC) was also increased compared to controls. The CROM was decreased in front row players compared to pack and back players for all age categories; Front row seniors also showed an increase in trapezius (T), splenius capitis (SCa), semispinalis capitis (SCb) and total thickness (TT), compared to back players.

**Conclusion:** In regard of the differences in cervical values found between player positions, the implementation of both range of motion and echography muscle thickness assessments could serve to create an additional measurement for all front row players, that could complement current pre-participation screening used by rugby federations by objectively monitoring muscular size and motion amplitude around the cervical spine.

**Keywords:** Ultrasonography, musculoskeletal ultrasound, rugby scrum, neck

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**Ethics approval**
Academic Ethical Committee of Brussels (Ethic committee B 200–2013-081)

**Statement of financial disclosure and conflict of interest:**
The authors affirm that they have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript. There are also no other conflicts of interest (ie, personal associations or involvement as director, officer, or expert witness).

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INTRODUCTION
Five percent of rugby injuries are to the cervical spine region, ranging from benign lesions such as sprains or muscular bruises, to spinal cord injuries.\textsuperscript{1,2} Fortunately, serious injuries are becoming less frequent, due to a continuous evolution of the game’s rules.\textsuperscript{3} Nevertheless, rugby remains one of the most injury-prone sports as far as cervical injuries are concerned.\textsuperscript{4} There is not a significant difference in types of injuries between professional players and amateurs.\textsuperscript{5} However, the younger player categories are spared, because of appropriate scrum rules, contacts being less rough and the power of players (weight and speed) being less developed. In fact, the incidence of cervical injury was shown to increase by age category: 68% for over 21 year old players, 23% for 17-21 year olds, 3% for 15-17 year olds, and 3% for 13-15 year olds.\textsuperscript{6}

During scrums, the front row players, positioned with arms interlocked and heads down with the rest of their pack (five other players) pushing from behind, are in direct frontal close contact with the opponent’s front row and pack players who are pushing against them. Fifty-eight percent of cervical spine injuries\textsuperscript{7,8} in rugby are sustained by front row players during scrums. Another important source of neck injuries in rugby comes in the form of facet dislocations caused by impact sustained during contacts and tackles.\textsuperscript{9}

In world Rugby Union regulations, it is the team’s responsibility to ensure that all front row players and potential front row replacements are suitably trained and equipped to deal with the demands of the position (especially scrummaging). It is not for the referee to determine whether any player is suitably trained or physically and morphologically equipped to play in the front row. Unfortunately, there are no specifications as to what comprises suitable training, nor does a standard objective assessment of the size of cervical muscles for front row players exist to determine minimum morphological readiness to playing in the front row. Researchers have shown that increased muscle strength and size reduces the risk of injuries.\textsuperscript{10-13}

Ultrasound imaging is a relatively inexpensive, portable, non-ionizing, non-invasive and real-time diagnostic modality. Ultrasound imaging is therefore proposed as a means to complement the usual medical assessment approaches by objectively assessing each muscle in the cervical region, and describing size norms for front row players which could be correlated to cervical protective support towards injury prevention in future studies. Since front row players are the most at risk for cervical spine injuries due to the specific type of contact during scrums, the purpose of this study is to ascertain whether significant differences exist in neck muscle size and range of motion between front row players and players of other positions, across playing categories.

METHODS
Subjects
This study was conducted in accordance with the Declaration of Helsinki after approval by the Academic Ethical Committee of Brussels (B 200–2013-081) and written informed consent.

Male volunteers were recruited from Belgian first division rugby clubs so that a minimum of 10 subjects were included in each of the following nine categories:

- Junior (J) < 19 years old, divided into front row players, (rest of the) pack and backs
- Senior (S) 19 to 35 years old, divided into front row players, (rest of the) pack and backs
- Veteran (V) > 35 years old, divided into front row players, (rest of the) pack and backs

In addition, three age-matched control groups, with a minimum of 10 subjects each, were also recruited for the junior, senior and veteran age categories.

All rugby players participating in the study had no current or previous cervical or spinal pathologies and had passed a medical examination confirming no contra-indication to the practice of rugby. The controls were all people practicing sports, at least three times a week for no less than 90 min per session. They were submitted to the same medical examination, which includes no contraindications to the practice of sports and no cervical or spinal problems.
Measurements
Each subject was measured at least three hours after having finished any form of physical activity. Ultrasound measurement reliability has been previously established for neck measurements, with an intraclass correlation coefficient of 0.82 and lower limit of detectable changes around 0.8-2.1 mm, as well as no demonstrable bias between experienced assessors. In this study, the average of three repeated measurements was taken for each parameter by the same researcher physiotherapist to further minimize measurement errors. Prior to the start of this study, the physiotherapist received additional training with a radiologist until measurement consistency was verified and accepted. A post-hoc evaluation of measurement consistency found an intra-class correlation coefficient of 0.98, demonstrating an excellent measurement consistency. This was done by measuring all five muscles’ thicknesses seven times with ultrasound (as described hereafter in Ultrasound muscle thickness measurements), on both the left and the right side, and repositioning the subject completely every time (starting from a standing position). For each of the seven measurements, as in the study, the average of three measurements was taken, and the breakdown of all individual measurements is reported in Appendix A. The intra-class correlation coefficient, a measure of measurement consistency for continuous data, was then calculated for all 10 muscles thicknesses (five left and five right side) between the seven measures.

Cervical range of motion (CROM):
The cervical range of motion (CROM) instrument (CROM Basic, PhysioSupplies, NL) was used to assess the amplitudes (range of motion) of different cervical movements, due to its practicality, good repeatability and accuracy. The subjects sat on a chair with a vertical backrest, both feet flat on the ground, head and back straight and detached from the backrest, looking straight forward to a fixed point (called the ‘neutral position’), adapted from the literature to maintain the natural spinal curves. After calibration, the CROM instrument was fixed onto the subject’s head and they performed maximum active range of movements, in flexion, extension, right and left rotation, and right and left side bending of the head (inclination of the neck). The experimenter placed his hands on the subjects' shoulders to detect and correct any errors in posture or compensation.

Ultrasound muscle thickness measurements:
The thicknesses of anterior and posterior muscles of the neck, choosing the most voluminous portion on the echography plane for repeatability, were also measured bilaterally, in the same sitting position as for the CROM measurements described above, using a portable ultrasound machine (DP 6600, Mindray Bio-Medical Electronics Co, Shenzhen, China): trapezius (T), splenius capitis (SCa), semispinalis capitis (SCb), semispinalis cervicis (SPC) and sternocleidomastoid muscles (SCOM). Measurements were performed at the cervical level C5-C6 corresponding with where the largest number of injuries occur in rugby. For the posterior muscles, the subject was asked to position himself in maximum active cervical flexion. The linear probe of the ultrasound (bandwidth 5-10MHz) was placed 2 cm laterally to the C6 level as determined by palpation of the spinous process to standardize measurements with an appropriate visualization of the desired structures. After freezing the image (Figure 1), the experimenter measured the thickness of the various muscles: T, SCa, SCb and SPC. The total thickness (TT) of these four structures was also recorded. For the SCOM on both sides, the subjects were asked to take the neutral position, as described above, and measurements were taken at the C6 level to visualize the thickest portion of the SCOM (Figure 2).

Neck circumference:
The neck circumference (NC) was measured using a flexible tape, with the subject seated in the neutral position. To guarantee accurate measurements, the tape measure was placed perpendicularly to the neck under the thyroid cartilage, directly below the laryngeal prominence, taking care not to compress any structures and/or subjacent tissue.

Statistical analyses
All statistical analyses were done with GraphPad Prism and the significance level set a priori at $p<0.05$. All twelve subgroups were compared to each other for each measurement. Normal distribution tests were done using Kolmogorov-Smirnov, d’Agostino and
Pearson and at least one sample was found non-normally distributed each time. Thus, Kruskal-Wallis (non-parametric) tests with Dunn’s post-test were used.

RESULTS
One hundred and twenty-nine male volunteers, aged 15 to 54 were recruited for this study and subdivided by age category and player position. A control group of non-rugby players was also recruited and divided into age-matched control groups, thus creating twelve sub groups, each with 10-12 subjects (Tables 1 and 2).

Comparisons between player positions within each age category
Tables 3, 4 and 5 show the statistical comparison for each measurement (CROM, muscle sizes and NC) between players from different position categories and include the statistical comparisons between players and age-matched controls.

For juniors, the significant differences between players and controls included NC, flexion, left and right T, left and right TT, left and right SCOM between pack players and controls, flexion, left and right SPC thickness between backs and controls, and all measures other than left rotation, left and right and SCa thickness, between front players and controls.

For veterans, the significant differences between players and controls included right rotation, left and right TT between pack players and controls, NC, flexion, extension, right and left rotations, left and right T, left and right SCb, left and right TT, left and right SCOM between front players and controls, NC between front and pack players, as well as NC and flexion between front and back players.

For seniors, the significant differences between players and controls included NC, flexion, right rotation, left and right SCb, left and right TT, left and right SCOM, right T between front and back players, NC between front and pack players, as well as NC, extension, right rotation, left and right SCb, left and right TT, left and right SCOM, right T between front players and controls. No differences were found between pack players, back players and controls in this age category.

Comparisons between age-categories for same player positions
In addition to position comparisons, players in the same position but in different age categories were also compared for each measured quantity. All results were not significant, apart from the following four quantities:

Figure 1. Example ultrasound image for anatomical measurements: trapezius (1), splenius capitis (2), semispinalis capitis (3), semispinalis cervicis (4) and the total thickness of these four structures (5).

Figure 2. Example ultrasound image for the sternocleidomastoid muscle (SCOM).
### Table 1. Anthropomorphic measurements of recruited subjects by age group. Reported as mean ± standard deviation.

<table>
<thead>
<tr>
<th>Age group definitions</th>
<th>Number of subjects</th>
<th>Age (yrs)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>BMI</th>
<th>Weekly training time (hrs/week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junior (J): 15 to 18 yrs old</td>
<td>42</td>
<td>17 ± 1.19</td>
<td>178 ± 6.45</td>
<td>77 ± 15.6</td>
<td>24.2 ± 4.0</td>
<td>7 ± 2</td>
</tr>
<tr>
<td>Senior (S): 19 to 34 yrs old</td>
<td>45</td>
<td>25 ± 2.53</td>
<td>180 ± 5.72</td>
<td>85 ± 14.4</td>
<td>26.3 ± 4.1</td>
<td>6 ± 1</td>
</tr>
<tr>
<td>Veteran (V): 35 to 54 yrs old</td>
<td>42</td>
<td>44 ± 6.39</td>
<td>180 ± 6.49</td>
<td>92 ± 15.5</td>
<td>28.4 ± 4.5</td>
<td>2 ± 1</td>
</tr>
</tbody>
</table>

### Table 2. Number of subjects in each age category by row position for rugby players and control subjects.

<table>
<thead>
<tr>
<th>Age group</th>
<th>Front (1)</th>
<th>Pack (2)</th>
<th>Back (3)</th>
<th>Control (C):</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junior</td>
<td>N=10</td>
<td>N=12</td>
<td>N=10</td>
<td>N=10</td>
</tr>
<tr>
<td>Senior</td>
<td>N=12</td>
<td>N=12</td>
<td>N=11</td>
<td>N=10</td>
</tr>
<tr>
<td>Veteran</td>
<td>N=11</td>
<td>N=10</td>
<td>N=11</td>
<td>N=10</td>
</tr>
</tbody>
</table>

Front= Front row players, Pack= 2nd and 3rd row players, Back= back players, Control= control group of non-rugby players.

### Table 3. Statistical comparisons of measured parameters for different row players within the junior (J) age category. All data are presented as means ± standard deviation.

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Neck circumference (cm)</td>
<td>41.5 ± 2.9</td>
<td>40.0 ± 2.5</td>
<td>39.0 ± 2.1</td>
<td>36.2 ± 1.1</td>
<td>ns</td>
<td>ns</td>
<td>***</td>
<td>ns</td>
<td>*</td>
<td>ns</td>
</tr>
<tr>
<td>Flexion (°)</td>
<td>54 ± 7</td>
<td>56 ± 5</td>
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1= front players; 2= pack players (middle); 3= backs; C= control (non-rugby players), SCOM= sternocleidomastoid muscle

* p<0.05, ** p<0.01 and *** p<0.001, ns= no statistically significant difference

### DISCUSSION

The results show few differences between age-categories for the same player positions; however, there were several significant differences between players and controls, as well as between the front row players versus other players (especially back players in some age-categories.)

- J1/V1 neck circumference (p<0.001)
- JC/VC neck circumference (p<0.001)
- J1/V1 neck extension range of motion (p<0.01)
- S3/V3 neck right rotation amplitude (p<0.05)
Neck circumference is a global size measurement; however, ultrasonography makes it possible to measure the size of specific muscles. In particular, SCb is significantly thicker in players than in controls, in particular in front row players, in all age-categories. This could be a result of the specific demands of rugby where the ball is always passed backwards and this sport specific movement is associated with significant trunk and neck rotations. Ultrasonography thus allows individual muscle assessment and could be used to monitor targeted strengthening, especially for front row players.

| Table 4. Statistical comparisons of measured parameters for different playing positions within the senior (S) age-category. All data are presented as means ± standard deviation. |
|---|---|---|---|---|---|---|---|---|---|
| | 1st Row (S1) | Pack (S2) | Back (S3) | Control Group (SC) | S1 / S2 | S1 / S3 | S1 / SC | S2 / S3 | S2 / SC |
| Neck circumference (cm) | 44.5 ± 1.9 | 41.2 ± 1.2 | 39.7 ± 1.6 | 38.0 ± 2.6 | * | *** | *** | ns | ns |
| Flexion (°) | 49 ± 5 | 55 ± 4 | 63 ± 9 | 61 ± 8 | ns | * | ns | ns | ns |
| Extension (°) | 49 ± 5 | 57 ± 5 | 60 ± 5 | 66 ± 6 | ns | ns | *** | ns | ns |
| Right Rotation (°) | 55 ± 4 | 61 ± 5 | 65 ± 6 | 66 ± 8 | ns | * | ** | ns | ns |
| Left Rotation (°) | 57 ± 4 | 63 ± 5 | 65 ± 9 | 65 ± 8 | ns | ns | ns | ns | ns |
| Right Side Bending(°) | 35 ± 6 | 38 ± 6 | 41 ± 5 | 45 ± 9 | ns | ns | ns | ns | ns |
| Left Side Bending (°) | 35 ± 6 | 39 ± 6 | 42 ± 4 | 44 ± 8 | ns | ns | ns | ns | ns |
| 1-L Trapezius (mm) | 4.13 ± 0.52 | 3.76 ± 0.74 | 3.00 ± 0.61 | 2.99 ± 0.93 | ns | * | ns | ns | ns |
| 2-L Splenius capitis (mm) | 7.77 ± 1.79 | 6.76 ± 1.31 | 5.46 ± 1.09 | 5.56 ± 1.58 | ns | * | ns | ns | ns |
| 3-L Semispinalis cervicis (mm) | 12.82 ± 1.98 | 9.93 ± 1.33 | 8.75 ± 1.35 | 8.40 ± 1.51 | ns | ** | *** | ns | ns |
| 4-L Semispinalis cervicis (mm) | 8.82 ± 1.64 | 8.09 ± 1.07 | 7.65 ± 1.90 | 6.93 ± 1.51 | ns | ns | ns | ns | ns |
| 5-L SCOM (mm) | 33.83 ± 2.16 | 29.19 ± 1.66 | 26.77 ± 1.63 | 24.8 ± 3.21 | *** | *** | *** | ns | ns |
| 1-R Trapezius (mm) | 4.30 ± 0.41 | 3.71 ± 0.76 | 3.19 ± 0.47 | 3.07 ± 0.86 | ns | * | ns | ns | ns |
| 2-R Splenius capitis (mm) | 7.99 ± 1.79 | 6.70 ± 1.31 | 5.63 ± 1.09 | 5.69 ± 1.58 | ns | * | ns | ns | ns |
| 3-R Semispinalis cervicis (mm) | 12.95 ± 2.01 | 10.41 ± 1.25 | 9.00 ± 0.95 | 8.39 ± 1.53 | ns | ** | *** | ns | ns |
| 4-R Semispinalis cervicis (mm) | 8.61 ± 1.53 | 8.01 ± 1.03 | 7.40 ± 1.89 | 7.20 ± 2.13 | ns | ns | ns | ns | ns |
| Total right (mm) | 34.18 ± 2.22 | 29.35 ± 2.00 | 28.09 ± 1.16 | 24.2 ± 2.81 | ns | ** | *** | ns | ns |
| 1-L SCOM (mm) | 33.83 ± 2.16 | 29.19 ± 1.66 | 26.77 ± 1.63 | 24.8 ± 3.21 | *** | *** | *** | ns | ns |
| 1= front players; 2= pack players (middle); 3= backs; C= control (non-rugby players), SCOM= sternocleidomastoid muscle
* = p<0.05, ** = p<0.01 and *** = p<0.001, ns = no statistically significant difference

| Table 5. Statistical comparisons of measured parameters for different playing positions within the veteran (V) age-category. All data are presented as means ± standard deviation. |
|---|---|---|---|---|---|---|---|---|---|
| | 1st Row (V1) | Pack (V2) | Back (V3) | Control Group (VC) | V1 / V2 | V1 / V3 | V1 / VC | V2 / V3 | V2 / VC |
| Neck circumference (NC) (cm) | 46.7 ± 2.7 | 42.0 ± 2.5 | 41.4 ± 1.70 | 40.5 ± 2.80 | *** | *** | *** | ns | ns |
| Flexion (°) | 45 ± 8 | 52 ± 6 | 58 ± 6 | 62 ± 6 | ns | * | *** | ns | ns |
| Extension (°) | 39 ± 7 | 50 ± 6 | 47 ± 6 | 56 ± 7 | ns | ns | ns | ns | ns |
| Right Rotation (°) | 48 ± 8 | 55 ± 7 | 56 ± 5 | 65 ± 8 | ns | ns | ns | ns | ns |
| Left Rotation (°) | 51 ± 7 | 55 ± 8 | 56 ± 6 | 66 ± 6 | ns | ns | ns | ns | ns |
| Right Side Bending(°) | 31 ± 7 | 34 ± 7 | 34 ± 6 | 40 ± 4 | ns | ns | ns | ns | ns |
| Left Side Bending (°) | 34 ± 5 | 34 ± 8 | 38 ± 6 | 40 ± 4 | ns | ns | ns | ns | ns |
| 1-L Trapezius (mm) | 3.97 ± 0.65 | 3.63 ± 0.61 | 3.03 ± 0.49 | 2.53 ± 0.44 | ns | ns | ** | ns | ns |
| 2-L Splenius capitis (mm) | 7.08 ± 1.05 | 6.62 ± 1.19 | 6.04 ± 1.09 | 5.20 ± 0.72 | ns | ns | ns | ns | ns |
| 3-L Semispinalis cervicis (mm) | 11.4 ± 1.31 | 10.68 ± 1.37 | 9.18 ± 0.80 | 8.27 ± 0.91 | ns | ns | ns | ns | ns |
| 4-L Semispinalis cervicis (mm) | 7.79 ± 1.19 | 7.47 ± 2.08 | 7.53 ± 1.10 | 6.01 ± 0.86 | ns | ns | ns | ns | ns |
| Total left (mm) | 31.15 ± 2.84 | 29.97 ± 2.48 | 27.57 ± 2.56 | 24.48 ± 1.30 | ns | ns | ** | * | ns |
| 5-L SCOM (mm) | 14.62 ± 1.87 | 13.57 ± 2.03 | 11.95 ± 0.94 | 10.83 ± 0.43 | ** | *** | *** | ns | ns |
| 1-R Trapezius (mm) | 3.88 ± 0.62 | 3.64 ± 0.76 | 3.06 ± 0.40 | 2.53 ± 0.25 | ns | ns | ns | ns | ns |
| 2-R Splenius capitis (mm) | 6.94 ± 1.05 | 6.23 ± 1.19 | 5.83 ± 0.93 | 5.33 ± 0.72 | ns | ns | ns | ns | ns |
| 3-R Semispinalis cervicis (mm) | 11.37 ± 1.30 | 10.75 ± 1.39 | 9.25 ± 1.18 | 8.46 ± 0.68 | ns | ns | ns | ns | ns |
| 4-R Semispinalis cervicis (mm) | 7.84 ± 0.72 | 7.63 ± 1.71 | 7.25 ± 0.86 | 6.07 ± 0.97 | ns | ns | ns | ns | ns |
| Total right (mm) | 31.43 ± 2.63 | 29.94 ± 2.15 | 27.42 ± 1.94 | 24.63 ± 1.32 | ns | ns | ns | ns | ns |
| 5-R SCOM (mm) | 14.94 ± 1.60 | 13.79 ± 1.91 | 12.36 ± 1.17 | 11.86 ± 0.89 | ns | ns | ns | ns | ns |
| 1= front players; 2= pack players (middle); 3= backs; C= control (non-rugby players), SCOM= sternocleidomastoid muscle
* = p<0.05, ** = p<0.01 and *** = p<0.001, ns = no statistically significant difference
Comparisons between age-categories
There are few statistical differences for the same player positions between different age-categories. The neck circumference of veteran front row players was larger than that of front row junior players; however, this increase with age was also found in the control population. Therefore, this is most likely not related to the practice of rugby and the difference is probably due to normal aging.

The only significant differences include neck extension range of motion, which decreases in veterans compared to junior front players, as well as neck right rotation range of motions, which decreases in veterans compared to senior back players. The extension range of motion decreases with the age of the front row rugby players: there is a statistically significant difference between front row junior and veteran players. The decrease in extension range of motion is consistent with previous studies but this seems to be exacerbated in rugby players since the same changes were not seen in the control group. There is evidence that exercise and training affects the flexibility of connective tissue and thus may impact the cervical range of motion. This can also potentially explain the decrease in the right rotation amplitude found in back player veterans compared to seniors, as the continued practice of rugby may exacerbate any normal aging differences due to the sustained cervical strains in response to the practice of rugby.

Comparisons between rugby players and controls
Differences in range of motion as well as muscle size were found between players and controls in all age-categories. This is not surprising as it points to specific adaptations that occur in response to the practice of rugby.

The decrease in motion amplitude found in rugby players could be related to the larger neck circumference compared to controls. This additional mass could restrict the range of movement and increase the endurance of the superficial (external) stabilizers of the vertebral column. This hypothesis is supported by the fact that these observations are most pronounced in front row players. Indeed, during a scrum push, a stabilizing isometric contraction of the deep and superficial muscles surrounding the cervical spine is present. This increase in stability could be developed to the detriment of the cervical spine flexibility. A previous study discussed the possibility that decrease in amplitude of prop players (the two players situated on the sides of the front row, who frame the hooker during scrums) could be due to an increased fatty mass in the neck area in these players compared to other rugby players. However, this explanation goes against the findings of other researchers who have shown that fatty mass and neck circumference do not play a role in limited cervical range of motion.

An alternative explanation, especially for older players, could be that the decreased range of motion in players compared to controls is due to an early stage, subclinical, articular pathology. Early disc degeneration is found in 56% of front row players, against only 15% of a matched non-rugby control group. In the same study 71% of players were shown to have a disk space narrowing, 36% a herniated disk and 48% a protrusion. In addition, an estimated 80% of rugby players older than 21 years of age develop osteophytes favoring the narrowing of the spinal canal and the development of osteoarthritis due to increased constraint and pressure on the joint system that increases the degeneration and inflammation leading to osteoarthritis.

Comparisons between front row players and players in other positions
The most pronounced differences between front row players and other positions were found for the senior age-category. One explanation for this difference could be that the development of physical capacity of the front row player is initiated during youth and only peaks in seniors, before decreasing in veterans. In addition, the muscular increases seen in the senior pack players can be explained by the practice of weight training which is typical for players wishing to play at a competitive level in the senior category. Among the players in the current study population, 73% of seniors trained in the gym (85% of the front row and pack, 50% of the backs), as compared to only 12% of juniors and 18% of veterans. It is common practice in training schedules for junior and senior (not veterans) playing categories in Belgian elite divisions, for players to have at
least one weekly whole body weight training session included in their training schedule. Nevertheless, no training routine is specifically developed to target cervical strength.

An important difference could also be that for senior players contacts are stronger and faster and the scrum rules less protective.\textsuperscript{31,32} To minimize the risk of injury, the rules of scrums differ by age category. Pushing in scrums is forbidden before 15 and after 35 years of age, whereas it is restricted to 1.5 meters between 15 and 19 years of age. An adapted cervical musculature is needed to face these severe constraints. The results show that the front row players have a bigger volume and a lesser amplitude of movement than other forward players, and backs. These findings are consistent with a previous study which found that the decrease in the cervical column movement amplitudes scales with rugby training frequency and total years of practice.\textsuperscript{33} It is clear that front row players develop their muscles to fight against the forces applied vertically on their cervical spine during scrums.

**Clinical Implication**

In recent years, rugby injury prevention systems have been put in place, such as New Zealand’s “Rugbysmart”, Australia’s “Smartrugby”, South Africa’s “Boksmart” and the International Rugby Board’s (IRB) “Rugby Ready”. They integrate education and training for rugby players, coaches and referees, as well as the medical and club personnel. In particular, they detail the physical preparation for developing the necessary strength, speed, and flexibility during training.

It is generally accepted that stabilization exercises, as well as high-intensity strengthening exercises that increase muscular mass, protect against acute injuries such as fractures or sprains.\textsuperscript{34,35} All front row rugby players have high intensity cervical preparation exercises as part of their specific training. However, it has also been shown that high-intensity strengthening exercises can sometimes result in early degenerative diseases of the cervical spine.\textsuperscript{36,37} Nevertheless, because of the scrums in rugby, in order to prevent serious cervical injuries in the front row, it remains necessary to strengthen and stabilize the cervical region muscles,\textsuperscript{40} so it is important to monitor this appropriately.

These injury prevention systems and high intensity exercises do not, at this time, include any monitoring of cervical muscle size over time to assess the effectiveness of proposed exercises, and more particularly cervical strengthening. From the findings of this study, implementation of cervical ultrasound measurements, with regular follow-ups, could help objectively ascertain the effectiveness of proposed neck strengthening exercises suggested by all injury prevention systems. This may also help define the readiness to play within the different rugby federations (see above “Smartrugby”, etc) and could eventually lead to the creation of minimum muscle size standards for playing in the front row.

In addition to the general rugby fitness requirements, in some countries, a specific paragraph of the medical certificate is devoted to “no contra-indications to the practice of rugby in front row position” for amateur championships. Since 2013, in France, a junior player moving into the senior category and wishing to play in the front row must hold a “front row passport”, based on physical tests, as well as a cervical MRI in case of cervical history or symptoms.\textsuperscript{36} To mitigate injury risk, the Scottish Rugby Federation stipulates that players have to be certified before playing in the front row a specific strength test of the neck.\textsuperscript{41}

The rules for scrums have been updated over several years in order to make rugby safer (2007, 2012, 2013 and 2014).\textsuperscript{42} Regulations in the youth category aim to avoid or limit the push to 1.50 m, however variations are used within each jurisdiction and for different age categories. Indeed, young people, who first transition into the senior category, find themselves suddenly having to push fully in the scrums, without preparation.\textsuperscript{42}

Assessing muscular volumes with ultrasound measurement, as done in this study, can be learned with practice. Prior to use, reliability of the operator should be confirmed by repeated measurements on the same individual and the ability to achieve correct anatomical positioning of the probe as per defined published protocols verified.\textsuperscript{14-16} It is a non-invasive and completely safe technique, with no contra-indications. With further research, the measurement protocol developed in this study could become the basis for describing minimal values by age to be reached in order to play in the front row.
Ultrasound imaging could also be particularly useful to capture functional movements in real time\textsuperscript{43} or verify the state and evolution of external muscle volume after a traumatic injury before the return of the player to the field. Since previous studies on the size of the muscles do not currently exist, the data presented in this paper can serve as a starting point for future research that may result in a consensus between the international federation and rugby leagues, once correlation to injury is established, by defining a minimum muscle size below which the player cannot get his “front row passport”. Below these limits, specific strengthening and stabilization exercises can be put in place for isometric development (as for during scrums), dynamic and proprioceptive, as well as stretching to increase range of motion.\textsuperscript{44} The outcome of these and other specific training exercises can also be directly assessed using ultrasound imaging to monitor progress.

Further studies with direct injury outcome correlation should investigate whether adding to the “front row passport”, in terms of cervical muscle size (circumference) benchmarking, range of motion amplitudes, and muscle thickness assessed via ultrasound could add to injury prevention. While the discussion is focused on the scrums, tackling remains the second cause of cervical spine injuries\textsuperscript{45} and one of most dangerous aspects of the sport.\textsuperscript{8} The focus of this study was mainly on front row players, but the above fact could justify implementing cervical muscle monitoring to all players. Finally, it is to be noted that only amateur players were considered in this study, and it would therefore be interesting to implement these measurements with professional players. In so doing, and for expanding on this pilot data to build a comprehensive database, the measurement values in Tables 3–5 could be used to establish minimum sample sizes for powering a future study.

**CONCLUSION**

Front row rugby players generally have thicker T, SCb and SCOM compared to other players in different positions. The range of motion and muscle size differences observed were even more pronounced in the senior age category, where the rules for pushing during scrums are the most permissive. Both ultrasound and range of motion measurements may complement current pre-participation screening used by rugby federations by objectively monitoring muscular size and motion amplitude around the cervical spine.

**REFERENCES**


Appendix A. Post-hoc evaluation of measurement consistency was established by intra-class correlation coefficient calculation from seven repeated measurements (trials) of all five muscles thicknesses measured in the study, on both the left and right side, of one subject volunteer. For each trial, the average of three measurements was taken, as done during the study. The volunteer was completely repositioned starting from a standing position between all seven trials. The intra-class correlation coefficient, a measure of measurement consistency for continuous data, was then calculated for all ten muscles thicknesses (five left side and five right side) between the seven repeats and found to be 0.98, demonstrating excellent agreement.

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ABSTRACT

Background: Glenohumeral internal rotation deficit and external rotation strength have been associated with the development of shoulder pain in overhead athletes.

Objective: To examine the bilateral passive shoulder rotational range of motion (ROM), the isometric rotational strength and unilateral serve speed in elite tennis players with and without shoulder pain history (PH and NPH, respectively) and compare between dominant and non-dominant limbs and between groups.

Study Design: Cohort study.

Methods: Fifty-eight elite tennis players were distributed into the PH group (n = 20) and the NPH group (n = 38). Serve velocity, dominant and non-dominant passive shoulder external and internal rotation (ER and IR) ROM, total arc of motion (TAM: the sum of IR and ER ROM), ER and IR isometric strength, bilateral deficits and ER/IR strength ratio were measured in both groups. Questionnaires were administered in order to classify characteristics of shoulder pain.

Results: The dominant shoulder showed significantly reduced IR ROM and TAM, and increased ER ROM compared to the non-dominant shoulder in both groups. Isometric ER strength and ER/IR strength ratio were significantly lower in the dominant shoulder in the PH group when compared with the NPH group. No significant differences between groups were found for serve speed.

Conclusion: These data show specific adaptations in the IR, TAM and ER ROM in the dominant shoulder in both groups. Isometric ER muscle weakness and ER/IR strength ratio deficit appear to be associated with history of shoulder injuries in elite tennis players. It would be advisable for clinicians to use the present information to design injury prevention programs.

Level of evidence: 2

Key words: Isometric strength, range of motion, serve speed, shoulder injury, tennis

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INTRODUCTION

High-performance tennis is a stressful game for the body, as it requires multiple repetitions of large ranges of motion (ROM) and high forces during strokes and movements around the court.1 Because of the repetitive nature of tennis, the glenohumeral joint is often injured through overuse, especially in competitive elite tennis players. In this regard, the incidence of tennis injuries is approximately 21.5 injuries per 1000 practice hours.2,3 Specifically shoulder complex injuries range between 25 and 47.7% of all injuries in the upper extremity for tennis players.1,2 Several anatomical and mechanical adaptations are associated with an increased injury risk in the tennis player's shoulder, including asymmetries in dominant shoulder rotational passive ROM4,5 and strength imbalance between the agonist/antagonist muscles of the glenohumeral joint (i.e., internal rotator (IR) and external rotator (ER) muscles).4,6,7 Several previous researchers have shown that shoulder ROM is modified as an adaptive response to tennis play,5,8,9 resulting in greater glenohumeral ER ROM, lower glenohumeral IR ROM and lower total arc of motion (TAM) of the dominant shoulder compared to the non-dominant shoulder.4,6,8-10

A glenohumeral IR deficit (GIRD) of the dominant shoulder compared to the non-dominant shoulder is considered a major risk factor for glenohumeral joint injury in overhead athletes as it causes imbalance in the soft tissues and could lead to shoulder instability11,12, resulting in subacromial impingement syndromes and labral tears.13 However, few studies have analyzed the relationship of asymmetries in shoulder rotation ROM and the shoulder pain history in tennis players, and these have shown different results.4,6,10,14 For example, while several authors have reported no relationship between GIRD and pain in the dominant shoulder in players of different levels (i.e., junior, amateur and professional),5,6,14 the authors of two studies found significant relationships in amateur and professional players.10

In addition to shoulder ROM, strength of the shoulder rotator cuff muscles seems to be essential in order to dynamically stabilize the joint.15 In overhead athletes15 and healthy tennis players,6,7,16-18 shoulder muscle imbalance and side to side differences between shoulders often occur as the result of an adaptation to frequent overhead motions.15 Several authors reported significantly greater IR strength6,7,16,19 and lower ER/IR ratio6,16 in the dominant shoulder in asymptomatic tennis players compared to the non-dominant shoulder. In uninjured elite tennis players, the recommended ER/IR strength ratio ranges between 61-76%, meaning that ER should have at least 2/3 of the IR strength.16 In this regard, a muscle imbalance in the ER/IR ratio together with weak ER in the dominant shoulder have been associated with a high risk of shoulder pain in overhead athletes,20-22 including tennis players.4 However, the studies regarding shoulder rotation strength (measured using hand held dynamometry) in tennis players are scarce.23 In addition, to the authors' knowledge, only a single previous study analyzed the relationship between ER/IR strength ratio and shoulder pain history in amateur tennis players.4

IR and ER strength of the shoulder muscles has also been related to performance in tennis, more specifically with serve speed, considered the most important shot in competitive tennis.24 In this regard, Baiget et al25 observed a relationship between shoulder IR isometric strength levels and serve speed. Moreover, previous authors have found a relationship between ball velocity and elbow and shoulder injuries in baseball players.26,27 It has been suggested that an effective energy flow during the serve would allow the player to produce a high ball velocity,28 but could also increase the mechanical load in the upper limb, thus leading to an increased risk of overuse injuries.29 However, to the best of the authors' knowledge, no previous research analyzed the relationship between serve speed and shoulder pain in elite tennis players.

Thus, the aim of the present study was to examine bilateral passive shoulder rotation ROM, isometric rotation strength, the ER/IR isometric strength ratio and unilateral serve speed in elite tennis players with and without shoulder pain history (PH and NPH, respectively) and then compare these variables between dominant and non-dominant limbs and between PH and NPH groups. It was hypothesized that elite tennis players with PH would demonstrate reductions in IR ROM and TAM, and increases in ER ROM in the dominant shoulder. Moreover, players with PH would also show reduced isometric ER strength and lower ER/IR muscle strength ratios in
Players were divided into two groups: a) NPH group, which included 38 individuals who had not experienced shoulder pain; b) PH group, which included 20 tennis players who had experienced shoulder pain that had prevented them from training and/or competing in the 12 months prior to the study (mean time from injury to testing 4.49 ± 2.06 months) and had no pain history in the two months prior to the study. Five male players were excluded from the study because they reported shoulder pain during the recording session. Groups were compared with an independent measures t-tests, and there were no significant differences for age, height, mass, years of tennis practice, or hours of training per day (Table 1).

**METHODS**

**Participants**

A total of 58 male elite tennis players recruited from 10 different high-performance Spanish academies volunteered to participate in the study (Table 1). All the players participated in ~17 h of combined training (i.e., on and off-court) per week. Fifty-seven (98.2%) players were right-handed and one (1.7%) was left-handed. Furthermore, fifty-five (94.8%) players used a two-handed backhand for stroke. The inclusion criteria were: subjects had to be healthy and actively competing at the time of the study, have no recent shoulder injury or surgery and not have taken any type of medication for the treatment of pain or musculoskeletal injuries at the time of the study. Furthermore, all players with PH had to be diagnosed by a specialist using ultrasound or magnetic resonance imaging. Exclusion criteria included players with pain and a positive Hawkins or Jobe’s test. Written informed consent was obtained from each participant prior to testing. The experimental procedures used in this study were in accordance with the Declaration of Helsinki and were approved by the Ethic Committee of the University. Based on the Consensus statement on epidemiological studies of medical conditions in tennis defined by Pluim et al and Fuller et al in soccer, the tennis

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<th>Table 1. Descriptive characteristics (mean ± standard deviation) of the tennis players organized by group.</th>
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<td>All tennis players (N = 58)</td>
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<td>Tennis experience (years)</td>
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Independent measures t-test with between-subject factor with 2 levels (without history of shoulder pain (NPH) and with shoulder pain (PH)).
of flexion/extension, abduction/adduction and rotation dynamic stretching exercises. All measurements were performed in a randomized and counterbalanced order for both, dominant and non-dominant shoulder. Shoulder measurements and serve speed were performed in the morning prior to training. Before the warm-up and stretching, players fulfilled a questionnaire regarding medical history. Finally, participants performed the rotational ROM test, followed by the serve speed and shoulder strength tests.

**Measurements**

**Questionnaire**

Participant’s characteristics such as age, upper and lower limb dominant side, years of tennis practice, training volume (i.e., hours per week), and characteristics of the injuries reported were documented. The questionnaire also included a visual analogue scale (VAS) for pain evaluation. In the present study, shoulder pain was defined according to Pluim et al. and Fuller et al. Specifically, any injury case included in the data analysis was operationally defined as “a physical complaint or manifestation sustained by a player that results from a tennis match or tennis training and led to an absence of the next training session or match”.

**Shoulder ROM test**

Passive shoulder IR and ER ROM (Fig. 1a, 1b, respectively) were measured with a manual inclinometer (ISOMED inclinometer, Portland, Oregon) of the dominant and non-dominant limbs, with the player in supine on a bench with the shoulder abducted 90 degrees (°) and elbow flexed to 90°. The inclinometer was placed approximately in the mid-point of the distal end of the forearm (for the IR and ER ROMs). The forearm was placed and remained in a pronated position for the duration of the testing. From this starting position, a researcher held the participant’s proximal shoulder region (i.e. clavicle and scapula) against the bench to stabilize the scapula while rotating the humerus in the glenohumeral joint to produce maximum passive IR and ER. The end of IR and ER was defined as the point at which the scapula was felt to move following the methodology described by Clarsen et al. Three maximal trials of each IR and ER ROM test for each limb were recorded and the mean score for each test was used in the subsequent analyses.

**Shoulder strength test**

Measurements of shoulder ER and IR strength were obtained with a hand-held dynamometer (HHD) (Nicholas Manual muscle test, Co, Lafayette IN; range 0–500 N, sensitivity 0.2 N) in a supine position on the bench with the arm in 90° of abduction and 0° of rotation, in the scapular plane (Fig. 2a and 2b). The elbow was flexed in 90° and the examiner stabilized the humerus by pressing it down toward the bench. The testing angle was checked by visual inspection. For ER strength, the player externally rotated the shoulder against the HHD, while the HHD was located proximal to the ulnar styloid process (Fig. 2a). For IR strength, the player internally rotated the shoulder, against the HHD, while

![Figure 1. Assessment of the shoulder rotation range of motion: A) testing for glenohumeral internal rotation position; B) testing for glenohumeral external rotation position.](image-url)
of them. To be accepted, serves had to fall into the service box. The highest speed recorded was used for further analyses.

**Statistical analysis**

Descriptive statistics (means and standard deviations) for each of the variables of shoulder flexibility, shoulder strength and serve speed were calculated. Normality of the data distribution was verified using the Kolmogorov-Smirnov test.

Two-way mixed-design ANOVAs were performed to explore the differences in the dependent variables. A within-subject factor (side: dominant and non-dominant) and a between-subject factor (pain group: NPH and PH) and their interactions were included in the model. A Levene's test for equality of variances was used to assess homogeneity of variances, and showed no differences in any of the measured variables. Effect sizes for ANOVAs are reported as partial omega squared calculated according to Lakens and interpreted as small, medium, and large, corresponding to values of 0.010, 0.059, and 0.138 respectively.\(^3^5\)

As a post-hoc comparison, a related measures t-test was conducted to identify differences in the shoulder's ROM and strength between dominant and non-dominant limbs. An independent measures t-test was conducted to compare between groups.

To determine the magnitude of differences between the groups or limbs for each variable, effect sizes
and their 95% confidence intervals were calculated using standardized mean difference corrected as Hedges’ $g$. The following interpretation of $g$ was used: 0.4 or less small; between 0.4 and 0.7 moderate; greater than 0.7 large.

All analyses were performed using the SPSS package (version 18, SPSS Inc., Chicago, IL, USA) and a custom-made Excel sheet was used to calculate the effect sizes. The level of significance chosen was $p < 0.05$. In addition, a comparison was considered statistically significant when the effect size confidence interval did not cross the zero value.

**RESULTS**

Characteristics of the participants are outlined in Table 1. Thirty-eight players (65.5%) did not suffer shoulder injuries during the previous season, and the remaining (34.4%) sustained 20 tendinopathies (3 biceps brachii and 17 supraspinatus), and all began with an overuse onset. In terms of severity, one was a mild injury (lasting 4–7 days), 10 were moderate injuries (8–28 days) and 9 were severe injuries (> 28 days). Specifically, 16 of the injuries (80%) occurred during match play and 4 (20%) during practice. There were no significant differences between groups with regard to descriptive characteristics, years of tennis practice, or hours of training per day (Table 1).

Table 2 displays the results of the ROM, isometric strength and serve speed measurements, including the within-subject comparisons (i.e. between dominant and non-dominant shoulders), and the between subject comparisons (i.e. dominant shoulder of each group). The two-way mixed-design ANOVA showed an interaction effect between the factors side*pain in the ER isometric strength ($F(1, 54) = 12.520$, $p=0.001$, $\omega_p^2 = 0.171$) and in the ER/IR isometric strength ratio ($F(1, 54) = 5.424$, $p=0.024$, $\omega_p^2 = 0.073$). There is also a main effect in the between-subjects factor in ER isometric strength ($F(1, 54) = 4.361$, $p=0.042$, $\omega_p^2 = 0.057$) and in the strength ratio ($F(1, 54) = 11.368$, $p=0.001$, $\omega_p^2 = 0.156$). The within-subjects factor shows a main effect in all the variables ($p < 0.001$, $0.179 < \omega_p^2 < 0.715$).

In the within-subject comparison, the PH and NPH groups presented significantly lower values of IR ROM (effect size 1.16 [0.50, 1.82] and 1.55 [1.04, 2.06] respectively, $p < 0.01$), and of TAM (.49 [-0.04, 1.01], $p < 0.05$ and .45 [0.09, 0.80], $p < 0.01$, respectively), but higher ER ROM (-0.77 [-1.34, -0.19], $p < 0.05$ and -0.97 [-1.39, -0.56], $p < 0.01$, respectively) on the dominant side (Fig. 3a).

Furthermore, PH and NPH players showed lower ER/IR isometric strength ratios (1.16 [0.48, 1.85], $p < 0.01$ and .38 [0.02, 0.73], $p < 0.05$, respectively) and higher IR isometric strength (-0.58 [-1.12, -0.04] and -0.75 [-1.14, -0.36] respectively, $p < 0.01$) in the dominant side compared with the non-dominant side (Fig. 3b). The NPH group also had significantly higher ER isometric strength in the dominant side compared with the non-dominant side (-0.59 [-0.96, -0.21], $p < 0.01$).

**Figure 3.** Range of motion (a) and strength (b) in the injured (dominant or D) and non-injured (non dominant or ND) limbs in both pain history (PH) and no pain history (NPH) groups (brackets denote $p < 0.05$ and effect size confidence interval out of zero).
Variables | NPH (N = 38) | PH (N = 20) | p | ES [95% CI]  
--- | --- | --- | --- | ---  
Total arc of motion (º)  
Dominant | 150.3 ± 14.9 | 143.1 ± 15.1 | .089 | 0.47 [-.09, 1.03]  
Non-dominant | 157.1 ± 12.0 | 150.8 ± 11.2 | .055 | 0.53 [-.03, 1.10]  
Diff | 6.8 ± 12.1 | 7.7 ± 12.2 | .807 | -0.07 [-.62, .49]  
Within-subject comparison | .001, | .011, | |  
 p, ES [95% CI] | 0.45 [.09, .80] * | 0.49 [-.04, 1.01]  
Internal rotation ROM (º)  
Dominant | 52.5 ± 9.7 | 48.7 ± 12.0 | .204 | 0.35 [-.21, .91]  
Non-dominant | 67.8 ± 7.9 | 63.2 ± 9.7 | .056 | 0.53 [-.03, 1.09]  
Diff | 15.3 ± 9.2 | 14.5 ± 8.8 | .728 | 0.10 [-.46, .65]  
Within-subject comparison | .000, | .000, | |  
p, ES [95% CI] | 1.55 [1.04, 2.06] * | 1.16 [.50, 1.82] *  
External rotation ROM (º)  
Dominant | 97.8 ± 8.5 | 94.4 ± 8.5 | .151 | 0.40 [-.16, .95]  
Non-dominant | 89.3 ± 8.3 | 87.6 ± 9.5 | .476 | 0.20 [-.36, .75]  
Diff | -8.5 ± 7.4 | -6.8 ± 9.5 | .454 | -0.21 [-.76, .35]  
Within-subject comparison | .000, | .005, | |  
p, ES [95% CI] | -0.97 [-1.39, -.56] * | -0.77 [-1.34, -.19] *  
Relative internal rotation strength (N/kg)  
Dominant | 1.51 ± 0.38 | 1.50 ± 0.40 | .953 | 0.02 [-.54, .57]  
Non-dominant | 1.22 ± 0.34 | 1.26 ± 0.28 | .610 | -0.14 [-.70, .42]  
Within-subject comparison | .000, | .001, | |  
p, ES [95% CI] | -0.75 [-1.14, -.36] * | -0.58 [-1.12, -.04] *  
Relative external rotation strength (N/kg)  
Dominant | 1.17 ± 0.29 | 1.01 ± 0.17 | .028 | 0.62 [.05, 1.19] †  
Non-dominant | 1.00 ± 0.29 | 1.01 ± 0.17 | .848 | -0.05 [-.61, .50]  
Within-subject comparison | .000, | .999, | |  
p, ES [95% CI] | -0.59 [-.96, -.21] * | 0.00 [-.49, .50]  
External rotation/Internal rotation strength ratio  
Dominant | 0.79 ± 0.12 | 0.68 ± 0.11 | .001 | 0.94 [.34, 1.53]  
Non-dominant | 0.83 ± 0.13 | 0.81 ± 0.11 | .643 | 0.13 [-.43, .68]  
Within-subject comparison | .037, | .001, | |  
p, ES [95% CI] | 0.38 [.02, .73] * | 1.16 [.48, 1.85] *  
Serve speed (km/h)  
Dominant | 167.9 ± 11.7 | 171.6 ± 12.4 | .273 | -0.30 [-.86, .25]  
ES = Effect size [95% confidence limits]; Diff = difference between shoulders (non-dominant – dominant).  
* and † Statistically significant within-subject and between groups difference respectively (p < 0.05 and effect size confidence interval out of zero).
The magnitude of side to side between groups comparison showed significant differences between the PH and NPH groups. Especially the PH group showed significantly lower ER and ER/IR isometric strength ratio in the injured side (dominant) compared with the dominant side in NPH players (0.62 [0.05, 1.19], p < 0.05 and 0.94 [0.34, 1.53], p < 0.01, respectively). In contrast, the comparison of serve speed showed no differences between groups (-0.30 [-.86, 0.25], p > 0.05).

**DISCUSSION**

Several authors have suggested that competitive tennis leads to alterations in IR ROM and shoulder rotation muscle strength imbalances (i.e., ER/IR ratio modifications), which may be a contributing factor to shoulder injuries. However, the association between shoulder injury and decreased rotational ROM, as well as strength imbalance and performance (i.e., serve speed) has not been widely analyzed previously in elite tennis players. Results obtained in the present study reported significant side to side differences in shoulder rotation ROM and isometric strength in elite tennis players with PH and NPH. Despite both groups showing important adaptations in the dominant shoulder, isometric ER strength and ER/IR strength ratio were significantly lower in the dominant shoulder in the PH players when compared with the NPH players.

The current results showed reductions in IR ROM and TAM, and increases in ER ROM in the dominant shoulder compared to the non-dominant side, which are in line with previous results obtained both in uninjured tennis players and in injured tennis players. These asymmetric rotational ROM have been considered specific adaptations in tennis players caused by the high repetitive loading forces generated by strokes, mainly the serve and groundstrokes. Also, the findings of the current study are in line with those of previous researchers who did not observe significant differences between the NPH and PH groups for the side-to-side asymmetries in glenohumeral rotation ROMs in players with different levels (i.e., professional, amateur and junior). However, these results differ from two previous studies reporting significant differences between PH and NPH players in the side to side IR. The lack of agreement between studies could be related to the differences among protocols or participant's characteristics, as in the present study the PH group was “healthy” at the time of the study, while the group analyzed in the study of Marcondes et al presented with shoulder pain at the time of the study. It is therefore logical to speculate that the presence of pain could alter the results of rotation ROM measures. Another possible explanation for these discrepancies can be related to the age differences in the participants, with previous studies analyzing players ranging between 19 and 33 years old (i.e., 26.2 ± 3.9 years), while in the present study players averaged 20.7 ± 4.9 years. In this regard, previous research analyzed IR ROM differences in the shoulders of players with different ages, highlighting a progressive decrease as age increases. In addition, in the present study, non-dominant shoulder in the PH group showed less glenohumeral IR (63.2º) and TAM (150.8º) than the NPH group (IR = 67.8º; TAM = 157.1º), although the differences did not reach statistically significant. These findings partially agree with the results reported by Moreno-Pérez et al in professional tennis players, which showed significantly less glenohumeral IR (in both shoulders) and TAM (in the non-dominant shoulder) than the NPH group. Perhaps, the small discrepancy might be due to participant age differences in the PH group; the current study had an average age in PH group of 20.2 ± 4.3 years, while in that of Moreno-Pérez et al it was 25.6 ± 3.0 years. Furthermore, in the study by Moreno-Pérez et al the years of tennis experience in the PH group (17.6 ± 6.0) were very different from the experience in the present sample (11.6 ± 5.3), which could affect results between groups.

Concerning the shoulder rotator muscle strength, previous studies conducted with tennis players and other overhead athletes and other overhead athletes have demonstrated similar significant results regarding higher IR isometric strength and decreased ER/IR isometric strength ratio in the dominant shoulder compared with the non-dominant side in uninjured and injured athletes. Increases in IR strength are likely due to the high demands imposed on these muscles during tennis strokes, especially the forehand and the serve, which can account for approximately 80% of the total number of strokes during a match. In addition, the repetitive high demands on IR strength in the dominant side during tennis strokes may increase the tensile...
stress on the posterior rotator cuff and scapular stabilizers, and could develop a strength imbalance between the ER and IR over time.

Interestingly, the PH group had reduced dominant ER strength and ER/IR isometric muscle strength ratio in the injured side compared with the dominant side in NPH players. These results support previous studies conducted in a population of baseball20,21 and handball22 players with shoulder injuries, whose authors reported a relationship between ER weakness and decreased ER/IR muscle strength ratio (measured with HHD). This suggests that a weakness in ER strength is associated with imbalance between the propulsive IR during throwing or serving and the ER muscles responsible for deceleration and stabilization of the shoulder during these sports actions. Therefore, poor ER strength may increase the risk of shoulder injury, and strength training, which aims to enhance strength of the ER muscles, and may contribute to reducing the risk of a future shoulder injury.

Several authors that have studied overhead sports believe that increasing IR strength of the dominant shoulder without simultaneously increasing ER strength would produce an imbalance that could possibly lead to higher injury risk.22,38 However, very few studies have specifically analyzed the relationship between shoulder injuries and strength ratio with HHD in tennis players.4 The present results were similar to those of Marcondes et al. who found that ER/IR strength ratio was a mean of 0.82 in the dominant shoulder in uninjured players and of 0.74 in the injured group. However, in the present study, a mean of 0.68 and 0.79 rotational strength ratio in the dominant side in the injured and uninjured players was found, respectively. The lower difference between studies could be due to differences in the demands of training and competition (intensity, duration, frequency, etc.) because while the sample of Marcondes et al played between 8 and 12 hours per week (training or playing), the players analyzed in the current study played an average of 17 hours per week. Probably the higher IR strength obtained in data in both shoulders would explain a greater imbalance between the ER/IR muscle strength ratio. Future research involving tennis players needs to be carried out to elucidate the effects of different training and competition demands on the strength and the risk of shoulder pain.

Regarding serve speed, the results showed no differences between groups. In the serve's kinetic chain, shoulder IR is the joint movement with the highest speed before ball impact.39 Present data showed no between group differences in IR strength, so it is not surprising that the serve speed remained similar. On the contrary, as stated before, the reduced ER strength presented in the PH group should increase injury risk when decelerating shoulder rotation in the follow-through phase, emphasizing the necessity of shoulder strengthening (i.e., ER focused) programs performed by the players.

Based on the present results, players who have suffered shoulder pain within the year prior to the study may continue to have a strength deficit after the injury has abated. Therefore, preventative strengthening of the shoulder ER muscles would be recommended and should be an integral part of a tennis player's conditioning and injury prevention program with the aim of avoiding future recurrences. However, future studies should determine if such a strengthening program does, indeed, result in reduced shoulder re-injury.

While the results of this study have provided information regarding the relationship between passive shoulder ROM, isometric strength and serve speed in elite tennis players with and without shoulder pain history, limitations to the study must be acknowledged. The evaluation of players was performed cross-sectionally. While it would be beneficial to analyze elite tournament players in a longitudinal study, it is logistically difficult due to their geographic mobility and uncertain future career paths. Similarly, a post-injury cross-sectional study informs us about the condition of athletes deemed recovered from a shoulder injury, which is valuable information as to their physical condition after they return to play. However, the post-injury rehabilitation programs undergone by the players with shoulder pain were neither controlled or investigated, and may have modified the outcomes of this study.

CONCLUSION
The results of the present study revealed significantly lower isometric ER strength and reduced ER/IR muscle strength ratios in the dominant shoulder in elite tennis players with a history of shoulder
pain when compared with NPH players. Furthermore, regarding the side to side asymmetries, the dominant shoulder in both groups reported adaptations of shoulder ROM, with reduction of the IR and TAM, and an increase in the ER ROM when compared with the non-dominant side. Additionally, the dominant limb showed higher IR isometric strength and decreased ER/IR isometric muscle strength ratio in the PH and NPH group. Understanding the tennis-specific adaptations of the shoulder complex could help tennis players, coaches, athletic trainers, and clinicians to design and utilize optimal exercise protocols, both preventatively and post-injury for players who had suffered shoulder pain within the previous year.

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ABSTRACT

Background: The forward head rounded shoulder (FHRS) sitting posture has been associated with decreased shoulder complex muscle strength and function. Upon clinical observation, the adverse effects of the FHRS sitting posture on shoulder complex isometric muscle strength is also present when testing controls for scapular position.

Hypothesis/Purpose: The purpose of the study was to assess the effect of various sitting postures on shoulder external rotator muscle isometric strength when the strength testing controls for scapular position.

Study Design: A cohort study, with subjects serving as their own controls.

Methods: One hundred subjects ages 20-26 participated in the study. Each subject was placed in a neutral cervical sitting (NCS) posture which was maintained for five minutes after which the strength of the dominant shoulder external rotators was immediately tested with the glenohumeral joint in the neutral position using a Micro-FET3 Hand Held Muscle Testing Dynamometer (HHMTD). Each subject was returned to the NCS posture for subsequent external rotator strength testing after five minutes in a FHRS sitting posture, five additional minutes in the NCS posture and five minutes in a retracted cervical sitting (RCS) posture resulting in each subjects' external rotator strength being tested on four occasions. Subjects were randomized for order between the FHRS and RCS postures.

Results: Mean strength values for each condition were normalized to the mean strength value for the 1st NCS condition for each subject. A statistically significant decline in shoulder external rotator strength following the FHRS sitting posture occurred compared to the appropriate postural conditions (p<.05). A frequency analysis revealed that 36% of the subjects demonstrated greater than 10% decline in external rotator strength following five minutes in the FHRS sitting posture. The average percentage of strength decline in those with greater than a 10% reduction in external rotator strength was 19%. Sixty-four percent of the subjects experienced less than a 10% decline in shoulder external rotator strength in response to the FHRS sitting posture.

Conclusion: Shoulder external rotator strength declined 8% following five minutes in the FHRS sitting posture. A sub-population of 36% demonstrated an average decline of 19% in shoulder external rotator strength following five minutes in the FHRS sitting posture. The strength decline appears to resolve over the short-term by returning to the NCS posture.

Level of Evidence: Level III

Key Words: Sitting posture, shoulder external rotator strength
INTRODUCTION

The forward head, rounded shoulder (FHRS) posture is routinely assumed by many individuals in modern society.1,2 The FHRS posture is seen in the standing position but appears to be accentuated in relaxed sitting. Subsequently, the FHRS sitting posture is commonly assumed when driving, using a computer or hand held device, reading and viewing television to name only a few routine daily activities. The upper extremity consequences of the FHRS posture have been described as decreased shoulder complex range of motion, decreased shoulder muscle strength, and a reduction in subacromial space, each of which may contribute to shoulder dysfunction and possibly pain.3-7

Previous authors who have examined the influence of the FHRS posture on muscle isometric strength have focused on the position of the scapula and the resultant influence on shoulder muscle force production.4-6 Kebaesta et al4 reported a 16.2 % reduction in shoulder abductor muscle force produced in the sitting FHRS posture compared to the shoulder abductor force produced in a neutral sitting posture. In the Kebaesta study, isometric shoulder abduction was tested in the plane of the scapula at the horizontal position. Smith et al5 reported an increase in isometric muscle force production of the shoulder flexors when tested with the shoulder at 90 degrees with the scapula maintained in a neutral position. This was compared to the isometric shoulder flexor muscle force produced when subjects were tested in both scapular protracted and retracted positions. In a subsequent study, Smith et al6 reported a reduction in isometric force production of the shoulder external rotators when tested with the scapula protracted, the shoulder flexed to 90 degrees and externally rotated to 90 degrees. The magnitude of the decrease was 20% when compared to the isometric force produced during the neutral scapular position.6 The cited studies suggest that scapular positions can influence shoulder muscle isometric force production.

The authors’ clinical observations have also noted changes in shoulder external rotator muscle strength in apparent response to the maintenance of various sitting postures. The FHRS posture has been observed to result in a reduction in shoulder external rotator muscle strength while the erect neutral cervical sitting posture has been noted to favorably influence external rotator muscle strength.

Pheasant, in two prior case reports, described an immediate improvement in rotator cuff strength and reduction in signs and symptoms of subacromial impingement in response to cervical retraction and retraction with extension ROM exercises combined with neutral cervical posturing. The reported responses to the stated interventions also included an abolishment of the presenting painful arc of active shoulder abduction and negative Hawkins-Kennedy and Jobe empty can testing.9 The author attributed the improved rotator cuff function to the changes in cervical position promoted by the cervical ROM exercises and neutral cervical posture positioning. The relationship reported by Pheasant among cervical retraction exercise, cervical retraction with extension exercise, neutral cervical posturing and the finding of improved rotator cuff strength prompted the authors to attempt to substantiate the observation through a systematic investigation. Specifically, the authors were interested in the influence the sustained position of the cervical spine had on the isometric strength of the shoulder external rotators.

The studies by Kebaesta et al4 and Smith et al5,6 focused on the influence the protracted scapula (rounded shoulder) that accompanies the FHRS posture, had on shoulder muscle force production. The current study, based on the case report by Pheasant, focused on the protruded position of the cervical spine (forward head) and the resulting influence on shoulder external rotator muscle strength. The influence of sitting cervical posture on shoulder muscle strength has not been reported in the literature to the best of the authors’ knowledge. Therefore, the purpose of the study was to assess the effect of various sitting postures on shoulder external rotator muscle isometric strength when the strength testing controls for scapular position. The hypothesis is the FHRS sitting posture will have an adverse effect on shoulder external rotator muscle strength when the strength testing controls for scapular position.

METHODS

The design was a cohort study with the subjects serving as their own controls. Participants included a convenience sample of 100 healthy volunteers.
(39 males, 61 females) between 20 and 26 years of age from a university setting (Table 1). Individuals were excluded from participation for the following reasons: a prior history of spinal surgery; a history of neck or back pain with radiating symptoms into the arms or legs; current spinal pain; a history of dominant shoulder surgery or a history of dominant shoulder injury within the prior year.

The isometric external rotator strength of the dominant shoulder of each subject was tested following five minutes of sustained positioning under each of the following four conditions: 1.) neutral cervical sitting (NCS) posture, 2.) forward head rounded shoulder (FHRS) sitting posture, 3.) second neutral cervical sitting (NCS) posture and 4.) retracted cervical sitting (RCS) posture. The FHRS sitting posture and RCS posture were alternated for order with each successive subject to minimize learning and/or fatigue effects. For example; the first subject was positioned in the NCS posture for five minutes and then immediately tested, the FHRS sitting posture for five minutes and immediately tested, the NCS posture for an additional five minutes and immediately tested, and then finally the RCS posture for five minutes and immediately tested. The order of postures and testing for the second subject was NCS, RCS, NCS and FHRS. This alternating pattern of assignment was maintained throughout the testing of the 100 subjects.

The five-minute period of posture maintenance was determined to coincide with the time frame the authors’ have observed strength changes to occur in response to various sitting postures in the clinic. Since the time frame for strength changes to occur in response to changes in sitting posture has not been formally objectified, five minutes was deemed a reasonable time frame to allow comparison of the four conditions listed above.

The NCS posture was defined by the vertical alignment of the tragus of the ear, bodies of the cervical vertebrae, acromion of the scapula, coronal mid-line of the thorax with the maintenance of the lumbar lordosis. Due to the frontal plane posture alignment, the scapulae were drawn into a retracted/adducted position. The FHRS sitting posture was defined as a position of relaxed, unsupported, slumped sitting. This was characterized by a protruded cervical spine, protracted/abducted scapulae and thoraco-lumbar flexion. Each subject was cued to maintain the head and eyes level in the transverse plane by focusing his or her gaze on a mark on the wall. The RCS posture was defined as an accentuation of the NCS posture to the extent each subject’s maximal cervical retraction range of motion permitted. The scapular position for the RCS was unchanged from the NCS posture. (Figure 1) In each of the postures, the subjects were seated unsupported on a table with feet positioned on a stool for stability.

An investigator was charged with visually monitoring each subjects’ sitting posture under each condition to assure the criteria of the condition was maintained throughout each five-minute period. Verbal and tactile cues were provided to each subject as needed throughout the test period to maintain the designated posture. All subjects were successful in maintaining each posture for the required five minutes. However, most subjects found the RCS posture more challenging and few required cuing to maintain the posture. The RCS posture was likely more challenging due to the novelty of the posture and the maintenance of the end ranges inherent to the RCS posture.

Strength testing of the dominant shoulder external rotators was performed using a Micro-FET3 Hand Held Muscle Testing Dynamometer (HHMTD) (Hoggan Scientific Salt Lake City, UT). Cools et al determined the protocol followed in the study to be reliable for testing the strength of the shoulder external rotators using the Micro-FET3. In addition, ICC values of 0.89-0.99 have been reported for intra-session reliability for shoulder external rotation strength testing utilizing a HHMTD. Strength testing consisted of three five second “make” tests for shoulder external rotation. “Make” testing has been demonstrated to be a more reliable test of shoulder external rotator strength than a “break” test although less force is produced with the method.

Each subject was instructed to provide a maximal effort for five seconds while the tester maintained

<table>
<thead>
<tr>
<th>Table 1. Subject Profile</th>
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<tbody>
<tr>
<td>Subject Profile</td>
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<tr>
<td>------------------</td>
</tr>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Height (inches)</td>
</tr>
<tr>
<td>Weight (pounds)</td>
</tr>
</tbody>
</table>
the static position of the HHMTD. A 10 second rest period separated each of the three trials. The subjects' upper extremity position for strength testing was 0 degrees of glenohumeral joint abduction, 0 degrees of glenohumeral joint external rotation and 90 degrees of elbow flexion. The HHMTD was held on the dorsum of the distal forearm 2 cm proximal to subjects' radial styloid process. A warm-up of 15 active IR/ER movements were performed from the testing position followed by three sub-maximal practice strength testing trials to familiarize the subjects to the testing protocol prior to the initial NCS condition. All strength testing was performed with the subject in the NCS posture in order to standardize the testing position regardless of the preceding posture.

Study approval was granted by the Misericordia University Institutional Review Board. Informed consent was obtained and the rights of the subjects protected.

RESULTS
External rotator mean strength values are provided for each of the postural conditions. (Table 2) Mean external rotator strength values for each postural condition were normalized for each subject to his or her initial NCS posture strength mean. (Table 3) (Figure 2) Strength values were normalized due to the wide variation in shoulder external rotator strength among subjects. The normalized external rotator strength mean values were calculated by obtaining the mean of the three trials for each subject and each condition and dividing by the mean of each subjects 1st NCS trials. ANOVA (Table 4) and paired sample testing (Table 5) demonstrated a significant decline in shoulder external rotator strength following the FHRS posture compared to each of the

<table>
<thead>
<tr>
<th>Non-normalized External Rotator Strength (pounds)</th>
<th>Mean</th>
<th>SD</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Conditions</td>
<td>19.48</td>
<td>±5.03</td>
<td>37.7</td>
<td>8.7</td>
</tr>
<tr>
<td>1st NCS</td>
<td>20.13</td>
<td>±5.09</td>
<td>37.7</td>
<td>11.2</td>
</tr>
<tr>
<td>RCS</td>
<td>19.81</td>
<td>±5.14</td>
<td>37.3</td>
<td>11.4</td>
</tr>
<tr>
<td>2nd NCS</td>
<td>19.42</td>
<td>±4.93</td>
<td>34.2</td>
<td>10.3</td>
</tr>
<tr>
<td>FHRS</td>
<td>18.55</td>
<td>±4.84</td>
<td>32.6</td>
<td>8.7</td>
</tr>
</tbody>
</table>

1st NCS: Neutral Cervical Sitting
RCS: Retracted Cervical Sitting
2nd NCS: Neutral Cervical Sitting
FHRS: Forward Head Rounded Shoulders
A frequency analysis revealed that 36% of the subjects demonstrated greater than 10% decline in shoulder external rotator strength following 5 minutes in the FHRS posture. The 10% decline was subjectively determined by the researchers to attempt to identify the presence of a sub-population of subjects experiencing a larger magnitude of strength decline consistent with the authors’ clinical observations. The average percentage strength deficit of those with greater than 10% decline was 19%.

**DISCUSSION**

The FHRS sitting posture is characterized by scapular protraction, lower cervical flexion and upper cervical extension. Previous studies have focused on the influence of scapular position on shoulder muscle strength. Smith et al. reported a 20% decline in external rotator strength when tested with the scapula protracted and the shoulder flexed to 90 degrees and externally rotated to 90 degrees compared to strength testing with the scapula in the neutral position. Smith et al. speculated the decline in external rotator strength was likely due to biomechanical factors effecting the scapulothoracic and rotator cuff musculature. The ability of the scapulothoracic musculature to stabilize the scapula and provide a firm base for the function of the rotator cuff may have been compromised in the protracted scapula position and may have resulted in reduced

**Table 3. Normalized Strength Means to 1st NCS Means**

<table>
<thead>
<tr>
<th>Normalized Strength Means</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st NCS</td>
<td>100</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>.00</td>
</tr>
<tr>
<td>RCS</td>
<td>99</td>
<td>.76</td>
<td>1.26</td>
<td>.99</td>
<td>.09</td>
</tr>
<tr>
<td>2nd NCS</td>
<td>100</td>
<td>.78</td>
<td>1.22</td>
<td>.97</td>
<td>.09</td>
</tr>
<tr>
<td>FHRS</td>
<td>100</td>
<td>.68</td>
<td>1.29</td>
<td>.92</td>
<td>1.09</td>
</tr>
</tbody>
</table>

1st NCS: Neutral Cervical Sitting  
RCS: Retracted Cervical Sitting  
2nd NCS: Neutral Cervical Sitting  
FHRS: Forward Head Rounded Shoulders

Figure 2. Strength values were normalized due to the wide variation in shoulder external rotator strength among subjects. The normalized external rotator strength mean values were calculated by obtaining the mean of the three trials for each subject and each condition and dividing by the mean of each subjects 1st NCS trials. The normalized shoulder external rotator strength means following five minutes in the FHRS sitting posture indicate an 8% decline compared to the shoulder external rotator strength means following five minutes in the 1st NCS posture.

**Table 4. ANOVA between Group Normalized Strength Means (1st NCS, RCS, 2nd NCS, FHRS)**

<table>
<thead>
<tr>
<th>ANOVA</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Squares</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>.332</td>
<td>3</td>
<td>.111</td>
<td>16.047</td>
<td>.000</td>
</tr>
<tr>
<td>Within Groups</td>
<td>2.726</td>
<td>395</td>
<td>.007</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3.059</td>
<td>398</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1st NCS: Neutral Cervical Sitting  
RCS: Retracted Cervical Sitting  
2nd NCS: Neutral Cervical Sitting  
FHRS: Forward Head Rounded Shoulders

**Table 5. Paired Samples Test between 2nd Neutral Cervical Sitting and Forward Head Rounded Shoulder Normalized Strength Means**

<table>
<thead>
<tr>
<th>Paired Samples Test</th>
<th>Mean</th>
<th>St. Dev</th>
<th>St. Error</th>
<th>t</th>
<th>df</th>
<th>Sig (2-tail)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd NCS-FHRS</td>
<td>.869</td>
<td>1.76</td>
<td>.176</td>
<td>4.934</td>
<td>99</td>
<td>.000</td>
</tr>
</tbody>
</table>

2nd NCS: Neutral Cervical Sitting  
FHRS: Forward Head Rounded Shoulders

mean strength values following the 1st NCS, RCS and 2nd NCS postures (p < .05). No significant difference was detected among the normalized strength means for 1st NCS, RCS and 2nd NCS postures (p > .05).
external rotator force production. This factor, when coupled with the relatively shortened position of the external rotator musculature in the testing position, result in length/tension considerations that may have further compromised force production.6

The results of the current study demonstrate an average decline of 8% in external rotator force production in response to five minutes in the FHRS sitting posture. Furthermore, 36% of the subjects experienced greater than a 10% decline in strength. The scapular and rotator cuff length/tension biomechanical explanations offered by Smith et al for the strength decline in their investigation are less influential considerations in the present study. Inherent to the design of the present study, all shoulder external rotator strength testing was performed in the NCS posture that place the scapular and rotator cuff musculature at a consistent length minimizing length/tension variability in that region. Although, the intent of the current study was to identify whether shoulder external rotator strength was influenced by cervical spine positioning inherent to various sitting postures and not to determine the cause of the decline, it is interesting to speculate possible causes in order to direct future research. The authors also suspect a biomechanical contribution to the shoulder external rotator muscle strength decline but one occurring at the cervical spine, therefore, indirectly influencing the shoulder complex. Given the FHRS sitting posture resulted in a transient strength decline of the shoulder external rotators, the authors surmise the strength decline may be related to intermittent compression of the C5 nerve root, possibly resulting in a temporary conduction block. A C5 nerve root conduction block could affect the peripheral nerves that receive predominantly C5 contribution, namely the suprascapular and axillary nerves. These nerves innervate the shoulder external rotator muscles, specifically the infraspinatus and teres minor.

The lower cervical flexion that accompanies the FHRS sitting posture has been estimated at 6.3 ± 4.1° at the C4/C5 level by Ordway.20 A study by Anderst et al21 offers additional information that may shed insight on a potential explanation for C5 nerve root compression through an intervertebral foraminal stenosis mechanism with the lower cervical flexion accompanying the FHRS sitting posture. An anterior shear of C4 on C5, on the magnitude of 33%, was reported to occur accompanying end range cervical flexion.21 This anterior shear is likely to result in a narrowing of the anterior/posterior dimension of the intervertebral foramen as the inferior articular process of C4 moves toward the posterior aspect of the C5 uncovertebral joint. Although, gross cervical flexion is not identical to the lower cervical flexion which accompanies the FHRS sitting posture, similarities in kinematics do exist. Consequently, a foraminal stenosis at C4-C5 may be created by the lower cervical flexion and resultant shear from time spent in the FHRS sitting posture, which in turn, may be a potential source of C5 nerve root compression and a possible explanation for the decline in shoulder external rotator strength found in the current study.

Furthermore, Topp and Boyd22 reported compressive forces between 20-30 mmHg can impair neural blood flow, and subsequently, may compromise nerve function. Short term changes in neural blood flow are believed to reverse once the compression is removed without residual nerve damage. However, compressive forces of 50 mmHg, for periods as brief as two minutes, have been shown to result in damage to the myelin and axon. Garfin et al23, using a pig model, demonstrated a diminution of nerve conduction in both afferent and efferent nerve fibers in response to 75-100 mmHg of compression. The magnitude of the compression represented the mean of the pig’s arterial blood pressure. Garfin23 also reported a return to near normal nerve function one and a half hours following release of two hours of the compression. The previous studies suggest a threshold exist where a level of compression may result in a temporary disruption of nerve function without resultant nerve damage.22,23 Therefore, the authors surmise temporary nerve compression may be the reason for the shoulder external rotator strength decline demonstrated in the study.

Based on Thompson and Kopell,24 the authors also offer traction to the suprascapular nerve as a possible explanation for the decline in shoulder external rotator strength in response to the FHRS sitting posture. Thompson and Kopell24 suggest the scapular protrac- tion that accompanies the FHRS sitting posture may result in traction to the suprascapular nerve. Since the contributing nerve roots of the brachial plexus
are anchored proximally by the cervical spine and the suprascapular nerve is anchored distally at the suprascapular notch, it can be tractioned as the scapula moves anteriorly. Rydevik et al\textsuperscript{25} report venular stasis to be induced in a nerve that has undergone a tensile stress resulting in a strain of 8\%. Topp and Boyd report a 6-8\% strain to a nerve results in transient physiologic changes.\textsuperscript{22} Furthermore, Rydevik et al\textsuperscript{25} report a complete “standstill” in intraneural blood flow in response to a traction force resulting in a 15\% strain, a strain that also leads to a loss of nerve conduction and muscle function. The vascular compromise and consequent neural dysfunction that has been reported as a result of neural tension warrants consideration as a potential cause of the shoulder external rotator strength decline observed in the study. However, once again, due to the nature of the strength decline observed, the magnitude of the traction would likely have been enough to impair neural function, yet not to the extent to result in permanent neural damage.

A primary limitation of the study is that the subjects were healthy 20-26 year old adults without significant history of previous cervical pathology and normal range of motion. This fact compromises the ability to generalize the findings to an older population with more advanced cervical degenerative changes and hypomobility. Additionally, the study only examined the effects of five minutes of cervical posturing and therefore cannot make assumptions regarding the effects of longer or shorter cervical posturing time frames.

The authors recommend that future research should focus on the particular cause of the shoulder external rotator strength decline in response to the FHRS posture when controlling for scapula position. This could include future research to examine the specific effect of the anterior shear of C4 on C5 on the cross sectional area of the intervertebral foramen during the FHRS sitting posture.

The authors would also like to point out a practical implication of the study’s findings and give the readers something to ponder. Imagine a baseball pitcher sitting in the dugout in a FHRS sitting posture expected to return to the field to throw a 90 mph fastball. One would suspect that this player may be at risk for compromised performance or potential injury if subjected to a possible 19\% decline in shoulder external rotator strength; a strength decline that may be preventable by merely modifying cervical posture.

**CONCLUSION**

The results of the study indicate that shoulder external rotator strength did not significantly decline in response to five minutes in either the 2\textsuperscript{nd} NCS or RCS postures. However, subjects demonstrated an average eight percent decline in shoulder external rotator strength in response to five minutes in a FHRS sitting posture. Furthermore, a sub-population of subjects (36/100) was identified that demonstrated a decline in shoulder external rotator strength of greater than ten percent with an average decline of 19\% after positioned five minutes in a FHRS sitting posture. The authors believe that this finding is clinically relevant in that a 19\% decline in external rotator strength may alter the external to internal rotator cuff strength ratio and is likely to compromise shoulder function and performance. Therefore, clinicians should be more conscious of the influence of cervical posture when examining the cervical spine and/or the shoulder since a FHRS sitting posture may result in a significant decrease in shoulder external rotator strength due to the possible factors discussed.

**REFERENCES**


ABSTRACT

Background: Impaired trunk motion during pitching may be a risk factor for upper extremity injuries. Specifically, increased forces about the shoulder and elbow have been observed in pitchers with excessive contralateral trunk lean during pitching. Because of the difficulty in identifying abnormal trunk motions during a high-speed task such as pitching, a clinical screening test is needed to identify pitchers who have impaired trunk motion during pitching.

Hypothesis/Purpose: The purpose of this study was to determine the relationship between the degree of lateral trunk lean during the single-leg squat and amount of trunk lean during pitching and if trunk lean during pitching can be predicted from lean during the single-leg squat.

Study Design: Controlled Laboratory Study; Cross-sectional.

Methods: Seventy-three young baseball pitchers (11.4 ± 1.7 years; 156.3 ± 11.9 cm; 50.5 ± 8.8 kg) participated. An electromagnetic tracking system was used to obtain trunk kinematic data during a single-leg squat task (lead leg) and at maximum shoulder external rotation of a fastball pitch. Pearson correlation coefficients for trunk lean during the single-leg squat and pitching were calculated. A linear regression analysis was performed to determine if trunk lean during pitching can be predicted from lean during the single-leg squat.

Results: There was a positive correlation between trunk lean during the single-leg squat and trunk lean during pitching ($r = 0.53; p < 0.001$). Lateral trunk lean during the single-leg squat predicted the amount of lateral trunk lean during pitching ($R^2 = 0.28; p < 0.001$).

Conclusions: A moderate positive correlation was observed between trunk lean during an SLS and pitching. Trunk lean during the single-leg squat explained 28% of the variance in trunk lean during pitching.

Level of Evidence: Diagnosis, level 3

Key Words: baseball, biomechanics, clinical screening test, lumbo-pelvic stability, throwing

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INTRODUCTION
Shoulder and elbow injuries are prevalent in youth and adolescent baseball pitchers.1-4 The injury incidence over the course of a season in youth baseball pitchers has been reported to be as high as 28.7%, with a large majority of injuries occurring to the upper extremity.1 Furthermore, ulnar collateral ligament reconstruction has become one of the most commonly performed procedures in pitchers5 and have doubled since 2000.6 Pitching is a complex activity that requires coordinated and controlled transfer of energy from the legs, through the trunk, to the shoulder, and then distal to the hand for ball release.7,8 It has been estimated that the proximal segments of the hip and trunk contribute 50% of kinetic energy and force during dynamic overhead activities.7,8 As such, trunk stability during pitching is important not only for postural control but to also generate and transfer force from the lower extremity to the upper extremity.10 Previous modelling simulations have identified 10° of contralateral trunk lean (lean away from the throwing arm) as the ideal trunk position to minimize varus moments about the elbow at maximum shoulder external rotation.11 In support of this premise, Oyama and colleagues12 found that high school pitchers with excessive lateral trunk lean (>10°) away from the throwing arm, at maximum shoulder external rotation, exhibited increased varus moment at the elbow and glenohumeral internal rotation moment about the shoulder. Solomito et al.13 examined the relationship between the amount of lateral trunk lean and upper extremity forces in college pitchers, and found that increased varus moment at the elbow and glenohumeral internal rotation moment increased as trunk lean increased at maximum shoulder external rotation of the pitching motion. These increased moments are potentially dangerous and could lead to injury.

Given the importance of trunk stability to the biomechanics of pitching, identifying individuals who exhibit altered trunk motion during pitching is important. However, the highly dynamic nature of pitching makes it difficult for clinicians to visually identify altered trunk mechanics during pitching without sophisticated motion analysis equipment or high-speed cameras. As such, there is a need for a clinical test to screen for the potential for altered trunk motion in pitchers. Screening tests have previously been developed to identify movement deficits in lateral trunk lean in pitchers.12 Specifically, the single-leg squat (SLS) has been used as a screening test to assess trunk control, however it is unknown if trunk lean in the frontal plane found during the SLS will inform trunk stability during pitching.14 Clinical screening tests that may be suggestive of altered pitching mechanics may help to decrease upper extremity injury rates.

The purpose of the study was to determine if there was a relationship between the degree of lateral trunk lean during the SLS and the degree of the lean at maximum shoulder external rotation of the pitching motion. It was hypothesized that the degree of lateral trunk lean during the SLS would be positively correlated to the degree of lateral trunk lean at maximum shoulder external rotation of the pitching motion. The second aim of this study was to determine if lateral trunk lean during the SLS could predict lateral trunk lean during pitching. Understanding the relationship between the amount of trunk lean during the SLS and the amount of trunk lean during pitching may provide important information related to the ability of the SLS to detect altered trunk mechanics during pitching.

METHODS
Participants
This study was a cross-sectional design performed in a controlled laboratory environment. Participants were recruited from local recreational leagues and through the use of flyers. Seventy-three youth baseball pitchers (11.4 ± 1.7 years; 156.3 ± 11.9 cm; 50.5 ± 8.8 kg) volunteered for this study. The only inclusion criterion was that participants were free from any injury within the past six months. An injury was defined as missing at least one practice or game. The Auburn University Institutional Review Board approved this study. Prior to data collection, all testing procedures were explained to each participant as well as their parent(s)/legal guardian(s) and informed consent and participant assent was obtained. Participants were instructed to not throw 48-hours prior to arrival for testing.
An *a priori* power analysis was performed for a between group comparisons for independent groups. A sample size of 29 participants was needed to achieve 80% power to determine if a correlation coefficient differs from zero, with an effect size 0.77, and an alpha level of 0.05.

**Procedures**

The MotionMonitor™ (Innovative Sports Training, Chicago, IL, USA) synched with an electromagnetic tracking system (Track Star, Ascension Technologies Inc., Burlington, VT, USA) was used to collect kinematic data at 100 Hz. Kinematic sensors were attached to the following locations: [1] the posterior/medial aspect of the torso at T1, [2] posterior/medial aspect of the pelvis at S1, [3] distal/posterior aspect of the upper arm, [4] the flat, broad portion of the acromion of the scapula, [5] distal/posterior aspect of the forearm, [6-7] bilateral distal/posterior aspect of the thigh, [8-9] bilateral distal/posterior aspect of the lower leg, and [10] the mid-foot at the 3rd metatarsal of the non-throwing foot (Figure 1). Sensors were attached to the skin using PowerFlex cohesive tape (Andover Healthcare, Inc., Salisbury, MA, USA).

Following the application of the electromagnetic sensors, an additional sensor was attached to a stylus that was used to digitize bony landmarks to define segments of the trunk, humerus, forearm, and shank. Specifically, the medial and lateral aspect of each joint was identified and digitized and the mid-point of the two points was calculated to determine the joint center. A link segment model was then developed through digitization of bony landmarks used to estimate the joint centers for the knee, hip, shoulder, thoracic vertebrae 12 (T12) to lumbar vertebrae 1 (L1), and C7 to thoracic vertebrae 1 (T1). The trunk segment was defined as the digitized space between the T12 and L1 spinous processes, whereas the knee was defined as the midpoints of the digitized medial and lateral femoral condyles. The shoulder and hip joint centers were estimated using the least squares rotation method. First, the humerus and the femur were moved in small arcs while respectively maintaining no movement of the scapula and pelvis. Then the shoulder and hip joint centers were calculated as the point on the humerus and femur that moved the least according to a least-squares algorithm. The variation in the measurement of the joint center had to have a root mean square error of less than 0.001 m to be accepted.

The global coordinate system was defined with the y-axis vertical (upward direction), the x-axis was perpendicular to the y and z-axes and directed anterior/posterior (forward direction), and the z-axis was directed in the medial/lateral direction and orthogonal to the x and y-axes (towards the right). Raw data regarding sensor orientation and position were transformed to locally-based coordinate systems for each respective body segment. Euler angle decomposition sequences were used to describe both the position and orientation of the trunk following the International Society of Biomechanics standards. All segment axes systems were the same as the global coordinate system. The trunk segment was defined by the T1 and S1 sensors. The y-axis of the trunk was the line connecting the midpoint between the xiphod process and C7 vertebrae (positive direction upward). The z-axis of trunk was defined as the plane formed by the suprasternal notch, C7, and the midpoint between the xiphoid process and T8 vertebrae (positive direction towards the right). The x-axis was the common line perpendicular to the z and y-axes (positive direction anterior/forward). The Euler angle decomposition sequence for the trunk segment was ZXY with the second rotation trunk lean. Trunk lean was defined as movement in the frontal plane angular excursion of the thorax segment relative to the global reference frame (Figure 2).
SLS testing protocol. Participants performed the SLS task on the lead leg, which is the leg contralateral to the throwing arm during pitching. The lead leg was selected as the support leg in the SLS because weight is transferred to this leg as the pitching motion progresses. Participants were instructed to place their hands on their hips and squat as low as possible before returning to a full upright position. Participants performed one practice trial and then a subsequent SLS trial was recorded for analysis. Cadence during the SLS was self-selected and not controlled for in this study. The trunk position in the frontal plane at 45° of knee flexion was selected for analysis. Reliability for assessing lateral trunk lean during a SLS has been reported as excellent (ICC = 0.86). The standard error of measurement (SEM) for trunk lean was 1.5°, and the minimal detectable change (MDC) at 95% confidence interval was 4.2° for the SLS.

Pitching protocol. Participants were allotted an unlimited time to perform their individual warm-up routine to gain familiarity with pitching with the sensors. Once the participant's completed the warm-up, testing began. Kinematic data were collected during three accurate two-seam fastball pitches. All participants reported pitching two-seam fastballs frequently during games and were confident in performing this pitch in a laboratory environment. An accurate pitch was defined as a pitch passing through the strike zone and was determined by a trained investigator. Participants threw to a catcher from their age-regulated pitching distance (46ft/14.02m). The fastest accurate pitch was selected for analysis. The position of maximum shoulder external rotation was the discrete point of the pitch that was selected to measure trunk lean towards and away from the throwing arm (Figure 3a & 3b). This event of pitching motion represents the end of the cocking phase (lead foot contact to maximum external rotation). Maximum shoulder external rotation was selected because maximum trunk lean has been reported to occur at this event of the pitching motion. Excellent reliability has been established for two-dimensional video analysis of angular measures of lateral trunk lean in high school pitchers at maximum external rotation (ICC2,k = 0.90; SEM = 3.2°).

Statistical analyses were performed using SPSS software (version 22; SPSS Inc., Chicago, IL, USA), with an alpha level set a priori at p ≤ 0.05. A Pearson correlation coefficient was calculated to determine the relationship between trunk lean in the SLS and lateral trunk lean in pitching. A linear regression was performed to assess the predictive ability of lateral trunk lean during the SLS on lateral trunk lean during pitching. The dependent variable entered into the model was lateral trunk lean during the SLS, and the independent variable was trunk lean during pitching.

RESULTS

Negative lateral trunk lean values indicate lean away from the throwing arm. A significant positive correlation between trunk lean during the SLS and trunk lean during pitching was observed (r = 0.53; p < 0.001) (Figure 4). Mean lateral trunk lean during pitching was -17.1° ± 13.0° (away from the throwing arm) and -5.8° ± 10.4° during the SLS. Lateral trunk lean during pitching could be predicted from the
amount of lateral trunk lean in the SLS ($R^2 = 0.28$; $p < 0.001$). No missing data were present.

**DISCUSSION**

Screening tests have been developed to identify lower extremity/upper extremity movement impairments and potential injury risk.\textsuperscript{26,27} The current study sought to characterize the relationship between lateral trunk lean during the SLS and the amount of lateral trunk lean observed during pitching. The first hypothesis was confirmed as a significant positive correlation between lateral trunk lean

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Figure 3. Sagittal (A) and frontal (B) plane depiction of maximum shoulder external rotation of the pitching motion.

Figure 4. Relationship between SLS trunk lean and trunk lean during pitching. Negative values indicate lateral trunk lean away from the throwing arm.
during the SLS and lateral trunk lean during pitching was observed. The results of this study suggest that the SLS may be useful as a screening tool to identify greater degrees of lateral trunk lean during pitching.

During pitching, lateral trunk lean away from the throwing arm functions to position the shoulder in the proper arm slot (position of the shoulder relative to the trunk) in preparation for ball release. Lateral trunk lean increases as the pitching motion progresses from foot contact to maximum shoulder external rotation. In the current study, pitchers had an average -17.9° of lateral trunk lean away from the throwing arm during pitching. These results agree with Solomito et al. who reported -18° of lateral trunk lean away from the throwing arm at maximum shoulder external rotation in collegiate pitchers. The importance of identifying the relationship between lateral trunk lean and moments about the shoulder and elbow has been established in high school and collegiate pitchers. Increased lateral trunk lean away from the throwing arm can impact shoulder and elbow moments. Solomito et al. reported that for every 10° increase in trunk lean there was an increase in elbow varus moment of 3.7 Nm and a 2.5 Nm increase in glenohumeral internal rotation moment. While the current study did not examine the moments about the shoulder or elbow, the SLS may have potential value in identifying baseball pitchers who may exhibit increased lateral trunk lean and shoulder/elbow moments during pitching. The results of this study valuable for clinicians and coaches who work with youth pitchers to identify potential trunk kinematic deficits during pitching that can be targeted with individualized interventions through the use of a SLS screening test. For example, if a pitcher has excessive trunk lean during a SLS then they may have similar trunk lean during pitching which warrants an intervention program to correct.

Lateral trunk lean during the SLS explained 28% of the trunk lean observed in pitching. Therefore, other factors likely contributed to the degree of lateral trunk lean observed during pitching that were outside the scope of this current study. Maintaining trunk stability during dynamic movements is dependent on neuromuscular control and strength of the trunk and lower extremity musculature. Muscle performance deficits in lumbo-pelvic musculature may contribute to the lateral trunk lean that was observed during the SLS and pitching. Specifically, decreased strength of the gluteus medius and maximus may also affect the pitchers’ ability to maintain control a neutral trunk position however further research is needed to substantiate this theory. Popovich and Kulig have shown that females classified by weak hip muscle strength had significantly greater trunk lean during a single-leg landing task than participants classified as strong. Activation of the erector spinae, gluteus medius and maximus, external oblique, and rectus abdominis muscles was also significantly greater in individuals with weak hip musculature. The findings of Popovich and Kulig suggest that individuals with weak hip musculature may exhibit altered neuromotor control of the trunk to maintain stability during single-leg tasks. The implication of these results during a landing task should be applied with caution as similar results in baseball players performing a SLS have not been examined.

Decreased hip strength and control have been shown to result in increased hip adduction and knee valgus during single-leg tasks. In single-leg tasks individuals with weak hip abductors lean towards the stance limb to reduce the demand on the abductors. The lateral lean in the SLS and pitching may occur as a compensation strategy in pitchers with weak hip abductors. Compensations in trunk motion to maintain energy transfer during pitching may contribute to upper extremity injury rates. Chaudhari and colleagues reported that professional pitchers with poor lumbar-pelvic control, as measured during a single-leg balance task, were 2.2-3 times more likely to miss ≥ 30 days during the season due to injury. As such, lumbar-pelvic and lower extremity control may be important in reducing injury in baseball pitchers. The SLS test may prove to be an easy and beneficial way to screen for lumbo-pelvic instability and compensatory trunk motions in pitchers, however further work in this area is needed.

There are several limitations of this study that need to be considered when interpreting the results. This study only examined the role of trunk stability, in a single plane, and fastball kinematics in youth pitchers. The results of this study may only
be generalizable to youth pitchers from a selected area of the country. Other factors such as knee valgus, hip abduction, pelvic drop, or pelvic and trunk rotation also may differentiate pitchers with altered trunk stability. This study did not measure strength of the lumbar or gluteal muscles and thus, the generalizations being made as to why the trunk lean occurred are purely speculation at this time. The relationship between trunk deficits and shoulder injuries were not examined because no pitchers in this sample reported a history of upper extremity injury. The next step of this work is to track injuries during the season and examine the relationship between trunk stability and upper extremity injury. Future research should aim to characterize the risk of poor trunk stability on upper extremity injury. Other potential contributing factors should also be considered, such as muscular performance impairments and range of motion deficits at the shoulder that can enable a comprehensive characterization of risk of injury.

**CONCLUSION**

The results of the current study indicate that pitchers with trunk lean during the SLS screening test have greater trunk lean during pitching. Increased lateral trunk lean has previously been reported to result in increased moments at the shoulder and elbow that may contribute to injury. Lateral trunk lean during the SLS is similar in magnitude to the amount of lean in pitching. Implementing the SLS may allow clinicians to identify pitchers with increased lateral trunk lean during pitching without performing a three-dimensional motion analysis of their pitching mechanics. Identifying pitchers with trunk deficits can enable the targeting of prevention programs of those modifiable impairments associated with these trunk deficits and to reduce the torque about the elbow and decrease the risk of injury.

**REFERENCES**


ABSTRACT

Background: Reduced lower extremity muscle strength as well as reduced lower extremity muscle pre-activity (defined as muscular activity just prior to initial ground contact) during high-risk movements are factors related to increased risk of non-contact ACL injury in adolescent female athletes. A strong relationship exists between muscle strength and muscle activity obtained during an isometric contraction, however, whether these two measures are related when muscle activity is obtained during a movement associated with a high risk of non-contact ACL injury is not known. Absence or presence of such a relationship may have implications for which training modalities to choose in the prevention of ACL injuries.

Purpose: The purpose of this study was to examine the relationship between maximal muscle strength of the hip extensors, hip abductors and knee flexors and the pre-activity of these muscle groups recorded during a sidecutting maneuver (high-risk movement) in adolescent female soccer and handball athletes.

Study design: Cross-sectional study.

Methods: Eighty-five adolescent (age 16.9±1.2 years) female elite handball and soccer athletes were assessed for maximal hip extensor, hip abductor and knee flexor muscle strength; and muscle pre-activity (electromyography recordings over a 10 ms time interval prior to foot ground contact) of the gluteus maximus (Gmax), gluteus medius (Gmed), biceps femoris (BF) and semitendinosus (ST) during a standardized sidecutting maneuver.

Results: The results of the correlation analyses demonstrated poor and statistically non-significant correlations. Maximal hip extensor force (N/kg bw) and Gmax pre-activity \( r_s = 0.012 \) (95% CI -0.202 – 0.224), \( p = 0.91 \), maximal hip abductor force (N/kg bw) and Gmed pre-activity \( r_s = 0.171 \) (95% CI -0.044 – 0.371), \( p = 0.11 \), maximal knee flexor force (N/kg bw) and BF pre-activity \( r_s = 0.049 \) (95% CI -0.166 – 0.259), \( p = 0.65 \), and maximal knee flexor force and ST pre-activity \( r_s = 0.085 \) (95% CI -0.131 – 0.293), \( p = 0.44 \).

Conclusion: In the present exploratory study, the results imply that no relationship exists between maximal lower extremity isometric muscle strength and lower extremity muscle pre-activity during sidecutting. This means that athletes with low muscle strength may not necessarily demonstrate high (or low) muscle pre-activity during sidecutting - a well-known risk movement for sustaining non-contact ACL injury.

Levels of evidence: Level 3

Key words: Anterior cruciate ligament, electromyography, muscle strength, neuromuscular activity
INTRODUCTION
The incidence rate (81-85 per 100,000)\(^1\) of non-contact anterior cruciate ligament (ACL) injuries is a major problem in sports. In the prevention of non-contact ACL injuries, the role of lower extremity muscle strength has been discussed extensively\(^{1-4}\) and research suggests that reduced isolated lower extremity muscle strength is related to an increased risk of non-contact ACL injury in healthy competitive athletes.\(^{5,6}\)

In a typical non-contact ACL injury situation (sidecutting),\(^{7,8}\) Bencke and colleagues found that the peak external hip-abduction, inward rotation and extension moments coincided with the peak external knee-valgus and outward rotation moment 30-40 milliseconds (ms) after landing in adolescent female handball players,\(^9\) all of which are factors known to predispose for non-contact ACL injury.\(^{10,11}\) These findings underline the importance of high dynamic restraint capacity of the hip extensors, hip abductors and knee flexors in the very initial phase of ground contact during sidecutting, in order to counter the stress forces generated in the ACL. To adequately counter these external forces early after foot ground contact during sidecutting, the hip extensors, hip abductors and knee flexors need to be pre-activated in relation to foot ground contact due to the latency of mechanosensory feedback reflexes (\(>75-100\) ms).\(^{12}\) A potential imbalance between external forces and internal counter-acting muscle force output may partly explain why non-contact ACL injury also is observed in the very initial time window i.e. \(<40\) ms after foot-strike.\(^{8,13}\) During a high risk ACL injury movement such as sidecutting where numerous lower limb muscles are active at the same time, electromyography (EMG) can be used to measure neuromuscular activity and provide a proxy measure of muscle force output.\(^{14-16}\) Based on this method, Zebis and colleagues previously reported that the combination of high quadriceps pre-activity along with low medial hamstring pre-activity during sidecutting was a risk factor for sustaining non-contact ACL injury in female athletes.\(^{17}\)

Reduced muscle strength and reduced muscle pre-activity are both modifiable risk factors for non-contact ACL injury, which can be targeted by specific training interventions.\(^{18-24}\) Their relationship, however, is currently unknown. As EMG activity provides a proxy measure of muscle force output during movements, the question is if, or how, the two risk factors – i.e. lower extremity muscle strength and neuromuscular pre-activity during sidecutting\(^{17}\) – are related. Three plausible scenarios exist, each with different consequences for the optimal design of injury prevention exercises: 1) High muscle strength down-regulates the amount of pre-activity (less pre-activity is needed to produce the same force output),\(^{18}\) - or low muscle strength up-regulates the amount pre-activity since more pre-activity is needed to produce the same force output (inverse relationship), implying that the two potential risk factors should be targeted by different training programs; 2) High muscle strength increases neuromuscular coordination by up-regulating pre-activity and thereby increasing the force output (positively related) as seen in static force testing,\(^{25}\) implying that strength training alone may target both potential risk factors concurrently; 3) No relationship exist between the two potential ACL injury risk factors, which imply that low muscle strength and low muscle pre-activity during high-risk movements should be independently targeted by distinct training programs.

While the hip extensors, hip abductors and knee flexors, also referred to as the posterior kinetic muscle chain, seem important for preventing non-contact ACL injuries,\(^3\) the present study intended to examine if maximal isometric muscle strength in the hip extensors, hip abductors and knee flexors are related to the amount of pre-activity of these muscle groups during a high-risk movement such as the sidecutting manoeuvre.

The purpose of this study was to examine the relationship between maximal muscle strength of the hip extensors, hip abductors and knee flexors and the pre-activity of these muscle groups recorded during a sidecutting maneuver (high-risk movement) in adolescent female soccer and handball athletes.

MATERIALS AND METHODS
Study design and participants
This exploratory study is an embedded part of an ongoing prospective parent cohort study designed to screen Danish adolescent (age range 14-19 years) female soccer and handball athletes for ACL risk.
factors (unpublished). The reporting of the study follows the STROBE 2007 statement (Strengthening the Reporting of Observational Studies in Epidemiology).26 Previously, Husted and colleagues reported the association of hamstring and quadriceps pre-activity between different ACL risk screening tests from the same cohort.27

Participants were recruited through collaboration with the Danish Soccer Association (DBU) and the Danish Handball Association (DHF). Participants who met the following criteria were included in the study: 1) selected for the national youth team in their respective sports (handball or soccer) and 2) physically fit to participate in a full competitive game or match. Participants were excluded if they were injured at the time of inclusion precluding them from performing the test protocol. Before the test in the motion analysis laboratory, all study participants went through a structured interview to assess number and severity of lower limb injuries sustained in the prior 12 months (anatomical region, cause of injury, type of injury, time away from sport due to injury), total duration of sports participation (playing experience) and on the involvement in systematic resistance training (>2 sessions/week). Data collection took place between November 2010 and December 2011.

Eighty-five adolescent female elite handball (52) and soccer (33) athletes with 10.2 (± 2.5) years of experience with their sport were recruited for the study (age 16.9±1.2 years; height 172.3±6.7 cm; weight 66.3±8.2 kg) (Table 1). All participants and their parents were informed about the purpose and content of the project, and all parents gave written informed consent for their child to participate in the study in accordance with The Declaration of Helsinki. The study was approved by the local Ethics Committee in the Capital Region of Denmark (H-2-2010-091).

**Test procedures**

Following a structured interview, the following test procedures were performed: 1) measurement of anthropometric data (age, height, weight and determination of dominant leg), 2) EMG-electrode placement on selected muscles, 3) warm-up following a standardized protocol, 4) MVC procedure measuring maximal isometric hip extensor, hip abductor and knee flexor strength and corresponding EMG activity, and 5) the sidecutting test maneuver.

Using procedures described in detail in previous reports9,10,27 participants were tested in a 3D motion analysis laboratory to assess lower limb muscle activity in selected muscles (Gluteus maximus (Gmax), Gluteus medius (Gmed), long head of the Biceps Femoris (BF) and Semitendinosus (ST)) during a standardized sidecutting maneuver (SC) (additional details given below) using synchronous surface EMG recording. Muscle activity was also recorded during maximal voluntary (isometric) contractions (MVC) for the respective muscles. In brief, maximal isometric hip extensor, hip abductor and knee flexor muscle strength were measured using a handheld dynamometer (details given below). Muscle strength and pre-activity testing was performed on the take-off/stance leg, defined as the leg contralateral to the preferred kicking leg or throwing arm.19

**EMG recording**

Neuromuscular activity was sampled at 1000 Hz using bipolar surface EMG-electrodes with 1.0 cm inter-electrode distance and built-in preamplifiers (Delsys DE-2.3 sEMG sensor; CMRR >80 dB).18,27 The skin was shaved to remove hair and dead skin cells and cleaned with ethanol to ensure minimal skin impedance.25 Subsequently, the EMG-electrodes were placed along the length of the fibers of the Gmax, Gmed, BF and ST muscles. To reduce noise contamination from external electric sources a reference electrode was placed on the anterior tibial crest.25 To ensure reliable EMG-electrode placement between days and testers the guidelines described by Perotto et al. were used.28 Bipolar EMG-recordings from lower extremity muscles during both isometric muscle contractions and ballistic movements have previously been found reliable.19,20

<table>
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<th>Table 1. Participant characteristics (n = 85).</th>
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Warm-up procedure
Before measuring maximal voluntary contraction strength all participants went through a standardized warm-up procedure consisting of ten submaximal vertical jumps, ten one-leg squats on each leg, ten medium vertical jumps (80% self-rated effort), ten lunges on each leg and finally ten maximal vertical countermovement jumps (100% self-rated effort).

Maximum voluntary contraction (MVC)
Maximal voluntary isometric muscle strength was measured using a portable hand-held dynamometer (PowerTrack II Commander, JTECH Medical, Salt Lake City, Utah, USA) according to procedures described elsewhere.30-32 In each trial the participants had four seconds to reach maximum isometric force production (i.e. hip extension, hip abduction and knee flexion). The participants performed three MVC trials for each muscle group separated by 30 seconds of rest to avoid fatigue, receiving strong verbal encouragement. The trial with highest (maximum) isometric force production for each muscle group was selected for later analysis.30 Maximal hip extensor, hip abductor and knee flexor muscle forces were normalized to body weight (N/kg bw).

Knee flexor muscle force: Maximal isometric knee flexor force was obtained with the participant lying prone on an examination table, the foot and ankle free of the edge of the couch, the knee in 10° flexion, a handheld dynamometer placed 5 cm proximal from the medial malleolus, a strap (attached to the floor) wrapped around the ankle and the dynamometer and then performing a maximal isometric knee flexion (Figure 1 A).31,32 Prior to each MVC trial it was ensured that the dynamometer was not registering any tension and that the leg was held closely against the strap to avoid any initial acceleration impact against the dynamometer.

Figure 1. Muscle force (N) was measured with a handheld dynamometer and muscle activity was measured using bipolar surface EMG recording. A. Maximal isometric knee flexor force, B. Maximal isometric hip abductor force, C. Maximal isometric hip extensor force, D. Side cutting maneuver in the 3D motion analysis laboratory. The left foot is placed on the force plate.
Hip abductor muscle force: Maximal hip abductor force was obtained with the participant supine on the examination couch, the test leg lifted 1 cm above the surface of the couch and 20° of hip abduction. In this position the dynamometer was positioned against the lateral side of the lower leg 5 cm proximal from the medial malleolus and a maximal isometric hip abduction trial was performed against the researcher (Figure 1 B).30,31

Hip extensor muscle force: Maximal hip extensor force was obtained using a set-up similar to that of knee flexor MVC testing except that the knee joint was fully extended and the instruction was to maximally extend the hip and not flex the knee (Figure 1 C).30,31

Sidecutting (SC)
As described in detail previously 18,27 the participants started five meters in front of an instrumented force plate and were instructed to perform the SC maneuver as fast and powerfully as possible to simulate an in-game situation (Figure 1 D). To best simulate a match situation neither cutting angle nor run-in speed was standardized. To ensure that the participants were able to move freely during the SC test all the EMG-electrodes were connected to a wireless transmitter placed on the participants back. The test was repeated until three approved SC trials were captured. The mean of the recorded EMG-signal amplitudes from the three approved SC trials was calculated for each muscle, respectively, for later analysis.18,27

EMG signal processing
For each muscle (Gmax, Gmed, BF and ST) all EMG recordings were high-pass filtered using 4th order zero-lag Butterworth filter and subsequently smoothed using a root-mean-squared (RMS) filter (30-ms symmetrical moving window with successive 1-ms steps). EMG-signal amplitudes recorded from the three SC trials of each participant were normalized to the maximum RMS EMG amplitude recorded during MVC testing of the respective muscles (i.e. hip extensor, hip abductor and knee flexor). Neuromuscular pre-activity during the SC maneuver thus refers to the mean normalized RMS EMG amplitude measured in the 10-ms time interval immediately preceding initial foot contact (time = 0) (Figure 2).17,16,27

Details of the EMG signal processing procedure have been described in detail elsewhere.27

Figure 2. The mean RMS EMG amplitude during the 10-ms time interval prior to initial contact (dotted red lines) was calculated for the Gmax, Gmed, BF and ST muscles and normalized to the peak EMG amplitude obtained during MVC of the respective muscles examined.
The Shapiro Wilk test was used to test for normal distribution of all obtained data. The EMG data were not normally distributed; consequently, it was decided to use non-parametric statistics and to present data as medians with corresponding 10th-90th percentile ranges. Accordingly the non-parametric Spearman’s Rho Correlation test (rs) was used to test the relationship between the maximal isometric hip extensor, hip abductor and knee flexor muscle force (N/kg bw) versus Gmax, Gmed, BF and ST muscle pre-activity. The following values were used to characterize the strength of correlation, 0.00-0.25 (no or poor relationship), 0.25-0.50 (low-to-moderate relationship), 0.50-0.75 (moderate-to-strong relationship) and above 0.75 (strong-to-excellent relationship).33 Level of significance was set at 0.05 (two-tailed testing). All statistical analyses were performed using Stata 11.2. No sample size estimation was conducted due to the explorative design of the study.

### RESULTS
Maximal isometric hip extensor, hip abductor and knee flexor force output in absolute (N), body mass normalized to terms (N/kg bw) and Gmax, Gmed, BF and ST pre-activity recorded during the sidecutting maneuver, are presented in Table 2.

The results of the correlation analyses demonstrated poor and statistically non-significant correlations. Maximal hip extensor force (N/kg bw) and Gmax pre-activity \( r_s = 0.012 \) (95% CI -0.202 – 0.224), \( p = 0.91 \), maximal hip abductor force (N/kg bw) and Gmed pre-activity \( r_s = 0.171 \) (95% CI -0.044 – 0.371), \( p = 0.11 \), maximal knee flexor force (N/kg bw) and BF pre-activity \( r_s = 0.049 \) (95% CI -0.166 – 0.259), \( p = 0.65 \), and maximal knee flexor force and ST pre-activity \( r_s = 0.085 \) (95% CI -0.131 – 0.293), \( p = 0.44 \) (Table 3).

### DISCUSSION
The results of the present study did not identify any systematic relationship between the maximal...
isometric muscle strength of the hip extensors, hip abductors and knee flexors and the pre-activity of these muscles recorded during a standardized sidecutting maneuver.

The cause of non-contact ACL injury is considered to be multifactorial with both lower extremity muscle strength and muscle pre-activity suggested as contributing factors.\textsuperscript{2,5,6,17} Interestingly, the results of the present study show no relationship between these two factors (muscle strength and pre-activity); suggesting that high muscle strength not necessarily is accompanied by high muscle pre-activity during standardized sidecutting maneuver or vice versa in adolescent female handball and soccer elite athletes.

With regard to the prevention of ACL injuries, recent systematic reviews have suggested that neuromuscular training (NMT) is effective for preventing lower limb injuries, i.e. reducing the incidence of non-contact ACL injuries.\textsuperscript{34-36} The concept of NMT involves multiple exercise options including muscle strengthening, balance/coordination, plyometric, and core exercises, altogether aiming at increasing muscle strength, improving postural balance control and muscle coordination during high-risk movement conditions related to non-contact ACL injury.\textsuperscript{34-36}

Interestingly, in a recent study Moeller and colleagues found that strength training was reported to be carried out more often in weekly training than ‘balance training’ and/or ‘specific jump training’ (i.e. 2-5 times a week vs. 1-2 times a week, respectively) among adolescent and senior elite handball players.\textsuperscript{37} The adolescent athletes examined in the present study are highly comparable to the athletes recruited by Moller and colleagues in terms of gender, age, type of sport, experience with their sport and time spent on resistance training (Table 1). While it is well established that strength training increases muscle strength via both increased neural drive to the muscles and gains in muscle cross-sectional area,\textsuperscript{21,23,24} the present data indicate no relationship between maximal muscle strength and the pattern of pre-landing neuromuscular motor activity during a sidecutting manoeuvre. Speculatively, this suggests that, strength gains from e.g. resistance training may not necessarily result in adopting a certain type of pre-activity motor pattern, probably unless combined with other NMT modalities. Conversely, significant motor pattern re-modelling has been suggested to occur in response to NMT involving balance/coordination exercises, specific jump training and strength training.\textsuperscript{18-20}

Although recent meta-analyses emphasize the importance of including all types of NMT modalities in the prevention of non-contact ACL injuries,\textsuperscript{38,39} a possible explanation why resistance training may be prioritized higher than the other modalities of the NMT concept could be that besides increasing muscle strength, resistance training is also documented to improve athletic performance ability e.g. making subjects jump higher or run faster.\textsuperscript{40,41} Interestingly, in this context, studies have found that plyometric exercises\textsuperscript{42} and balance/coordination exercises\textsuperscript{19,43} have shown similar improvements in functional performance (e.g. comparable gains in maximal vertical jump height), suggesting some transfer effect from these other exercises modalities of the NMT concept onto athletic performance gains.

To describe the distribution of athletes with high or low muscle force and high or low muscle pre-activity during the standardized side-cutting manoeuvre a subsequent analysis was performed by dividing the plots from the correlation analyses into four median frames (A: low muscle force and high muscle pre-activity, B: high muscle force and high muscle pre-activity, C: low muscle force and low muscle pre-activity, D: high muscle force and low muscle pre-activity), e.g. maximal knee flexor force normalized to body weight and normalized ST pre-activity (Figure 3, Figures for remaining muscles can be found in supplementary online material). This distribution divided the athletes into four subgroups for analysis. This supplemental analysis shows a similar distribution of participants in the four median subgroups (A-D) for all investigated muscles (Table 4). Thus, there appear to be no tendency towards athletes clustering more in one median subgroup compared to the others. However, this analysis highlights one particular subgroup (Figure 3 C), namely athletes with both low muscle force and low muscle pre-activity representing a high total sum of risk factors.\textsuperscript{5,6,17} Thus, based on previous observations, the present study participants identified in median subgroup C may be expected to be at higher risk
of sustaining non-contact ACL injury compared to their fellow athletes (especially athletes in subgroup B: high muscle force and high muscle pre-activity) as they are found to have both risk factors (low muscle force and low muscle pre-activity), underlining the importance of initiating specialized and targeted NMT among this specific subpopulation of presumed high-risk athletes.

Not only the present observations (no relationship exists between maximal lower extremity isometric muscle strength and lower extremity muscle pre-activity during sidecutting) but also the fact that plyometric and balance/coordination exercises seem poorly integrated in daily training among adolescent female athletes seems alarming bearing in mind the high risk of non-contact ACL injury in this particular population.\textsuperscript{1,44-47} Future preventive efforts should focus on implementing all types of NMT in the daily training routines, i.e. exercise programs featuring training drills that target muscle strength, plyometric, balance/coordination, and core exercises.

**LIMITATIONS**

The present study participants were not asked to which extent they performed various sub-types (balance/coordination, plyometric and core exercise) of NMT exercises. However, the participants in the present study were highly comparable to those recruited by Moller and coworkers in regard to age, gender, sport, level of competition and resistance training background.\textsuperscript{37}

There are some limitations to the MVC assessments. Isometric MVC assessments cannot provide specific information on individual muscle force contributions. Assessing muscle force with a handheld dynamometer provides the muscle force produced in the assessed movement direction not the muscle force produced by specific muscles. E.g. when assessing hip abductor force, the prime mover is the gluteus medius, however, other hip abductor muscles contribute as well. When assessing hip extensor force, contralateral hip flexor activation may have added to the force output. This could overestimate the recorded muscle force output. Also, isometric MCV assessments may not be representative of muscle activity during dynamic muscle actions.

Because only isometric muscle force was measured, a limitation to the current study is the lack of data on the rate of force development (RFD) during the respective muscle contractions. This could potentially have provided an important input to

<table>
<thead>
<tr>
<th>Table 4. Supplemental analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Athlete distribution in four median subgroups</td>
</tr>
<tr>
<td>Gmax pre-activity and hip extensor force median, n (%)</td>
</tr>
<tr>
<td>Gmed pre-activity and hip abductor force median, n (%)</td>
</tr>
<tr>
<td>BF pre-activity and knee flexor force median, n (%)</td>
</tr>
<tr>
<td>ST pre-activity and knee flexor force median, n (%)</td>
</tr>
</tbody>
</table>

Gmax = gluteus maximus, Gmed = gluteus medius, BF = biceps femoris, ST = semitendinosus. Total n = 85. A = Low muscle force, High muscle pre-activity. B = High muscle force, High muscle pre-activity. C = Low muscle force, Low muscle pre-activity. D = High muscle force, Low muscle pre-activity. Median subgroups were determined by the median value of the two variables in the correlation analysis (isometric muscle strength and muscle pre-activity).
the present analysis, as RFD assessment previously have added further perspective on the aspect of non-contact ACL injury in female soccer athletes.46

CONCLUSIONS
In the present exploratory study, the results imply that no relationship exists between maximal lower extremity isometric muscle strength and lower extremity muscle pre-activity during sidecutting. This means that athletes with low muscle strength may not necessarily demonstrate high (or low) muscle pre-activity during sidecutting - a well-known risk movement for sustaining non-contact ACL injury.

REFERENCES


Supplementary File 1. Scatterplot of correlation between maximum knee flexor force normalized to body weight (N/kg bw) and m. biceps femoris pre-activity with median lines dividing the scatterplot into four frames; A = Low muscle force, High muscle pre-activity. B = High muscle force, High muscle pre-activity. C = Low muscle force, Low muscle pre-activity. D = High muscle force, Low muscle pre-activity.

Supplementary File 2. Scatterplot of correlation between maximum hip extensor force normalized to body weight (N/kg bw) and m. gluteus maximus pre-activity with median lines dividing the scatterplot into four frames; A = Low muscle force, High muscle pre-activity. B = High muscle force, High muscle pre-activity. C = Low muscle force, Low muscle pre-activity. D = High muscle force, Low muscle pre-activity.

Supplementary File 3. Scatterplot of correlation between maximum hip abductor force normalized to body weight (N/kg bw) and m. gluteus medius pre-activity with median lines dividing the scatterplot into four frames; A = Low muscle force, High muscle pre-activity. B = High muscle force, High muscle pre-activity. C = Low muscle force, Low muscle pre-activity. D = High muscle force, Low muscle pre-activity.
ABSTRACT

**Background:** The lateral step-down test is an established clinical evaluation tool to assess quality of movement in patients with knee disorders. However, this test has not been investigated in individuals after anterior cruciate ligament reconstruction (ACLR) in association with quantitative 3D motion analysis.

**Purposes:** The purpose of this study was to determine the strength of association between visually-assessed quality of movement during the lateral step-down test and 3D lower limb kinematics in patients with history of ACLR. A second purpose was to compare kinematics between subgroups based on the presence or absence of faulty alignments during the task. The final purpose was to compare visually-assessed quality of movement scores between box heights during lateral step-down testing.

**Methods:** Twenty subjects at least one year status post-ACLR (18 females, age of 24.5 ± 4.6 years and body mass index of 23.4 ± 2.3 kg/m²) performed the lateral step-down test unilaterally on the surgical limb atop four and six inch boxes. A board-certified orthopedic physical therapist scored overall quality of movement during the lateral step-down test using established criteria during 2D video playback. Lower limb kinematics were simultaneously collected using 3D motion capture. An alpha level of 0.05 was used for all statistical treatments.

**Results:** Overall 2D quality of movement score significantly correlated (r = 0.47-0.57) with 3D hip adduction and hip internal rotation across box heights. Across box heights, the presence of faulty pelvic alignment differentiated a subgroup exhibiting less peak knee flexion, and the presence of faulty knee alignment differentiated a subgroup exhibiting greater peak hip adduction. The six inch box elicited worse quality of movement compared to the four inch box.

**Conclusions:** These results suggest that visually-assessed quality of movement is associated with several kinematic variables after ACLR. 2D movement deviations at the pelvis appear to consistently relate to less knee flexion, and 2D deviations at the knee appear to suggest greater hip adduction. Generally, poorer quality of movement was observed for the six inch box height. Clinically, these data suggest that interventions targeting hip abductor and knee extensor strength and neuromuscular control may be useful in the presence of poor quality of movement during lateral step-down testing.

**Level of Evidence:** 2b

**Key words:** Anterior cruciate ligament reconstruction, lateral step-down test, movement, 2D motion analysis, 3D motion analysis
INTRODUCTION
Anterior cruciate ligament reconstruction (ACLR) is the predominant standard of care for a ruptured ACL in the United States. The incidence of ACLR increased from 86,687 patients in 1994 to 129,836 patients by 2006.1 The incidence rate for secondary ACL injury has been shown to be six times greater than for primary injury.2 Movement patterns in these individuals remain abnormal years after ACLR.3 Perhaps of greatest concern, a three-fold increased risk of developing knee osteoarthritis has been shown in the ACLR knee compared to the contralateral knee 14-years post-surgery.4 Based on these data, contemporary rehabilitation practices likely remain suboptimal. As a component of the rehabilitative process, clinical evaluation tools capable of assessing quality of movement after ACLR merit further exploration.

The lateral step-down (LSD) test is a well-established clinical assessment of lower extremity quality of movement.5-16 This test aims to identify faulty movements at the trunk, pelvis and knee during a step-down maneuver off a box. Several rating systems have been adapted for visually scoring the LSD test.5,6,8 Rabin et al. used a modified version13 of previously established criteria5 and yielded excellent inter-rater reliability for visually assessing quality of movement in patients with patellofemoral pain syndrome. It has been reported that quality of movement scores may be affected by decreased ankle dorsiflexion range of motion.14

Associations between visually-assessed quality of movement using the LSD test and findings from an objective measure are relevant in establishing clinical usability of this test. Jones and colleagues11 revealed observational ratings of frontal plane knee position during the LSD test using 2D video were related to the frontal plane projection angle. Rabin et al.16 showed that faulty pelvis and knee alignments during the LSD test were associated with greater peak knee external rotation, contralateral pelvic drop, and hip adduction during 3D motion capture. However, these studies were conducted on healthy individuals, and it is unclear how visually-assessed quality of movement relates to 3D movement in the ACLR population.

Therefore, the purpose of this study was to determine the strength of association between visually-assessed quality of movement during the lateral step-down test and 3D lower limb kinematics in patients with history of ACLR. A second purpose was to compare kinematics between subgroups based on the presence or absence of faulty alignments during the task. The final purpose was to compare visually-assessed quality of movement scores between box heights during lateral step-down testing.

METHODS
Subjects
Twenty individuals between the ages 18-40 with a history of unilateral ACL reconstruction at least one year prior were recruited from a university setting via electronic and paper advertisements. All subjects completed formal rehabilitation and had been cleared by a physician for return to sport if an athlete. Subjects with any other recent (six months) or current spinal or lower extremity pathology were excluded. This study was approved by the university Institutional Review Board and written informed consent was obtained for all subjects. Height was then measured using a stadiometer upon arrival to the laboratory environment.

Ankle Dorsiflexion Range of Motion
Weight-bearing ankle dorsiflexion range of motion was measured using a lunge test as previously described and found to be highly reliable.12 In brief, a 1 m piece of tape was fixed on the floor perpendicular to a wall. Subjects stood in bare feet while the researcher placed a black sticker 15 cm distal to the tibial tuberosity. Next, subjects faced the wall and positioned the test foot such that the second toe and heel lay directly over the tape. Subjects then placed the palms of their hands against the wall in front of them and were instructed to lunge as far forward as possible without lifting the heel of the test foot off the ground. The researcher then positioned a smartphone running a digital inclinometer application (iHandy Level, iHandySoft Inc, NY, USA) over the tibial sticker and dorsiflexion range of motion was recorded. Use of this particular inclinometer application has been found to have good intra-rater and inter-rater reliability for spinal measures (ICC > 0.80).17 Three measures were recorded and averaged for the test limb.
Motion Capture Preparation
An eight-camera motion capture system (VICON, Centennial, CO, USA) was used to collect kinematic data (150 Hz). In preparation for motion capture, 47 reflective markers were placed on the subject’s bilateral lower extremities and pelvis: L5-S1 interspinous space, iliac crests, anterior superior iliac spines, greater trochanters, medial and lateral femoral condyles, medial and lateral tibial plateaus, medial and lateral malleoli, first and fifth metatarsal heads, the proximal, distal and lateral heels. Four rigid clusters of four tracking markers were placed bilaterally on the distal posterolateral thighs and shanks. Static standing and functional hip motion trials were captured to later build and define segment coordinate systems for the pelvis, thighs, shanks and feet.

Lateral Step-down Test
The LSD test was conducted according to the procedure used by Piva and colleagues. Subjects performed the test unilaterally on both a four and six inch box. The two conditions were tested in random order. Prior to the first condition, the investigator demonstrated the LSD maneuver. Subjects were instructed to place hands on their hips and stand with the test limb on the edge of the box. The contralateral limb hung off the side of the box with the knee in full extension and foot fully dorsiflexed. To initiate the movement, subjects were instructed to bend the test limb and lower themselves until the contralateral heel tapped a floor-level force plate (BERTEC Corp., Worthington, OH, USA) and return to the starting position. The force data were captured (1500 Hz) to confirm heel touch on each repetition. Subjects were allowed to practice the LSD for familiarization prior to each condition as needed. Six continuous repetitions were performed for each condition at a self-selected pace, with the middle four repetitions extracted for analysis. Two minute rest periods between conditions were used.

Data Processing
Marker trajectories were labelled and gap-filled in Vicon Nexus. Trials were then exported in c3d file format and post-processed using Visual 3D (C-motion, Bethesda, MD, USA) software. Angle data were derived using an X (flexion/extension) -Y (adduction/abduction) -Z (internal/external rotation) Cardan rotation sequence. Kinematic variables of interest included frontal, sagittal, and transverse plane peak hip and knee joint angles, as well as peak ankle dorsiflexion, and peak contralateral pelvic drop. Custom software was used to extract the discrete variables from the data (Labview 2010, National Instruments, Austin, TX, USA).

2D Digital Video Assessment
The LSD test was video recorded at 30 Hz using the camera from an iPhone 5c (Apple Inc., Cupertino, CA, USA). The camera was mounted on a tripod positioned 3 m in front of the subject at a height of 31 inches and in portrait orientation. Quality of movement was scored using a modified version of previously established criteria assessing five aspects of the movement: arm strategy, trunk alignment, pelvis plane, knee position, and steady stance. Each aspect of the movement was individually scored. A score of 0 was given if the aspect of movement was deemed “not faulty”. A score of 1 was given if movement deviations occurred, deeming the aspect of movement as “faulty”. Movement deviations included: hand removed from waist, trunk leaning in any direction, contralateral pelvic drop or rotation, or wavering on tested limb and/or stepping down on non-tested limb. For knee position, subjects received a score of 1 if the tibial tuberosity was medial to the second toe and 2 if the tibial tuberosity was medial to the entire medial border of the foot (Figure 1). The possible range in aggregate score was 0 to 6. A physical therapist with board certification as an orthopedic clinical specialist rated both LSD conditions.

Self-report questionnaires
Each subject completed the International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, Tegner Activity Scale (TAS), and an intake form. In patients with various knee disorders, the IKDC has been found to be a valid and reliable questionnaire to assess knee symptoms, function, and sports activity. The TAS is an activity rating system with established reliability, validity, and responsiveness for individuals with ACL injuries. The intake form gathered further descriptive information including limb dominance, graft type, surgical and rehabilitation history, age, and sex.
Statistical Analysis
Associations between the aggregate score for quality of movement and the target kinematic variables were assessed using Spearman’s rank correlation coefficients. Separate Mann-Whitney U tests were used to compare each kinematic variable by groups determined by the observational ratings for the pelvis and knee. Paired t-tests were used to determine differences in the kinematic variables between the two box heights. A Wilcoxon Signed Ranks test was used to compare the number of movement deviations exhibited between box heights. An alpha level of 0.05 was used for all tests. Data were analyzed using SPSS 23.0 (IBM Corp, Armonk, NY, USA).

RESULTS
Subjects
Descriptive data are presented in Table 1. Weight bearing ankle dorsiflexion range of motion was consistent with previously reported means for healthy individuals with at least a score of 2 on the Piva criteria. The average time since surgery was nearly five years. Average current activity level represented participation in recreational or competitive sports at least five times per week.

Spearman’s Correlations
Spearman’s correlations between overall quality of movement score and kinematic variables are displayed in Table 2. Positive correlations between visually-assessed quality of movement and peak hip adduction and internal rotation were seen during performances on both the four and six inch box. Additionally, correlations were seen between overall quality of movement and contralateral pelvic drop, peak knee flexion, abduction, and internal rotation only on the four inch box.

Kinematics by Knee Position Score(s)
Kinematic variables among individuals with “not faulty” and “faulty” knee positions are displayed in Table 3. A knee position score of 1 did not differentiate any kinematic variables for either box height. A knee position score of 2 differentiated greater peak
Table 1. Subject demographics (mean ± standard deviation).

<table>
<thead>
<tr>
<th>Sex</th>
<th>18 females; 2 males</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>24.55 ± 4.61</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.71 ± 0.08</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>68.35 ± 9.73</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>23.36 ± 2.32</td>
</tr>
<tr>
<td>Ankle dorsiflexion range of motion (degrees)</td>
<td>47.48 ± 6.84</td>
</tr>
<tr>
<td>Time since surgery (months)</td>
<td>56.80 ± 38.20</td>
</tr>
<tr>
<td>International Knee Documentation Committee score</td>
<td>83.16 ± 7.22</td>
</tr>
<tr>
<td>Tegner Activity Scale score</td>
<td>6.90 ± 1.94</td>
</tr>
</tbody>
</table>

Table 2. Spearman's correlations between overall quality of movement score and kinematic variables for the pelvis, hip, and knee at different box heights.

<table>
<thead>
<tr>
<th>Kinematic variables</th>
<th>4-inch box</th>
<th>6-inch box</th>
<th>p-value</th>
<th>4-inch box</th>
<th>6-inch box</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contralateral pelvic drop</td>
<td>-0.51</td>
<td>0.02*</td>
<td>-0.15</td>
<td>0.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip flexion</td>
<td>0.04</td>
<td>0.86</td>
<td>0.09</td>
<td>0.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip adduction</td>
<td>0.57</td>
<td>&lt; 0.01*</td>
<td>0.51</td>
<td>0.02*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip internal rotation</td>
<td>0.55</td>
<td>0.01*</td>
<td>0.41</td>
<td>0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee flexion</td>
<td>0.75</td>
<td>&lt; 0.01*</td>
<td>0.26</td>
<td>0.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee adduction</td>
<td>0.15</td>
<td>0.52</td>
<td>-0.05</td>
<td>0.82</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee abduction</td>
<td>0.56</td>
<td>0.01*</td>
<td>0.35</td>
<td>0.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee internal rotation</td>
<td>0.55</td>
<td>0.01*</td>
<td>0.12</td>
<td>0.61</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* indicates statistically significant difference

Table 3. Kinematic variables presented as mean (SD) among individuals with “not faulty” and “faulty” knee positions, by box height.

<table>
<thead>
<tr>
<th>Kinematic Variables</th>
<th>Score of 1</th>
<th>Score of 2</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Not Faulty</td>
<td>Faulty</td>
<td>p</td>
<td>Not Faulty</td>
<td>Faulty</td>
<td>p</td>
<td>Not Faulty</td>
<td>Faulty</td>
</tr>
<tr>
<td>Contralateral pelvic drop</td>
<td>-2.0</td>
<td>-3.2</td>
<td>0.32</td>
<td>-3.6</td>
<td>-6.1</td>
<td>0.90</td>
<td>-2.1</td>
<td>-6.3</td>
</tr>
<tr>
<td>Hip flexion</td>
<td>29.1</td>
<td>28.5</td>
<td>0.82</td>
<td>39.4</td>
<td>38.6</td>
<td>0.90</td>
<td>28.2</td>
<td>31.3</td>
</tr>
<tr>
<td>Hip adduction</td>
<td>14.9</td>
<td>18.7</td>
<td>0.06</td>
<td>20.8</td>
<td>24.1</td>
<td>0.32</td>
<td>16.3</td>
<td>21.9</td>
</tr>
<tr>
<td>Hip internal rotation</td>
<td>5.2</td>
<td>8.3</td>
<td>0.22</td>
<td>6.4</td>
<td>10.0</td>
<td>0.18</td>
<td>5.8</td>
<td>14.3</td>
</tr>
<tr>
<td>Knee flexion</td>
<td>-47.9</td>
<td>-45.2</td>
<td>0.25</td>
<td>-54.3</td>
<td>-57.9</td>
<td>0.28</td>
<td>-46.7</td>
<td>-43.7</td>
</tr>
<tr>
<td>Knee adduction</td>
<td>1.2</td>
<td>0.2</td>
<td>0.28</td>
<td>1.2</td>
<td>0.6</td>
<td>0.76</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Knee abduction</td>
<td>-4.6</td>
<td>-4.8</td>
<td>0.82</td>
<td>-3.8</td>
<td>-4.6</td>
<td>0.63</td>
<td>-5.0</td>
<td>-2.8</td>
</tr>
<tr>
<td>Knee internal rotation</td>
<td>4.7</td>
<td>8.3</td>
<td>0.17</td>
<td>4.3</td>
<td>4.1</td>
<td>0.76</td>
<td>5.6</td>
<td>14.3</td>
</tr>
</tbody>
</table>

*Indicates statistically significant difference
pelvic drop, hip adduction, and hip and knee internal rotation on the four inch box. A knee position score of 2 differentiated greater hip adduction and less knee abduction on the six inch box.

**Kinematics by Pelvis Position Score**

Kinematic variables among individuals with “not faulty” and “faulty” pelvis positions are displayed in Table 4. Faulty pelvis alignment differentiated less knee flexion for both the four and six inch box conditions, as well as greater hip internal rotation and less knee abduction for the six inch box.

**Comparisons by Box Height**

Kinematic differences between the four and six inch box heights are displayed in Table 5. The six inch box condition displayed significantly greater pelvic drop, hip and knee flexion, hip and knee adduction, and hip internal rotation compared to the four inch box condition. The median scores on the Piva et al.5

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**Table 4. Kinematic variables presented as mean (SD) among individuals with “not faulty” and “faulty” pelvis positions, by box height.**

<table>
<thead>
<tr>
<th>Kinematic variables</th>
<th>4-inch box</th>
<th>6-inch box</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Not Faulty</td>
<td>Faulty</td>
<td></td>
</tr>
<tr>
<td>Contralateral pelvic drop</td>
<td>-1.5 (2.8)</td>
<td>-3.4 (2.8)</td>
<td>0.10</td>
</tr>
<tr>
<td>Hip flexion</td>
<td>27.4 (7.9)</td>
<td>29.4 (8.9)</td>
<td>0.84</td>
</tr>
<tr>
<td>Hip adduction</td>
<td>15.3 (4.1)</td>
<td>18.1 (4.0)</td>
<td>0.10</td>
</tr>
<tr>
<td>Hip internal rotation</td>
<td>5.2 (6.1)</td>
<td>8.0 (5.5)</td>
<td>0.29</td>
</tr>
<tr>
<td>Knee flexion</td>
<td>-51.3 (3.8)</td>
<td>-43.6 (3.3)</td>
<td>&lt; 0.01*</td>
</tr>
<tr>
<td>Knee adduction</td>
<td>0.1 (1.9)</td>
<td>0.4 (3.0)</td>
<td>0.61</td>
</tr>
<tr>
<td>Knee abduction</td>
<td>-6.3 (3.8)</td>
<td>-3.8 (2.1)</td>
<td>0.10</td>
</tr>
<tr>
<td>Knee internal rotation</td>
<td>5.2 (6.1)</td>
<td>7.7 (5.6)</td>
<td>0.36</td>
</tr>
</tbody>
</table>

* indicates statistically significant difference

**Table 5. Differences in kinematic variables between the 4- and 6-inch lateral step-downs.**

<table>
<thead>
<tr>
<th>Kinematic Variables</th>
<th>4-inch box</th>
<th>6-inch box</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contralateral pelvic drop</td>
<td>-2.7 (2.9)</td>
<td>-6.1 (3.5)</td>
<td>&lt;0.01*</td>
</tr>
<tr>
<td>Hip flexion</td>
<td>28.7 (8.4)</td>
<td>38.8 (7.7)</td>
<td>&lt; 0.01*</td>
</tr>
<tr>
<td>Hip internal rotation</td>
<td>7.1 (5.7)</td>
<td>9.1 (5.2)</td>
<td>&lt; 0.01*</td>
</tr>
<tr>
<td>Hip adduction</td>
<td>17.1 (4.2)</td>
<td>23.3 (5.3)</td>
<td>&lt; 0.01*</td>
</tr>
<tr>
<td>Knee flexion</td>
<td>-46.3 (5.1)</td>
<td>-57.0 (6.1)</td>
<td>&lt; 0.01*</td>
</tr>
<tr>
<td>Knee internal rotation</td>
<td>6.9 (5.8)</td>
<td>4.2 (4.8)</td>
<td>0.21</td>
</tr>
<tr>
<td>Knee adduction</td>
<td>0.3 (2.7)</td>
<td>0.8 (2.7)</td>
<td>0.02*</td>
</tr>
<tr>
<td>Knee abduction</td>
<td>-4.7 (3.0)</td>
<td>-4.4 (2.8)</td>
<td>0.42</td>
</tr>
</tbody>
</table>

* indicates statistically significant difference
criteria for the four and six inch box height conditions were 2 and 3, respectively.

DISCUSSION
The purposes of the present study were to determine 1) the strength of association between 2D visual observation for quality of movement during the LSD test and lower limb kinematic variables using 3D motion capture in the ACLR population; 2) to compare kinematics between subgroups based on the presence or absence of faulty pelvis and knee alignments; and 3) to compare the number of visually-assessed movement deviations during LSD testing between box heights. Consistent with the first hypothesis, scores for overall quality of movement were shown to be correlated with several kinematic variables associated with ACL injury at the pelvis, hip, and knee. For the subgrouping hypothesis, across both box heights, greater 3D hip adduction and internal rotation was observed in those with faultier 2D knee alignments, and less 3D knee flexion was seen in those with faulty 2D pelvis alignments. Finally, more 2D movement deviations were identified for the six inch test condition, suggesting box height is influential on total movement, reflected in deviation scoring.

As expected, overall 2D quality of movement was associated with 3D joint kinematics. On the four inch box, overall 2D quality of movement score moderately correlated with most of the 3D variables related to ACL injury risk. Interestingly, on the six inch box, overall 2D quality of movement related to only two of the 3D parameters. Generally, across all variables, stronger relationships between overall quality of movement and all kinematic variables were seen for the four compared to six inch box height. This weaker association may be partly explained by the limitations of 2D assessment. As most 3D joint rotations were greater in magnitude (Table 5) on the six inch box, particularly for the proximal assessments at the hip and knee, the potential to amplify 2D perspective errors may have also increased. Of interest, Jones et al.\(^1\) reported that the knee abduction angle did not differ across 2D observational rating groups for quality of movement during LSD testing in healthy individuals using box heights of 6-10 inches. This lack of relationship was also evident in the current study. In another study evaluating single-leg squatting, no relationship was found between the 2D knee frontal plane projection angle and 3D knee abduction angle, but rather an association with 3D hip adduction.\(^2\) These findings are again supported by the current data on the six inch step. No comparable data using four inch step downs were found in the literature. The only 3D parameters that related to 2D overall quality of movement across box heights were peak hip adduction and peak hip internal rotation, both of which are important in lower extremity injury risk and function. The consistency of these relationships across box heights suggests that 2D assessment of overall quality of movement is sensitive to 3D peak hip adduction and internal rotation movement patterns. Including the current findings, most evidence suggests that 2D perspective errors associated with visual assessment of these tasks are of concern when compared to 3D analysis, but that more robust relationships may exist at the hip when compared to the knee.

During the 2D assessment, the observation that the tibial tuberosity moved past the medial border of the foot yielded a knee position score of 2. This event differentiated individuals after ACLR with increased hip adduction, hip internal rotation, knee internal rotation, and contralateral pelvic drop for the four inch box height and increased hip adduction and decreased knee abduction on the six inch box height. Visualization of a medialized knee was consistently associated with greater 3D hip adduction across box heights. A similar analysis\(^3\) reported greater amounts of knee external rotation with “faulty” knee alignment using a 15 cm box, which is similar to the six inch box height used in the current study. However, Rabin and colleagues did not evaluate the knee position relationship to 3D hip mechanics, did not observe any knee medialization past the medial border of the foot, and their study was conducted on a healthy sample.\(^4\) For the four inch box, individuals after ACLR with knee medialization past the medial border of the foot were differentiated by greater amounts of knee internal rotation. However, no comparable analyses on four inch LSD testing are available.

The presence of “faulty” pelvic alignments consistently differentiated individuals with decreased knee flexion for both the four and six inch box height and increased hip internal rotation and decreased knee
abduction for the six inch box height. These results suggest that increased contralateral pelvic drop may be used as a compensatory movement during the LSD test in order to avoid positions of deeper knee flexion. Diminished quadriceps strength has been shown to be associated with decreased knee flexion angles during single-legged hop and landing tasks in individuals after ACLR at the time of return to activity.\textsuperscript{21,22} Thus, decreased knee flexion angles seen in this study may be indicative of decreased quadriceps strength of the involved limb after ACLR.

A greater number of overall movement deviations were observed on the six compared to four inch box height, as hypothesized. Median frequencies of scores for overall quality of movement were 2 and 3 for the four and six inch box heights, respectively. For the four inch box height, 25\% of individuals received scores of 0 and 1. Only 5\% of individuals received scores of 0 or 1 for the six inch box height. These findings suggest that taller box height elicited a greater number of movement deviations and may be useful in eliciting subtle deviation patterns. Other studies that have applied this rating system to assess quality of movement in healthy individuals during the LSD test reported that 60\% and 31\% of participants received a score of 0-1.\textsuperscript{12,16} The only other study to test a pathologic population reported 38\% of individuals with patellofemoral pain syndrome received a score of 0-1.\textsuperscript{13} These comparative data suggest that individuals with a history of ACLR often exhibit worse quality of movement than healthy individuals, and perhaps even worse than those with patellofemoral pain syndrome.

This study has several limitations. First, it is unknown whether kinematic variables or visually-assessed movement deviations during the LSD test are associated with risk for ACL re-injury. Thus, future work should aim to link movement patterns during the LSD test with kinematics relevant to ACL re-injury during other dynamic tasks such as the drop vertical jump. Second, data from this study was limited to the involved limb. Incorporation of a healthy control group may be useful in identifying movement deviations unique to the ACLR population during the LSD test. Finally, this study did not explore the frontal plane projection angle. As this is another readily available 2D assessment approach that may be used to evaluate movement, it is possible that a combined assessment approach using the LSD scoring and frontal plane projection angle would have greater clinical utility than either approach alone. Finally, the study utilized a smaller sample, which may have inhibited the subgroup comparisons.

CONCLUSION
In conclusion, these results suggest that poorer visually-assessed quality of movement during the LSD test is associated with increased hip adduction and hip internal rotation after ACLR. 2D movement deviations at the pelvis appear to consistently relate to less knee flexion, and 2D deviations at the knee appear to suggest greater hip adduction. Generally, poorer quality of movement was observed during LSD performance using the six inch box height. Clinically, these data suggest that interventions targeting hip abductor, hip lateral rotator, and knee extensor strength and neuromuscular control may be useful in the presence of poor quality of movement during lateral step-down testing.

REFERENCES


ABSTRACT

**Background:** Two-dimensional (2D) analysis has the potential to identify individuals at risk for knee injury by measuring genu valgus during sport related tasks. The reliability of 2D mobile motion analysis in measuring genu valgus during a single leg hop test on individuals with anterior knee pain has not been examined.

**Purpose:** To assess the reliability and concurrent validity of 2D mobile motion analysis and compare it to visual observation while analyzing dynamic genu valgus during a single leg hop test in subjects with anterior knee pain.

**Study Design:** Cohort study; repeated measures

**Methods:** Nineteen subjects experiencing anterior knee pain completed a single leg hop test with both lower extremities. Two investigators independently estimated the degrees of genu valgus with visual observation alone during the subjects' single leg hop. After the visual estimation, the investigators watched the video again using the 2D Spark Motion Pro™ application to pause the video and measured the amount of knee valgus with a virtual goniometer tool on the application. Interrater reliability was calculated using intraclass correlation coefficients (ICC) model 2, k and intrarater rater reliability using model 3, k. Minimal detectable change, concurrent validity and limits of agreement were calculated.

**Results:** Visual observation alone demonstrated interrater reliability ICCs of 0.682-0.685 on the symptomatic and non-symptomatic lower extremities respectively. The interrater reliability using the 2D application had ICC's of 0.927 and 0.792 on the symptomatic and non-symptomatic lower extremities respectively. The concurrent validity for 2D analysis and visual observation on the symptomatic lower extremity had ICC values of 0.96 (rater A) and 0.85 (rater B). The non-symptomatic lower extremity demonstrated concurrent validity ICC values of 0.95(rater A) and 0.65(rater B). The standard error of measurement(SEM) was 3.89° and 3.25° for the symptomatic and non-symptomatic lower extremity(LE) respectively for visual observation. When using the Spark Motion Pro™ application the SEM was 1.64° and 2.71° for the symptomatic and non-symptomatic LE respectively. The minimal detectable change (MDC) using visual observation alone was 5.5° and 4.6°. When using the application, it was noted at 2.32° and 3.83° on the symptomatic and non-symptomatic LE respectively.

**Conclusion:** The results of this study support the use of a 2D mobile application as a reliable tool for measuring knee valgus in symptomatic subjects and offers reduced error (SEM = 1.64°) when compared to visual observation alone (SEM = 3.89°).

**Level of evidence:** 2B

**Key words:** genu valgus, injury prevention, injury screening, two-dimensional

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The authors report no conflicts of interest
INTRODUCTION
According to the National Collegiate Athletic Association (NCAA), lower extremity injuries comprise more than 50% of all injuries occurring in collegiate athletes.1 Approximately 37% of these were caused by non-contact mechanisms. Throughout a ten-year study, Majewski et al.2 followed 17,397 athletes during their athletic careers. They discovered 40% of the total injuries that occurred were related to the knee joint, with anterior cruciate ligament (ACL) tears comprising 20.3%, medial meniscal tears accounting for 10.8%, lateral meniscus tears 3.7%, medial collateral ligament tears 7.9%, and lateral collateral ligament injuries 1.1%. In a study evaluating running related injuries, 42.1% of the injuries involved the knee joint.3

The risk for knee injury with increased dynamic valgus during landing has been evaluated over the last two decades.4-8 Movement patterns that result in hip adduction, hip internal rotation, tibial abduction and foot pronation have been related to anterior knee pain and patellofemoral pain syndrome during dynamic sport related tasks.3,6,8-10 Specifically, in a prospective study of 205 female athletes followed by Hewett et al.,6 hip abduction moments had a sensitivity of 78% and specificity of 73% for predicting ACL injury.6 A 2.5 time increase in knee abduction moments (p<.001) in athletes who went on to suffer an ACL injury was discovered by the authors.6 There is strong evidence to suggest that incorporation of injury prevention programs has the potential to reduce knee injury rates.11,12,13 These programs, which include neuromuscular and proprioceptive training have been found to reduce knee and ACL injury by 26.9% and 50% respectively.12 Therefore, effort must be made to identify reliable methods in which to recognize faulty movement patterns and initiate interventions to reduce probability for injury.

The use of 3D motion capture systems and force plates is well known to be the gold standard for kinematic analysis during movement. This type of system, which is typically used in a laboratory setting, is not universally available. Additionally, use of such systems is costly and requires extensive set-up and education. Two alternate resources available for use in assisting in quantifying joint angles during functional sport specific tasks include 2D video analysis and visual observation. The advantages of these alternatives include applicability, availability, minimal expense, practicality, and ease of use. However, when using visual observation alone, Ekegren et al.14 described the sensitivity of objectifying genu valgus during a drop jump task to range between 67% to 87% when compared to the gold standard of 3D analysis. This resulted in one-third of the tested athletes failing to be labeled as “high risk” who were labeled as such by 3D analysis. Therefore, it was concluded that adequate assessment of knee valgus angles during sport specific tasks is questionable without the use of technological resources.14

The use of 2D video assessment of human movement has been demonstrated to be a valid and reliable alternative in measuring dynamic movement tasks when 3D analysis is not available.15,16 Munro et al.15 reported intraclass correlation coefficient (ICC) values between .83 and .88 in males and females respectively when measuring the reliability of 2D video analysis of frontal plane projection angles during a drop jump task. They concluded that in the absence of access to 3D motion analysis, this method can be used to reliably quantify genu valgus values. In another study, McLean et al.17 examined 3D analysis vs. a 2D standard video measurement technique to determine its potential to screen for excessive genu valgus in elite basketball players. Although their 2D measurement technique demonstrated greater frontal plane knee angles when compared to 3D measurements, the researchers determined 2D analysis to be a reliable method for identifying increased genu valgus. It appears that 2D analysis may appropriately identify athletes who demonstrate an increased risk of injury.17 To the authors knowledge, despite the aforementioned research, no study has evaluated the reliability of 2D motion analysis in measuring genu valgus among individuals with knee pain. The objectives of this study were as follows: To assess the reliability and concurrent validity of 2D mobile motion analysis and compare it to visual observation while analyzing dynamic genu valgus during a single leg hop test in subjects with anterior knee pain.

METHODS
Subjects
Nineteen adult subjects, (female n = 12; male n = 7, average age 28.5 years, +/- 7.29), who were
experiencing anterior knee pain for no greater than twelve months, were recruited from the local community using brochures displayed at two hospital based fitness facilities over the course of six months. Anterior knee pain, as characterized by Cook et al., was defined as having at least two of the three following characteristics; pain with squatting, peripatellar palpable tenderness and/or pain with resisted knee extension. In addition to anterior knee pain, inclusion criteria consisted of being between 18 and 40 years of age and a pre-symptom score of five or greater on the Tegner activity scale. Patients between the ages of 18 and 40 years old were chosen for two reasons. Firstly, to eliminate the need for parental consent and secondly this is the most common age range which the authors treat this population in their clinics. The pre-symptom score of ≥ level 5 on the Tegner scale was chosen based on the Tegner et al. recommendation, as the point of tolerance and ability to perform a single leg hop test. Subjects were excluded from the study if they were unable to read or speak English as required for understanding forms and instructions, were currently participating in a structured strength and conditioning program, had a history of knee surgery, or were unable to perform a single leg hop. This study was approved by the Institutional Review Board of Florida Hospital-Adventist Health System and all subjects meeting inclusion criteria consented to participate. Subjects provided demographic information including age, height, mass, dominant leg, symptomatic lower extremity, gender, and health status.

**Instruments**
The Spark motion Pro™ application was downloaded from the Apple App store to a fourth generation iPad on the iOS 6.0.1 operating system. The iPad had a display of 9.7 inches, 2,048 x 1,536-pixel color IPS LCD display with a 4:3 aspect ratio and captured video at 30 frames per second. The iPad was placed on a 2014 Manfrotto compact, aluminum tripod with the Amazon standard identification number (ASIN, B00L6CBKaK). An Adonit Jot Pro fine point precision stylus, (ASIN, B00931K1QK), was used to measure genu valgus with the applications goniometer tool.

**Procedures**
Upon agreeing to participate and receiving documentation of consent, subjects completed the Tegner activity level scale. The Tegner activity level scale has been used in similar studies to ascertain if a subject will be able to tolerate the single leg hop. The Tegner activity scale consists of a self-reporting 10-item level scale ranging from level 0 (sick leave or disability pension because of knee problems) to level 10 (competitive sports-soccer, football, rugby, national elite). The subjects were required to rate themselves at pre-symptom level and current level of function. The single leg hop test has demonstrated ICC’s ranging from .93 to .96 for prediction of dynamic knee stability. It has the potential to demonstrate insufficiencies in functional knee stability in healthy subjects.

After completion of the Tegner activity scale, the subject watched an investigator perform a single leg hop in the designated testing area and questions were answered to ensure the subject had a verbal understanding of the expected activity. No cuing on mechanics or posture was provided to avoid coaching bias. The subjects advised the investigator which knee was symptomatic and hopped as far as possible with their non-symptomatic lower extremity while keeping their balance for a minimum of two seconds. If the subject was unable to maintain their balance for at least two seconds, a 30 second rest period was provided and another attempt at the single leg hop was made. Once this reference hop distance was made, athletic tape was placed on the ground to mark this location. The subjects then had a one-minute rest period, while the investigators set up the tripod and equipment for video analysis. The tripod was placed five feet from the reference landing location to maintain universal distance from recording to landing point and avoid variations in depth of field during video analysis angle measurements.

Once the landing spot was determined and equipment was set-up accordingly, testing began. The subject performed a single leg hop on their non-symptomatic lower extremity to the designated marked location, maintained the landing for two seconds and received a 60 second rest period between each of three trials. The same occurred on the symptomatic lower extremity. If the subject was unable to maintain the qualifications of a successful hop as described above, a rest period of 60 seconds was provided and another hop was performed. When
the first three successful hops were completed and recorded on the non-symptomatic lower extremity, a three-minute rest period was provided prior to initiation of the symptomatic lower extremity hop trials.

After all trials and video recording were complete visual estimation of genu valgus was performed. Two investigators blinded to each other’s results (both Doctors of physical therapy and familiar with the use of video analysis) visually estimated the degrees of genu valgus during a single video play of each trial hop. Genu valgus was estimated at the point where knee eccentric momentum ended and the subject began their return into knee extension. After each investigator completed the visual estimation alone analysis, the goniometric tool on the application was utilized to measure genu valgus. The same still video image was utilized by the same examiner for both the visual estimation analysis and the goniometric measurement analysis using the application. The reference points used for both visual estimation and goniometric measurements were the anterior superior iliac spine (ASIS), a line bisecting the medial and lateral femoral condyles and a line bisecting the medial and lateral malleoli at the talocrural joint. Frontal plane knee collapse was measured as the difference from a vertical line (180 degrees), with varus recorded as a negative value and valgus as a positive value. Figure 1 demonstrates a subject’s single leg hop with associated goniometric measurement using the Spark Motion Pro™ goniometer. The genu valgus measured in Figure 1 using the application was recorded as 19 degrees by subtracting 180 (vertical) from 199.

Statistical methods

SPSS version 15.0 for Windows was utilized for statistical analysis. Descriptive data including mean measurement angles with standard deviations (SD) were calculated for each session. The ICC model 3, k was used for the intrarater component of analysis and model 2, k for the interrater reliability analysis. To analyze whether the Spark Motion Pro™ software can be used reliably between equally trained clinicians, model 2, k was used. A value of ≥ 0.75 was classified as having good reliability based on recommendations of Portney and Watkins. Values below 0.75 were classified as moderate to poor reliability. The minimal detectable change (MDC) was calculated using the following formula: \( MDC_{95} = 1.96 \times SEM \). This formula was used to determine the magnitude of change that would exceed the threshold of measurement error at 95% confidence level. The 95% limits of agreement were calculated by using the formula: 95% limits of agreement = mean difference +/- 2SD. These values were rounded to the nearest degree to reflect the smallest unit of measurement on the virtual goniometric tool on the Spark Motion Pro™ application. An ICC model 3, k was used in the concurrent reliability analysis to determine if both methods of measurement analysis produced comparable results. ICC value interpretations were also based on the guidelines set forth by Portney and Watkins.

RESULTS

A total of nineteen adult subjects, 12 females and 7 males were recruited. All subjects recruited and initially eligible were able to complete the single leg hop protocol. The average and standard deviation for participants’ age, mass, and height is described in Table 1.

The interrater reliability for visual estimation of knee valgus during the single leg hop trials is depicted in Table 2. The ICC for visual estimate alone (Table 2) demonstrates poor reliability (.682-.685). The mean, standard deviation, ICC, SEM, and MDC_{95} were calculated for the symptomatic (painful) and non-symptomatic (non-painful) lower extremities.
The ICC using the goniometer on the application demonstrated higher reliability (.927) on the symptomatic lower extremity than the non-symptomatic extremity (.792). Table 4 presents the concurrent validity on the symptomatic extremity when comparing visual estimation and the use of the goniometer. The concurrent validity of the symptomatic lower extremity demonstrated an ICC of 0.96 for rater A and 0.85 for rater B (95% CI: 0.92-0.99; 0.61-0.94 for rater A and B respectively) (Table 4). Table 5 presents the concurrent validity of the non-symptomatic lower extremity (ICC = 0.954 and 0.65; 95% CI: 0.88-0.98, 0.092-0.87 for rater A and B respectively). Reliability tended to be greater when evaluating the symptomatic lower extremity when compared to the non-symptomatic lower extremity.

**DISCUSSION**

To date, the reliability of 2D analysis of genu valgus during a single leg hop test has not been evaluated on symptomatic subjects. Therefore, this study

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**Table 1. Demographics (n=19)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>28.53 (7.29)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>171 (10.07)</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>69.73 (12.35)</td>
</tr>
<tr>
<td>BMI</td>
<td>23.67 (2.15)</td>
</tr>
<tr>
<td>Sex (% Female)</td>
<td>63.2%</td>
</tr>
<tr>
<td>Leg Dominance (% Right)</td>
<td>94.7%</td>
</tr>
<tr>
<td>Symptomatic LE (% Right)</td>
<td>42.1%</td>
</tr>
</tbody>
</table>

SD: standard deviation; BMI: Body Mass Index

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**Table 2. Interrater reliability of functional knee valgus using visual estimate during single leg hop**

<table>
<thead>
<tr>
<th>Rater</th>
<th>Mean angle (SD)</th>
<th>Rater</th>
<th>Mean angle (SD)</th>
<th>ICC 2, k</th>
<th>SEM°</th>
<th>MDC°</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6.37 (6.89)</td>
<td>B</td>
<td>5.35 (3.48)</td>
<td>.682</td>
<td>3.89</td>
<td>5.50</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-symptomatic LE</td>
<td>6.46 (5.79)</td>
<td>B</td>
<td>4.04 (3.07)</td>
<td>.685</td>
<td>3.25</td>
<td>4.60</td>
</tr>
</tbody>
</table>

SD: standard deviation; ICC: intraclass coefficient; SEM: Standard error of the measurement; and MDC 95: minimum detectable change at 95% confidence interval.

**Table 3. Interrater reliability of functional knee valgus using Spark Motion Pro™ during single leg hop.**

<table>
<thead>
<tr>
<th>Rater</th>
<th>Mean angle (SD)</th>
<th>Rater</th>
<th>Mean angle (SD)</th>
<th>ICC 2, k</th>
<th>SEM°</th>
<th>MDC°</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5.90 (6.07)</td>
<td>B</td>
<td>6.63 (5.52)</td>
<td>.927</td>
<td>1.64</td>
<td>2.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-symptomatic</td>
<td>5.86 (5.94)</td>
<td>B</td>
<td>4.67 (3.91)</td>
<td>.792</td>
<td>2.71</td>
<td>3.83</td>
</tr>
</tbody>
</table>

SD: standard deviation; ICC: intraclass coefficient; SEM: standard error of the measurement; and MDC 95: minimum detectable change at 95% confidence level.

**Table 4. Concurrent validity of the symptomatic lower extremity using visual assessment and Spark Motion Pro™**

<table>
<thead>
<tr>
<th>Rater</th>
<th>ICC (k,4)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.96</td>
<td>0.92-0.99</td>
</tr>
<tr>
<td>B</td>
<td>0.85</td>
<td>0.61-0.94</td>
</tr>
</tbody>
</table>

ICC: intraclass correlation coefficient; CI: confidence interval.
Table 2 demonstrates that when using visual estimation alone, reliability tended to decrease when measuring symptomatic and non-symptomatic lower extremity angles. The SEM and MDC between visual estimation and the Spark Motion Pro™ also demonstrated some differences. The SEM for the symptomatic and non-symptomatic LE was 3.89° and 3.25° respectively during visual estimation. When using the application, this decreased to 1.64° and 2.71° respectively. This demonstrates the increased chance for error in measuring genu valgus when visual estimation is used in isolation. The lower SEM calculated while using the 2D analysis application (1.64°) versus visual estimation (3.89°) demonstrates greater precision in measuring genu valgus when using technological resources. Nevertheless, the error rate is high with both assessment options as the SEM was in some cases close to 33% of the measurement.

Herrington et al., 24 set out to calculate normative values of genu valgus during a drop jump task for non-pathological subjects. The results of their study indicated that valgus measurements should be symmetrical and in the range of 7° to 10° for females and 3° to 8° for males.24 The researchers noted the potential risk for knee injury increases, if genu valgus values are larger than the normative observation. The results of the current study validate the importance of using methods or devices that decrease the opportunity for misclassification of at risk athletes. If valgus measurements are determined to be outside the norm, injury prevention programs and rehabilitation have had some success in decreasing knee injury risk.25, 26

The utility of implementation of injury prevention strategies and interventions in the rehabilitation and sports performance settings was demonstrated in a prospective study by Hewett et al.25 The investigators followed 1,263 high school student athletes who were instructed in a six-week injury prevention program that included neuromuscular training,
Compared to an untrained group of high school athletes, the results of their findings demonstrated that the untrained group had a 3.6 times higher rate of knee injury than the trained group and untrained female athletes were 4.8 to 5.8 times more likely to experience a serious knee injury than their male counterparts. In 2012, Wouters et al.26 analyzed the results of a four-week neuromuscular training program on hip and knee kinematics in sixty nine female runners. The program included visual (mirror), tactile and verbal cues during exercises emphasizing gluteus medius and maximus recruitment. Their results demonstrated a decrease in internal hip moments by 23% (p=0.007) and knee abduction moments by 29% (P= .033) when compared to pre-training values. Knee adduction and abduction angles were reduced by 2.1° (P=.050) and 2.7° (p=.0008) respectively. The use of 2D mobile motion analysis can provide reliable information informing the determination of individuals (e.g. athletes, patients etc.) who are at risk for knee injury, and according to Hewitt et al.27 can assist in the development of individualized intervention approaches that have demonstrated effectiveness in reducing knee injury rates.27

This study is not without limitations. Physical markers were not used to identify the ASIS, mid-line of the thigh and talocural joint. This decision was made in an effort to simulate how the Spark Motion Pro™ application may be used in the clinic or on the field.28 An additional limitation to this study includes the limited number of subjects used as well as the exclusion criteria. The limited number of subjects reduced the generalizability of the study findings. Subjects who were participating in a structured strengthening program were excluded from the study. This was to eliminate bias for subjects who may have already been coached or trained for proper landing and jump mechanics.

Future research should include comparing various lower extremity functional hop tests (single leg triple hop for distance, crossover hop for distance, vertical jump) on a larger sample of symptomatic subjects.

CONCLUSION
Two-dimensional mobile motion analysis using the Spark Motion Pro™ application demonstrated higher reliability than visual observation while analyzing genu valgus during a single limb hop in subjects with anterior knee pain. Although good reliability was noted in the non-symptomatic extremity, higher reliability values were achieved when measuring genu valgus on the symptomatic lower extremity. When 3D motion analysis is not available, a mobile motion analysis application could be used as a reliable tool when measuring dynamic knee valgus during a single leg hop test.

REFERENCES


ABSTRACT

Background: Two-dimensional (2D) analysis has the potential to identify individuals at risk for knee injury by measuring genu valgus during sport related tasks. The reliability of 2D mobile motion analysis in measuring genu valgus during a single leg hop test on individuals with anterior knee pain has not been examined.

Purpose: To assess the reliability and concurrent validity of 2D mobile motion analysis and compare it to visual observation while analyzing dynamic genu valgus during a single leg hop test in subjects with anterior knee pain.

Study Design: Cohort study; repeated measures

Methods: Nineteen subjects experiencing anterior knee pain completed a single leg hop test with both lower extremities. Two investigators independently estimated the degrees of genu valgus with visual observation alone during the subjects' single leg hop. After the visual estimation, the investigators watched the video again using the 2D Spark Motion Pro™ application to pause the video and measured the amount of knee valgus with a virtual goniometer tool on the application. Interrater reliability was calculated using intraclass correlation coefficients (ICC) model 2, k and intrarater rater reliability using model 3, k. Minimal detectable change, concurrent validity and limits of agreement were calculated.

Results: Visual observation alone demonstrated interrater reliability ICCs of 0.682-0.685 on the symptomatic and non-symptomatic lower extremities respectively. The interrater reliability using the 2D application had ICC's of 0.927 and 0.792 on the symptomatic and non-symptomatic lower extremities respectively. The concurrent validity for 2D analysis and visual observation on the symptomatic lower extremity had ICC values of 0.96 (rater A) and 0.85 (rater B). The non-symptomatic lower extremity demonstrated concurrent validity ICC values of 0.95(rater A) and 0.65(rater B). The standard error of measurement(SEM) was 3.89° and 3.25° for the symptomatic and non-symptomatic lower extremity(LE) respectively for visual observation. When using the Spark Motion Pro™ application the SEM was 1.64° and 2.71° for the symptomatic and non-symptomatic LE respectively. The minimal detectable change (MDC) using visual observation alone was 5.5° and 4.6°. When using the application, it was noted at 2.32° and 3.83° on the symptomatic and non-symptomatic LE respectively.

Conclusion: The results of this study support the use of a 2D mobile application as a reliable tool for measuring knee valgus in symptomatic subjects and offers reduced error (SEM = 1.64°) when compared to visual observation alone (SEM = 3.89°).

Level of evidence: 2B

Key words: genu valgus, injury prevention, injury screening, two-dimensional

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The authors report no conflicts of interest
The advantages of these alternatives include applicability, availability, minimal expense, practicality, and ease of use. However, when using visual observation alone, Ekegren et al. described the sensitivity of objectifying genu valgus during a drop jump task to range between 67% to 87% when compared to the gold standard of 3D analysis. This resulted in one-third of the tested athletes failing to be labeled as “high risk” who were labeled as such by 3D analysis. Therefore, it was concluded that adequate assessment of knee valgus angles during sport specific tasks is questionable without the use of technological resources.

The use of 2D video assessment of human movement has been demonstrated to be a valid and reliable alternative in measuring dynamic movement tasks when 3D analysis is not available. Munro et al. reported intraclass correlation coefficient (ICC) values between .83 and .88 in males and females respectively when measuring the reliability of 2D video analysis of frontal plane projection angles during a drop jump task. They concluded that in the absence of access to 3D motion analysis, this method can be used to reliably quantify genu valgus values. In another study, McLean et al. examined 3D analysis vs. a 2D standard video measurement technique to determine its potential to screen for excessive genu valgus in elite basketball players. Although their 2D measurement technique demonstrated greater frontal plane knee angles when compared to 3D measures, the researchers determined 2D analysis to be a reliable method for identifying increased genu valgus. It appears that 2D analysis may appropriately identify athletes who demonstrate an increased risk of injury. To the authors knowledge, despite the aforementioned research, no study has evaluated the reliability of 2D motion analysis in measuring genu valgus among individuals with knee pain. The objectives of this study were as follows: To assess the reliability and concurrent validity of 2D mobile motion analysis and compare it to visual observation while analyzing dynamic genu valgus during a single leg hop test in subjects with anterior knee pain.

**METHODS**

**Subjects**

Nineteen adult subjects, (female n = 12; male n = 7, average age 28.5 years, +/- 7.29), who were
experiencing anterior knee pain for no greater than twelve months, were recruited from the local community using brochures displayed at two hospital based fitness facilities over the course of six months. Anterior knee pain, as characterized by Cook et al. was defined as having at least two of the three following characteristics: pain with squatting, peripatellar palpable tenderness and/or pain with resisted knee extension. In addition to anterior knee pain, inclusion criteria consisted of being between 18 and 40 years of age and a pre-symptom score of five or greater on the Tegner activity scale. Patients between the ages of 18 and 40 years old were chosen for two reasons. Firstly, to eliminate the need for parental consent and secondly this is the most common age range which the authors treat this population in their clinics. The pre-symptom score of ≥ level 5 on the Tegner scale was chosen based on the Tegner et al. recommendation, as the point of tolerance and ability to perform a single leg hop test. Subjects were excluded from the study if they were unable to read or speak English as required for understanding forms and instructions, were currently participating in a structured strength and conditioning program, had a history of knee surgery, or were unable to perform a single leg hop. This study was approved by the Institutional Review Board of Florida Hospital-Adventist Health System and all subjects meeting inclusion criteria consented to participate. Subjects provided demographic information including age, height, mass, dominant leg, symptomatic lower extremity, gender, and health status.

**Instruments**

The Spark motion Pro™ application was downloaded from the Apple App store to a fourth generation iPad© on the IOS 6.0.1 operating system. The iPad© had a display of 9.7 inches, 2,048 x 1,536-pixel color IPS LCD display with a 4:3 aspect ratio and captured video at 30 frames per second. The iPad© was placed on a 2014 Manfrotto compact, aluminum tripod with the amazon standard identification number (ASIN, B00L6CBKaK). An Adonit Jot Pro fine point precision stylus, (ASIN, B00931K1QK), was used to measure genu valgus with the applications goniometer tool.

**Procedures**

Upon agreeing to participate and receiving documentation of consent, subjects completed the Tegner activity level scale. The Tegner activity level scale has been used in similar studies to ascertain if a subject will be able to tolerate the single leg hop. The Tegner activity scale consists of a self-reporting 10-item level scale ranging from level 0 (sick leave or disability pension because of knee problems) to level 10 (competitive sports-soccer, football, rugby, national elite). The subjects were required to rate themselves at pre-symptom level and current level of function. The single leg hop test has demonstrated ICC's ranging from .93 to .96 for prediction of dynamic knee stability. It has the potential to demonstrate insufficiencies in functional knee stability in healthy subjects.

After completion of the Tegner activity scale, the subject watched an investigator perform a single leg hop in the designated testing area and questions were answered to ensure the subject had a verbal understanding of the expected activity. No cuing on mechanics or posture was provided to avoid coaching bias. The subjects advised the investigator which knee was symptomatic and hopped as far as possible with their non-symptomatic lower extremity while keeping their balance for a minimum of two seconds. If the subject was unable to maintain their balance for at least two seconds, a 30 second rest period was provided and another attempt at the single leg hop was made. Once this reference hop distance was made, athletic tape was placed on the ground to mark this location. The subjects then had a one-minute rest period, while the investigators set up the tripod and equipment for video analysis. The tripod was placed five feet from the reference landing location to maintain universal distance from recording to landing point and avoid variations in depth of field during video analysis angle measurements.

Once the landing spot was determined and equipment was set-up accordingly, testing began. The subject performed a single leg hop on their non-symptomatic lower extremity to the designated marked location, maintained the landing for two seconds and received a 60 second rest period between each of three trials. The same occurred on the symptomatic lower extremity. If the subject was unable to maintain the qualifications of a successful hop as described above, a rest period of 60 seconds was provided and another hop was performed. When
The first three successful hops were completed and recorded on the non-symptomatic lower extremity, a three-minute rest period was provided prior to initiation of the symptomatic lower extremity hop trials.

After all trials and video recording were complete visual estimation of genu valgus was performed. Two investigators blinded to each other’s results (both Doctors of physical therapy and familiar with the use of video analysis) visually estimated the degrees of genu valgus during a single video play of each trial hop. Genu valgus was estimated at the point where knee eccentric momentum ended and the subject began their return into knee extension. After each investigator completed the visual estimation alone analysis, the goniometric tool on the application was utilized to measure genu valgus. The same still video image was utilized by the same examiner for both the visual estimation analysis and the goniometric measurement analysis using the application. The reference points used for both visual estimation and goniometric measurements were the anterior superior iliac spine (ASIS), a line bisecting the medial and lateral femoral condyles and a line bisecting the medial and lateral malleoli at the talocrural joint. Frontal plane knee collapse was measured as the difference from a vertical line (180 degrees), with varus recorded as a negative value and valgus as a positive value. Figure 1 demonstrates a subject’s single leg hop with associated goniometric measurement using the Spark Motion Pro™ goniometer. The genu valgus measured in Figure 1 using the application was recorded as 19 degrees by subtracting 180 (vertical) from 199.

Statistical methods
SPSS version 15.0 for Windows was utilized for statistical analysis. Descriptive data including mean measurement angles with standard deviations (SD) were calculated for each session. The ICC model 3, k was used for the intrarater component of analysis and model 2, k for the interrater reliability analysis. To analyze whether the Spark Motion Pro™ software can be used reliably between equally trained clinicians, model 2, k was used.21 A value of ≥ 0.75 was classified as having good reliability based on recommendations of Portney and Watkins.21 Values below 0.75 were classified as moderate to poor reliability. The minimal detectable change (MDC) was calculated using the following formula: \( MDC_{95} = 1.96 \times SEM \). This formula was used to determine the magnitude of change that would exceed the threshold of measurement error at 95% confidence level.21,22 The 95% limits of agreement were calculated by using the formula: 95% limits of agreement = mean difference +/− 2SD. These values were rounded to the nearest degree to reflect the smallest unit of measurement on the virtual goniometric tool on the Spark Motion Pro™ application. An ICC model 3, k was used in the concurrent reliability analysis to determine if both methods of measurement analysis produced comparable results. ICC value interpretations were also based on the guidelines set forth by Portney and Watkins.21

RESULTS
A total of nineteen adult subjects, 12 females and 7 males were recruited. All subjects recruited and initially eligible were able to complete the single leg hop protocol. The average and standard deviation for participants’ age, mass, and height is described in Table 1.

The interrater reliability for visual estimation of knee valgus during the single leg hop trials is depicted in Table 2. The ICC for visual estimate alone (Table 2) demonstrates poor reliability (.682-.685). The mean, standard deviation, ICC, SEM, and MDC95 were calculated for the symptomatic (painful) and non-symptomatic (non-painful) lower extremities.
The ICC using the goniometer on the application demonstrated higher reliability (.927) on the symptomatic lower extremity than the non-symptomatic extremity (.792). Table 4 presents the concurrent validity on the symptomatic extremity when comparing visual estimation and the use of the goniometer. The concurrent validity of the symptomatic lower extremity demonstrated an ICC of 0.96 for rater A and 0.85 for rater B (95% CI: 0.92-0.99; 0.61-0.94 for rater A and B respectively) (Table 4). Table 5 presents the concurrent validity of the non-symptomatic lower extremity (ICC = 0.954 and 0.65; 95% CI: 0.88-0.98, 0.092-0.87 for rater A and B respectively). Reliability tended to be greater when evaluating the symptomatic lower extremity when compared to the non-symptomatic lower extremity.

**DISCUSSION**

To date, the reliability of 2D analysis of genu valgus during a single leg hop test has not been evaluated on symptomatic subjects. Therefore, this study...
evaluated the reliability of 2D video analysis of genu valgus utilizing the Spark Motion Pro™ application vs. visual estimation alone. It also assessed the validity of the applications ability to measure genu valgus during a single leg hop in symptomatic subjects. Higher reliability was noted when using the application on the symptomatic lower extremity when compared to the non-symptomatic lower extremity. This further validates the importance of using technology when evaluating subjects with complaints of anterior knee pain.

The findings of this study are consistent with the results found in other studies that examine the reliability of 2D mobile motion analysis. Mobile motion capture software has the potential to objectively quantify joint angles during video analysis with good reliability. In a study by Krause et al., the researchers found the reliability of Coach’s Eye (TechSmith Corporation, Okemos, MI), to range from .96-99 when measuring sagittal plane knee motion during a squat maneuver in non-symptomatic subjects. A novel finding of this study includes the identification of increased reliability while using the 2D mobile motion analysis on the symptomatic lower extremity (ICC .927) when compared to the non-symptomatic lower extremity (ICC .792). To the authors knowledge, no study has examined the reliability of 2D mobile motion analysis on subjects with anterior knee pain.

Maykut et al. evaluated the reliability of numerous frontal plane kinematic variables during running using Dartfish Motion Analysis Software (Dartfish, Fribourg, Switzerland). The researchers found excellent intrarater reliability for peak knee abduction angles (ICCs: 0.955-0.976), and in terms of concurrent validity, moderate correlations were presented between 2D and 3D measures on the left lower extremity (pearson product correlation coefficient, 0.541; p = .006).

Table 2 demonstrates that when using visual estimation alone, reliability tended to decrease when measuring symptomatic and non-symptomatic lower extremity angles. The SEM and MDC between visual estimation and the Spark Motion Pro™ also demonstrated some differences. The SEM for the symptomatic and non-symptomatic LE was 3.89° and 3.25° respectively during visual estimation. When using the application, this decreased to 1.64° and 2.71° respectively. This demonstrates the increased chance for error in measuring genu valgus when visual estimation is used in isolation. The lower SEM calculated while using the 2D analysis application (1.64°) versus visual estimation (3.89°) demonstrates greater precision in measuring genu valgus when using technological resources. Nevertheless, the error rate is high with both assessment options as the SEM was in some cases close to 33% of the measurement.

Herrington et al., set out to calculate normative values of genu valgus during a drop jump task for non-pathological subjects. The results of their study indicated that valgus measurements should be symmetrical and in the range of 7° to 10° for females and 3° to 8° for males. The researchers noted the potential risk for knee injury increases, if genu valgus values are larger than the normative observation. The results of the current study validate the importance of using methods or devices that decrease the opportunity for misclassification of at risk athletes. If valgus measurements are determined to be outside the norm, injury prevention programs and rehabilitation have had some success in decreasing knee injury risk.

The utility of implementation of injury prevention strategies and interventions in the rehabilitation and sports performance settings was demonstrated in a prospective study by Hewett et al. The investigators followed 1,263 high school student athletes who were instructed in a six-week injury prevention program that included neuromuscular training,
reliability than visual observation while analyzing genu valgus during a single limb hop in subjects with anterior knee pain. Although good reliability was noted in the non-symptomatic extremity, higher reliability values were achieved when measuring genu valgus on the symptomatic lower extremity. When 3D motion analysis is not available, a mobile motion analysis application could be used as a reliable tool when measuring dynamic knee valgus during a single leg hop test.

REFERENCES

CONCLUSION
Two-dimensional mobile motion analysis using the Spark Motion Pro™ application demonstrated higher reliability than visual observation while analyzing genu valgus during a single limb hop in subjects with anterior knee pain. Although good reliability was noted in the non-symptomatic extremity, higher reliability values were achieved when measuring genu valgus on the symptomatic lower extremity. When 3D motion analysis is not available, a mobile motion analysis application could be used as a reliable tool when measuring dynamic knee valgus during a single leg hop test.


ABSTRACT

Purpose/Background: Strength asymmetries are related to knee injuries in intermittent sports players. The purpose of this study was to examine whether elite futsal players demonstrate strength asymmetries during knee isokinetic testing applying the Croisier et al.21 criteria.

Methods: Forty male elite (27.9 ± 6.5 years) Brazilian futsal players participated in the study. The testing protocol required players to perform concentric contractions of both quadriceps and hamstring muscles at angular velocities of 60°·s⁻¹ and 240°·s⁻¹ and eccentric contractions of hamstring at 30°·s⁻¹ and 120°·s⁻¹. Conventional (concentric:concentric) and mixed (eccentric:concentric) hamstrings/quadriceps (H/Q) ratios were calculated. Subjects were determined to have an imbalanced strength profile if an athlete had at least two parameters that were asymmetrical across speeds and conditions. Asymmetry was operationally defined as peak torque asymmetry greater than 15% in bilateral comparison, and H/Q ratio less than 0.47 for conventional and 0.80 for mixed conditions.

Results: Significant differences were observed between preferred and nonpreferred limbs in the concentric contractions of flexors at 240°·s⁻¹ and eccentric contractions of extensors and flexors at 30°·s⁻¹ and 120°·s⁻¹. However, these asymmetries did not exceed 15%. The conventional and mixed H/Q ratios were greater in the preferred than in nonpreferred limbs, but only the mixed hamstrings_ecc/quadriceps_conc in the nonpreferred limbs showed values lower than recommended (<0.80). In addition, 50% of elite futsal players had preseason strength imbalances per the developed criteria.

Conclusion: The studied elite futsal players had preseason strength imbalances, which may increase the risk of hamstring injuries.

Level of evidence: 3

Key words: Asymmetry, injury risk, isokinetic, peak torque.
INTRODUCTION

Futsal is currently sanctioned by soccer’s international governing body, the Fédération Internationale de Football Association (FIFA), which has periodically organized futsal international competitions since 1989. This game started in South America in the 1930s as an indoor version of soccer/football, and it has rapidly expanded worldwide. Futsal is a very dynamic sport in which many goals are usually scored per match. Although futsal and soccer present similar technical characteristics,1 the physical demands are somewhat different. Soccer is played on a 90-120 × 45-90 m pitch in two 45-minute periods. Players cover ~ 10,000 m per game, and only 0.5 to 3% of effective playing time is covered at high-intensity sprints2. Meanwhile, futsal players cover ~ 3300 m per match,3,4 of which >7.5% are covered at high-intensity3 and ~ 26 sprints are performed per match.5 In contrast, futsal is played on a 40 × 20 m hard court surface in two 20-minute periods, with a 10-minute break between periods,1 and the numbers of substitutions are unlimited, so high-intensity efforts are maintained throughout the matches.1,6 As a consequence of the exposure to high-intensity actions, the requirement of concentric and eccentric muscular actions in the legs to sustain kicking, jumping, pulling up, tackling, turning, changing pace, decelerating and sprinting during a game is very high.1,7

Soccer and futsal are among the top ten injury-prone sports with incidence rate of 20.3 and 55.2 injuries per 10000 hours sport participation, respectively.8 Most injuries affect the lower extremity (i.e., knee and thigh) in both soccer9 and futsal.10,11 For soccer, hamstrings injuries are the most common single injury subtype, representing 12% of all injuries,12 and amounting 1.20 injuries per 1000 h exposure.13 These high injury rates are associated with the short recovery (i.e., less than four days) periods between match and/or high match loads (matches sequence).14 In futsal, prospective studies with hamstring injury rates are scarce, but Junge and Dvorak10 demonstrated that thigh strain is among the most prevalent diagnoses of time-loss injuries in futsal players. In addition, recently Martinez-Rianza et al.15 analyzed medical assistance to Spanish national futsal team over five seasons and showed that in 43.3% of the cases, injuries were sustained in the thigh, followed by the leg (12.6%) and knee (10%). Most assistance cases (52.6%) were due to muscle overload (i.e., when the individual did not have an anatomical injury but the muscle was painful and slightly tight when manually explored) and 14.4% were due to residual pain.

Keeping in mind the high hamstring injury rates in soccer, Croisier et al.16 created a protocol to assess bilateral asymmetries and hamstring/quadriceps (H/Q) ratios, which was shown to be useful for screening for hamstring injury risk in soccer players. It is known that soccer and futsal players have a preferred leg to perform specific skills (i.e., kicking and cutting), which may cause side-to-side asymmetry between legs.17 Bilateral strength asymmetries have been frequently used during sport rehabilitation programs to quantify the functional deficit consequent of lower extremity injury or surgery.18,19 Also, several authors have suggested that bilateral strength asymmetries can be a risk factor for musculoskeletal injuries.20,21,22 For soccer and futsal players, some researchers have suggested that the presence of bilateral asymmetries is a risk for injuries.21,23,24 However, bilateral asymmetries of peak torque (PT) production (as assessed through isokinetic testing) of up to 15% are considered acceptable.20

In intermittent sports, explosive muscular contractions play a significant role in athletes’ performance due to the high number of sprints required in the match or competition.25,26 Therefore, the necessary short phase of deceleration requires an aggressive eccentric hamstring activation, which can potentially harm or damage the muscle-tendon unit.27 Futsal requires many sudden sprints and intense braking, during which the activation of quadriceps and hamstrings are maximally required. Furthermore, in soccer players it has been suggested that the hamstring muscles are vulnerable to injury during quick changes from eccentric to concentric action, mainly when the hamstrings become active extensors of the hip joint.28 Thus, the H/Q ratio may be an important screen for injury risks if strength imbalances are detected in athletes of football.21,23,29,30

The purpose of this study was to examine whether elite futsal players demonstrate strength asymmetries during knee isokinetic testing applying the Croisier et al.21 criteria. Based on technical
similarities between soccer and futsal, the authors hypothesized that some isokinetic strength differences predisposing to lower limb injuries would be detected in this specific sample of athletes, which may inform prevention strategies.

METHODS

Participants
Forty male elite futsal players (27.9 ± 6.5 years; 75.1 ± 8.1 kg; 1.76 ± .03 m) from three different Brazilian professional teams volunteered to participate in the study. The players had at least five years of experience in futsal training and competition. Their respective futsal teams were ranked first, second, and fourth in the 2010 season of the Brazilian Futsal League, which is considered one of the best leagues in the world. Fifteen players evaluated in this study were regular athletes from the Brazilian futsal team, including the best goalkeeper and the best overall player of the FIFA Futsal World Cup.

The purpose, experimental procedures, possible risks and benefits of the study were explained to the athletes, who provided written informed consent before starting the participation. All procedures were approved by the Local Ethics Committee for Research with Humans (protocol number 5263.0.000.09110).

Experimental design
All study procedures were performed during the initial phase of the competitive season. In this phase, athletes were engaged in a training program one to two sessions per day (five to six days each week), including official futsal matches. Specifically, they performed four to five conditioning sessions (approximately 30-40 min per session) per week that were designed to develop sprinting abilities and explosive strength, as well as two to three resistance training sessions per week. Small-sided games were used to develop aerobic fitness and were included in the technical and/or tactical training sessions. Before starting the study, each athlete was instructed to refrain from heavy exercise, to avoid alcoholic or caffeinated products in the 48 hours preceding the tests and to present themselves at the experimental settings in a two-hour post-prandial state. Before the experiments the players were familiarized with the isokinetic test.

The futsal players were assessed in isokinetic dynamometer during a single visit to the laboratory (familiarization and protocol test). The angular speeds used in the current study were chosen according to the protocol used in soccer players described by Croisier et al. Accordingly, bilateral asymmetry and H/Q ratios were identified and compared to normative values.

Knee Maximal Strength Test
Isokinetic measurements were performed on hamstring and quadriceps muscles. All professionals conducting the isokinetic assessment received instructions to strictly apply a standardized testing procedure. Measurements were preceded by a 5 min warm-up consisting of pedaling on a cycle ergometer (75 to 100 watts). Each player was placed in an upright seated position on the adjustable Cybex dynamometer chair (Cybex Norm, Lumex, Ronkonkoma, USA) and firmly stabilized by straps so that only the knee to be tested was movable with a single degree of freedom. The lateral epicondyle of the tested knee was aligned with the dynamometer’s axis of rotation, and the machine’s lever arm was attached to the lower leg 2 cm above the lateral malleolus. The range of knee motion was fixed at 90° of flexion from the active maximum extension. The axis of rotation of the knee was then aligned with the axis of rotation of the dynamometer lever arm.

After a standard warm-up consisting of three to five submaximal and one maximal concentric (Conc) contraction efforts of the quadriceps and hamstring muscles at the angular speed of 120°·s⁻¹. The testing protocol required players to perform concentric contractions of both quadriceps and hamstring muscles at 60°·s⁻¹ (three repetitions) and 240°·s⁻¹ (five repetitions) angular velocities of movement. Athletes were then required to perform eccentric (Ecc) contractions of hamstring at 30°·s⁻¹ (three repetitions) and 120°·s⁻¹ (four repetitions) angular velocities of movement. Verbal encouragement was continuously provided throughout the tests. A passive rest period of 90 seconds was allowed between limbs and each angular velocity, but the participant did not receive any visual feedback during the test.

The analyses of results were expressed in absolute (Nm) and relative (Nm/kg) concentric and eccentric
peak torque (PT) of extensors and flexors of the knee, and the bilateral comparison (preferred and non-preferred limbs) led to the determination of asymmetries expressed in percentage form according to Equation 1.32 Concentric H/Q peak torque ratio of flexors and extensors was established (at 60°·s⁻¹ or 240°·s⁻¹) and mixed H_{ecc}/Q_{conc} ratio was associated with eccentric performance of the hamstrings and the concentric action of the quadriceps muscles (hamstrings at 30°·s⁻¹ versus quadriceps at 240°·s⁻¹).20 Regarding imbalance strength profile, this study followed the procedures described by Crosier et al.20: bilateral differences above 15% in concentric and/or eccentric on the hamstrings; concentric ratio (on at least one leg) of less than 0.47; and a mixed ratio of less than 0.80 (on at least one leg). Thus, at least two of the following parameters were used to characterize athletes with imbalances: concentric (at 60°·s⁻¹ or 240°·s⁻¹) and eccentric (at 30°·s⁻¹ or 120°·s⁻¹) bilateral asymmetries (>15%); conventional H_{conc}/Q_{conc} (at 60°·s⁻¹ or 240°·s⁻¹); and mixed H_{ecc}/Q_{conc} ratio. Data collection was performed in an acclimatized room. Temperature and relative humidity were maintained at 22-23°C and 50-60%, respectively. The tests were conducted in morning (9-11 a.m.) and afternoon (2-6 p.m.) periods during one week.

\[ AI_{\%} = \left( \frac{P - NP}{P} \right) \cdot 100 \]  

(1)

AI equals the percent asymmetry index, calculated by using the outputs for PT measurements of the preferred (P) and non-preferred (NP) limbs.

### Statistical Analyses

Data are reported as the mean, standard deviation (SD), and frequencies (absolute and relative) with a 95% confidence interval. Shapiro-Wilk tests were used to verify the normality of the data. Where the differences were not normally distributed, the values were calculated on the log transformation data. The differences between preferred and non-preferred lower limbs torque and H/Q ratios were compared using independent t-test. Paired t-tests were used to identify differences between angular velocities for AI%. Significance was assumed at 5% (\( P \leq .05 \)) a priori. All statistical analyses were performed using SPSS 18.0 for Windows (SPSS Inc., Chicago, USA).

### RESULTS

Table 1 shows the relative and absolute isokinetic concentric and eccentric knee PT of extensors and flexors at the P and NP limbs. The difference was analyzed according to the lower limbs (P vs NP). The knee flexor PT concentric at 240°·s⁻¹ was significantly greater in the preferred limb. Regarding eccentric contractions, in both angular speeds (30°·s⁻¹ and 120°·s⁻¹) of extensors and flexors, the preferred limb also showed higher values than the nonpreferred.

Table 2 shows the bilateral asymmetries for concentric and eccentric PT of knee extensors and flexors at all angular speeds. The differences were analyzed according to the angular speeds. Significant differences in the bilateral asymmetries were observed in the concentric contractions to extensors at 60°·s⁻¹ compared to 240°·s⁻¹ (\( p = 0.011 \)) and eccentric extensors.

| Table 1. Relative and absolute values of isokinetic concentric and eccentric peak torque (PT) of knee extensors and flexors in both lower limbs. |
| --- | --- | --- | --- |
|  | 60°·s⁻¹ (Conc) | 240°·s⁻¹ (Conc) |  |
|  | P | NP | p-value | P | NP | p-value |
| Extensors |  |  |  |  |  |  |
| PT (Nm/kg) | 2.85±0.58 | 2.88±0.59 | 0.67 | 2.37±0.67 | 2.35±0.64 | 0.71 |
| PT (Nm) | 214.7±49.6 | 216.5±51.6 | 0.62 | 178.1±53.1 | 176.8±52.0 | 0.71 |
| Flexors |  |  |  |  |  |  |
| PT (Nm/kg) | 1.81±0.35 | 1.80±0.42 | 0.77 | 1.65±0.51 | 1.54±0.49 | 0.006* |
| PT (Nm) | 136.6±31.7 | 135.8±36.3 | 0.81 | 124.3±40.3 | 115.9±38.1 | 0.007* |
|  | 30°·s⁻¹ (Ecc) | 120°·s⁻¹ (Ecc) |  |  |  |  |
| Extensors |  |  |  |  |  |  |
| PT (Nm/kg) | 3.95±0.99 | 3.70±0.95 | .003* | 3.98±0.75 | 3.70±0.80 | .013* |
| PT (Nm) | 296.0±75.7 | 277.2±73.0 | .003* | 299.3±66.4 | 277.3±66.1 | .012* |
| Flexors |  |  |  |  |  |  |
| PT (Nm/kg) | 2.32±0.49 | 2.16±0.50 | .006* | 2.48±0.43 | 2.29±0.49 | .008* |
| PT (Nm) | 173.5±35.8 | 162.9±40.8 | .099 | 185.7±34.1 | 172.7±38.0 | .089 |

PT = peak torque; P = preferred limb; NP = nonpreferred limb; Conc = Concentric; Ecc = Eccentric. *significantly greater in P than NP (\( p<0.05 \)).
mixed H/Q ratios were acceptable, except the mixed H\textsubscript{ec}/Q\textsubscript{conc} in the nonpreferred limb (Table 3).

Table 4 shows the number of futsal players with strength imbalances (bilateral asymmetries and H/Q ratio deficits) according to the Croisier et al.\textsuperscript{20} criteria. Regarding the predefined cutoffs, there seems to be a high prevalence of futsal players with torque imbalances in at least two criteria (50%).

Table 2. Bilateral asymmetries for concentric and eccentric peak torque of extensors and flexors at the knee.

<table>
<thead>
<tr>
<th></th>
<th>60°·s(^{-1}) (CI 95%)</th>
<th>240°·s(^{-1}) (CI 95%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentric</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensors (%)</td>
<td>2.5 (-1.35 – 6.35)</td>
<td>5.86 (-9.0 – 10.83)*</td>
<td>.011</td>
</tr>
<tr>
<td>Flexors (%)</td>
<td>-1.40 (-5.06 – 2.26)</td>
<td>.72 (-3.23 – 4.68)</td>
<td>.637</td>
</tr>
<tr>
<td>Eccentric</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensors (%)</td>
<td>7.92 (3.11 – 12.73)*</td>
<td>3.39 (-1.68 – 8.46)</td>
<td>.004</td>
</tr>
<tr>
<td>Flexors (%)</td>
<td>6.95 (3.11 – 10.78)</td>
<td>6.65 (1.69 – 11.6)</td>
<td>.26</td>
</tr>
</tbody>
</table>

CI= confidence interval; * statistically significant differences between angular speeds (p<0.05).

Table 3. The relative peak torque values for conventional concentric and mixed hamstring/quadriceps ratios in both lower limbs.

<table>
<thead>
<tr>
<th></th>
<th>P Mean (CI95%)</th>
<th>NP Mean (CI95%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional concentric H\textsubscript{conc}/Q\textsubscript{conc} ratio</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conc60°·s(^{-1})/Conc60°·s(^{-1})</td>
<td>0.64 (0.61 – 0.68)</td>
<td>0.64 (0.61 – 0.68)</td>
<td>.470</td>
</tr>
<tr>
<td>Conc240°·s(^{-1})/Conc240°·s(^{-1})</td>
<td>0.69 (0.66 – 0.73)*</td>
<td>0.65 (0.61 – 0.69)</td>
<td>.044</td>
</tr>
<tr>
<td>Mixed H\textsubscript{ec}/Q\textsubscript{conc} ratio</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ecc30°·s(^{-1})/Conc240°·s(^{-1})</td>
<td>1.05 (0.93 – 1.18)*</td>
<td>0.76 (0.71 – 0.82)</td>
<td>.000</td>
</tr>
</tbody>
</table>

Conc= concentric; Ecc= eccentric; H/Q = hamstring/quadriceps ratio; P = preferred limb; NP = nonpreferred limb; CI= confidence interval; *significantly greater for P than NP (p<0.05).

Table 4. Number of futsal players with strength imbalances according to Croisier criteria.

<table>
<thead>
<tr>
<th></th>
<th>Rate of Players (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bilateral difference</td>
<td></td>
</tr>
<tr>
<td>Conc 60°·s(^{-1})</td>
<td>7/40 (17.5)</td>
</tr>
<tr>
<td>Conc 240°·s(^{-1})</td>
<td>14/40 (35.0)</td>
</tr>
<tr>
<td>Ecc 30°·s(^{-1})</td>
<td>16/40 (40.0)</td>
</tr>
<tr>
<td>Ecc 120°·s(^{-1})</td>
<td>13/40 (32.5)</td>
</tr>
<tr>
<td>H\textsubscript{ec}/Q\textsubscript{conc} ratio (P)</td>
<td></td>
</tr>
<tr>
<td>Conc60°·s(^{-1})/Conc60°·s(^{-1})</td>
<td>1/40 (2.5)</td>
</tr>
<tr>
<td>Conc240°·s(^{-1})/Conc240°·s(^{-1})</td>
<td>0/40 (0.0)</td>
</tr>
<tr>
<td>Mixed Ecc30°·s(^{-1})/Conc240°·s(^{-1})</td>
<td>11/40 (27.5)</td>
</tr>
<tr>
<td>H\textsubscript{ec}/Q\textsubscript{conc} ratio (NP)</td>
<td></td>
</tr>
<tr>
<td>Conc60°·s(^{-1})/Conc60°·s(^{-1})</td>
<td>2/40 (5.0)</td>
</tr>
<tr>
<td>Conc240°·s(^{-1})/Conc240°·s(^{-1})</td>
<td>3/40 (7.5)</td>
</tr>
<tr>
<td>Mixed Ecc30°·s(^{-1})/Conc240°·s(^{-1})</td>
<td>14/40 (35.0)</td>
</tr>
<tr>
<td>Injury criteria</td>
<td></td>
</tr>
<tr>
<td>Deficiency in at least two parameters</td>
<td>20/40 (50.0)</td>
</tr>
</tbody>
</table>

Conc= concentric; Ecc= eccentric; H/Q = hamstring/quadriceps ratio; P = preferred limb; NP = nonpreferred limb.
DISCUSSION

The aim of this study was to examine the strength and identify imbalances in elite futsal players using a protocol developed by Croisier et al.,20 which established normative values for conventional and mixed H/Q ratio and bilateral asymmetries. Among the main findings of the present study, it can be highlighted that: a) Significant differences were observed between preferred and nonpreferred limbs in the concentric contractions of flexors at 240°·s⁻¹ and eccentric contractions of extensors and flexors at 30°·s⁻¹ and 120°·s⁻¹, but the group-average asymmetries did not exceed 15%; b) Conventional and mixed H/Q ratios were higher for preferred than nonpreferred limbs; however, only the mixed $H_{ec}/Q_{conc}$ in the nonpreferred limb showed values lower than those recommended (<0.80); c) Through strength imbalances (bilateral asymmetries, conventional and mixed H/Q ratios) criteria,20 a high prevalence of players with hamstring injury risk was observed (50%). Some studies have already used this protocol in soccer players,21,29,33 but not in futsal players.

Humans tend to use preferentially one side of the body in voluntary motor acts.34 Lateral preference can be associated with task complexity,35 gender35 and developmental characteristics.36 In sports scenarios, lateral preference can influence aspects related to force production due to long term adaptations from repeated use.37 Accordingly, bilateral asymmetries have been reported in sports with predominant unilateral movements, such as soccer,21,29,38 volleyball,38,39 basketball38,40 and handball.41 Futsal also requires unilateral movements17; however, there is no previous evidence of isokinetic bilateral asymmetries in futsal players. During isokinetic tests the athlete cannot perform a functional movement specific to a futsal match, however, this objective test may be important to identify strength asymmetries, which can relate to muscle injury risk that are common in high-intensity team sports.20,21,38,42 To date, studies that evaluated peak isokinetic knee torque in futsal players have assessed strength performance or fatigue,43 but not bilateral asymmetries.

The present study reported higher PT concentric in flexors at 240°·s⁻¹ for preferred than nonpreferred limb. Regarding eccentric contractions, in both angular speeds (30°·s⁻¹ and 120°·s⁻¹) for flexors and extensors, the relative PT was greater in preferred than nonpreferred limb. Similarly, Ruas et al.23 measured knee strength asymmetries in soccer players in different field positions, and their results indicated that in all players, the preferred leg's eccentric hamstring strength was greater than that of the nonpreferred leg. Bilateral asymmetry above 15% of maximum torque production has been associated with muscular injury risk.20 Although the current findings reported higher values for preferred than nonpreferred lower limbs, these asymmetries, on average, did not exceed 15% (Table 2). Some authors have found that lack of bilateral asymmetry may be due to the importance of the nonpreferred limb's supportive strength to coordinate dominant knee actions,44 and also due the idea of inter-hemispheric transfer of learning during practice.45

Some studies with soccer players have used knee extensor concentric actions during isokinetic tests20,23,26,29 because the quadriceps muscles are devoted to explosive efforts such as propulsion jumps and pulls after quick changes in direction. Concentric muscular actions are primarily used during passing and kicking.30 However, the eccentric phase of hamstrings also has a substantial influence on muscular performance.46 When sprinting, a short phase of deceleration is required as a result of eccentric hamstring activation to compensate the forward momentum, which can harm or damage the muscle-tendon unit, and consequently increases the injury risk to hamstrings.47 During a futsal game, there is a greater proportion of high-intensity exercise such as sudden sprints (maximal or near-maximal single and multiple sprint bouts) compared to during a traditional soccer game.3 Thus, the H/Q ratio may be a useful variable to help identify muscle imbalances in futsal players, since it was related to both hamstring strain injury42 and anterior cruciate ligament rupture.48

The current study showed acceptable values for conventional concentric and mixed H/Q ratios in preferred leg. For nonpreferred leg, the conventional H/Q ratio presented acceptable values, while the mixed ratio presented average values lower than recommended (<0.80). Notably, the mixed H/Q ratio has been proposed to better reflect biomechanical conditions during sprints, passes and kicks.33 The
hamstring muscles play an important role in decelerating the extension of the lower limb on the thigh during ball-striking. Also, normally, futsal players have one preferred leg for specific skills. Thus, the authors hypothesized that because the nonpreferred limb performs fewer passes and kicks during a futsal match, muscle imbalances may have increased in the nonpreferred limb. On the other hand, studies of soccer players have produced similar values between preferred and nonpreferred limbs in the conventional concentric and mixed $H_{ec}/Q_{conc}$. For futsal players, there are no studies that used a similar protocol to determine conventional or mixed $H/Q$ ratios in order for comparison to occur.

Because hamstring strains are frequent in soccer and futsal players and muscle weakness and strength imbalance are considered to be their main causes, a standard protocol to screen for hamstring injury risk is necessary. Croisier et al. developed an isokinetic protocol for detecting strength imbalances during the preseason in soccer players based on cutoffs related to bilateral hamstring asymmetries and $H/Q$ ratios. The criteria for being allocated to the groups of players with strength imbalances corresponded to a significant deficiency in at least two parameters as previously described. Croisier et al. observed that one in two players had isokinetic strength disorders (47%), and players who performed soccer activities performed with untreated strength imbalances had an increased four-fold increased risk of hamstring injury compared to players with normal strength balance profile.

Nevertheless, the use of isokinetic dynamometry for screening hamstrings for injury risk has demonstrated contradictory results. Dauty et al. showed that the isokinetic test in the beginning season was able to predict a third of soccer players who would get injured during the season. Conversely, in a large cohort study of professional soccer players Van Dyk et al. observed that the use of isokinetic testing to determine the association between strength differences and hamstring strain injury was not supported. Likewise, the meta-analysis by Freckleton and Pizzari showed that $H/Q$ ratio was not associated with hamstring strain injury. These literature inconsistencies can be related to methodological aspects, including different angular velocities and types of muscle contraction (i.e., concentric and/or eccentric).

Considering strength imbalances, Lehance et al. reported that approximately one in three uninjured Belgian soccer players had strength imbalances in the preseason, including concentric or eccentric bilateral asymmetries and conventional or functional $H/Q$ ratio deficits, while in Australian soccer players' strength imbalances were observed in approximately one in four players. In the present study one in two Brazilian futsal players possessed strength imbalances, which related to hamstring injury risk criteria established by Croisier et al. The current study used the isokinetic test as a tool to identify strength imbalances in futsal players. Therefore, when imbalances are identified, exercise programs such as Fédération Internationale de Football Association's “the 11 +” Nordic hamstrings exercise and isoinertial eccentric-overload may be useful to increase the quadriceps concentric and hamstring concentric and eccentric peak torque, and improved mixed $H/Q$ ratio in futsal players.

Among the limitations of this study, it is well documented that the isokinetic dynamometer assessment does not reflect the functional aspects of the practice of futsal. However, it is a useful tool for the objective evaluation of strength, and it can be used to identify strength imbalances in futsal players. In addition, the study did not include a prospective observation for hamstring injuries of futsal players during the full competitive season. To the authors knowledge, the present study is the first to test an isokinetic protocol for strength imbalances in elite futsal players. Future studies looking for development of specific isokinetic screening protocols for futsal players, and the development of prevention strategies for hamstring injuries through prospective studies are needed.

**CONCLUSION**

Although the current study showed significant differences between preferred and nonpreferred limbs peak torque outputs, elite futsal players did not have, as a group, bilateral asymmetries (>15%). In addition, conventional and mixed $H/Q$ ratios showed acceptable average values; however, the mixed $H_{ec}/Q_{conc}$ in the nonpreferred limb showed values lower.
than those recommended (<0.80). In contrast, when analyzing the individual results, one in two elite futsal players had preseason strength imbalances per the developed criteria, which may be impact the risk of hamstring injuries. Therefore, coaches, physiotherapists, athletic trainers, and sport physiologists could use isokinetic tests to identify strength imbalances and consider the use of a preventive training program to reach a strength balance in lower limbs before the competitive season begins.

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48. Monajati A, Larumbe-Zabala E, Goss-Sampson M, Naclerio F. The effectiveness of injury prevention...


ABSTRACT

Background: Self-massage is a ubiquitous intervention similar to massage, but performed by the recipient him- or herself rather than by a therapist, most often using a tool (e.g., foam roller, roller massager). Self-massage has been found to have a wide range of effects. It is particularly known for increasing flexibility acutely, although not always. The variability of the results in previous studies may potentially be a function of the tool used. Recent findings also suggest that self-massage exerts global effects. Therefore, increased flexibility should be expected in the areas adjacent to the ones treated.

Purpose: To investigate the acute effects of foam rolling and rolling massage of anterior thigh on hip range-of-motion (ROM) – i.e., hip extension and hip flexion – in trained men.

Methods: Eighteen recreationally active, resistance trained males visited the lab on two occasions over a 4-day period separated by at least a day. Each session included two baseline ROM measures of passive hip flexion and extension taken in a randomized fashion. Recording of baseline measures was followed by the intervention of the day, which was either foam rolling or rolling massage of the anterior thigh as per randomization. Immediately post intervention, passive hip flexion and hip extension ROM were reassessed. In order to assess the time course of improvements in ROM, hip flexion and hip extension ROM were reevaluated at 10, 20, and 30 minutes post-intervention.

Results: Hip flexion and hip extension ROM increased immediately following both interventions (foam rolling or roller massager) and remained increased for 30 minutes post intervention. Foam rolling was statistically superior in improving hip flexion and hip extension ROM immediately post intervention. However, immediately post-intervention was the only time point that measurements exceeded the minimum detectable change for both interventions.

Conclusion: Both foam rolling and rolling massage appear to be effective interventions for improving hip flexion and extension ROM when applied to the anterior thigh, but the observed effects are transient in nature.

Level of evidence: 2b

Key words: Flexibility, foam rolling, rolling massage, self-manual therapy, self-myofascial release

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The authors report no conflicts of interest
INTRODUCTION

Self-massage is a ubiquitous intervention similar to massage, but performed by the individual rather than by a therapist, most often using a tool. Self-massage has been found to have wide range of effects.\(^1\) It is particularly known for increasing flexibility acutely,\(^2\) although not always.\(^5\) Importantly, self-massage has been found to increase range of motion (ROM) without impeding neuromuscular performance,\(^1\) based on no attenuation of maximal voluntary contraction,\(^2,4,5\) muscle activation as assessed by interpolated twitch technique,\(^2\) rate of force development,\(^2,5\) twitch force\(^2,4\) and half relaxation time,\(^2\) and electromechanical delay.\(^4\) While not fully elucidated, many possible mechanisms have been proposed for the aforementioned effects, including both mechanical and neurophysiological ones. Mechanical mechanisms describe a number of sub-mechanisms, such as fascial adhesions, piezoelectricity, cellular responses, myofascial trigger points, and/or thixotropic and viscoelastic properties of the tissue.\(^1\) Neurophysiological mechanisms can be divided into two primary submechanisms,\(^1\) spinal – associated with mechanoreceptors within muscle and fascia\(^1,8\) – and supraspinal – which include central pain modulation and descending noxious inhibitory control – both of which have been asserted to mediate perception.\(^6,9\)

While self-massage has been shown to increase ROM in the majority,\(^1\) but not all,\(^6\) of investigations, the degree of ROM increase has been variable.\(^1\) These differences in outcomes may not only be due to the muscle group treated, overall volume of treatment, and differences in the applied pressure, but also the type of the tool used,\(^1\) particularly since it has been suggested that even the type of foam roller can have an effect on pressure that is applied to the underlying area.\(^10\) The two most commonly-employed tools for self-massage are the foam roller\(^2,6,11\) and roller massager.\(^3\) Roller massagers are similar to foam rollers in that they consist of a solid plastic cylinder enclosed by a small layer of dense foam, but differ from foam rollers insofar as they have a central axle that is grasped by hands, and that way applied to different parts of the body.\(^2\) MacDonald et al.\(^2\) applied a foam roller to the quadriceps muscle group for 2 sets of 60 seconds and observed an increase in knee joint ROM by 10.6° post intervention. When a roller massager was applied to the same muscle group, albeit only for 60 seconds, and the same test was used to measure ROM, the ROM increased by 8.6°.\(^3\) While the difference between the studies may be explained by different pressures applied, as the participants of the former were instructed to apply as much of their body mass as possible onto the foam roller\(^2\) and the pressure in the latter study was controlled by a custom-made device,\(^3\) the influence of the type of tool used on the observed effect cannot be discounted. Furthermore, while the differences between the aforementioned studies are small and it is unclear whether the outcomes are real or meaningful, the results cannot be extrapolated to other modalities or body parts. Thus, more work is needed to understand the effect of different self-massage tools in order to guide appropriate practice. Specifically, should the effects be dependent on the type of the tool applied, it is important that practitioners are aware of it as to make their treatment more time-efficient.

Recent findings suggest that self-massage elicits global effects; that is, when one area of the body is treated, the effects are extended to neighboring regions. For example, it has been recently shown that overhead deep squat performance improved regardless of the body part rolled (i.e., lateral thigh, plantar surface of the foot, and lateral side of the trunk).\(^12\) Furthermore, Aboodarda et al.\(^13\) showed that pain pressure tolerance increases both in the ipsilateral (treated) calf as well as the contralateral one, and the same research group also demonstrated contralateral reductions in acute pain with evoked tetanic contractions after roller massage.\(^14\) Similarly, Kelly & Beardsley\(^15\) demonstrated a cross-over effect, whereby foam rolling the calf increased both ipsilateral and contralateral ROM of the ankle. However, whether the effects of self-massage are extended to different directions of movement about the same joint remains unclear. These findings have important clinical implications, in that non-local effects may be beneficial in rehabilitative protocols when an individual’s skin or muscle is hypersensitive; for example, following surgery. That is, non-local effects allow for treatment outcomes (increased ROM) without the potential harms associated with direct contact.

Therefore, the purpose of this study was to investigate the acute effects of foam rolling and rolling massage of the anterior thigh on hip ROM – i.e.,
hip extension and hip flexion – in trained men. If observed effects are ‘global’ rather than ‘local’, one can expect to see changes in both hip extension and hip flexion, while ‘local’ effects will only be reflected by changes in hip extension.

METHODS

Participants
Eighteen resistance-trained men from the local university (age: 26.5 ± 4.2 years, height: 180.0 ± 4.2 cm, body mass: 92.8 ± 22.9 kg, BMI: 28.7 ± 6.3 m²/kg), with no prior foam rolling (FR) or rolling massage (RM) experience were recruited for the study. As per the questionnaire, participants had to be free of musculoskeletal injury or pain and were without existing neurological conditions. If participants were found to be hypermobile during baseline testing, they were excluded from the study. An a priori sample size calculation (effect size = 1.0; 1 − β = 0.95; α = 0.05) using G*Power² found that 12 participants would be sufficient to investigate the question posed; however, in order to increase statistical power by 50%, 18 were recruited. Anthropometric data included height (Stadiometer ES 2030 Sanny, São Paulo, Brazil) and body mass. Before the start of the study, all participants read and signed an informed consent document and a Physical Activity Readiness Questionnaire. Subjects were instructed to refrain from any lower body exercise or strenuous activity throughout the duration of the study. All procedures were in accordance with Declaration of Helsinki and the study was approved by the Institutional Review Board of University Hospital Clementino Fraga Filho of the Federal University of Rio de Janeiro.

Experimental design
A single-blinded, randomized, crossover, within-subject design was used (Figure 1). Subjects visited the laboratory on two occasions over a four-day period with at least a day between each visit. Each session included two baseline ROM measures of passive hip flexion and extension, the order of which was randomized. The two measures were later averaged (average baseline). Recording of baseline measures was followed by the intervention of the day, which was either foam rolling or rolling massage as per randomization. Immediately following the intervention, passive hip flexion and extension ROM were measured again. In order to assess the time course of improvements in ROM, hip flexion and extension ROM were also measured at 10, 20, and 30 minutes post-intervention. These time points have been chosen to make the results more comparable to previous work.²,⁵,¹⁷ Only the dominant limb was tested as referenced to the limb that they would kick a ball with.¹¹

Procedures

Self-massage
Self-massage consisted of two protocols, depending on the tool used, both of which lasted for a single set
of 120 seconds. This duration is similar to the study of MacDonald et al.,\textsuperscript{2} but different insofar as they split it into two sets.

The FR intervention was performed in a prone position with the anterior thigh of the test limb atop the foam roller (Foam Roller Brazil, Porto Alegre, RS, Brazil) as demonstrated previously (Figure 2).\textsuperscript{6} The foam roller used in this study consisted of a hard inner core enclosed in a layer of ethylene vinyl acetate foam, and has been shown to produce more pressure on the soft tissue.\textsuperscript{10} While keeping the knee of the dominant limb extended, participants were instructed to use their arms and the non-dominant limb to propel themselves backward and forward on the foam roller between the acetabulum and quadriceps tendon in fluid, dynamic motions. Subjects were encouraged to support their entire bodyweight with the foam roller and thus maximize pressure on the foam roller.

The RM intervention was performed with a self-massage stick (Stick Trigger Point Technologies, Austin, Texas, USA) up and down the anterior aspect of the thigh while in a seated position with the knee resting and extended. Subjects would then flex forward with their trunk to massage their anterior thigh. While it could be argued that this position placed the muscles of the thigh in an active state, the muscles are still thought to be relaxed as evidenced by electromyography recordings.\textsuperscript{18} Because the contact area during FR is likely greater, RM was applied with the self-massage stick at different angles in order to target all areas of the anterior thigh; i.e., medial (vastus medialis), lateral (vastus lateralis) and central (rectus femoris). Subjects were instructed to roll between the acetabulum and quadriceps tendon in fluid, dynamic motions. The pressure application was controlled by a pain level scale, in which a score of one represented no pain at all and a score of 10 represented the maximum pain that can be tolerated. Participants were instructed to apply pressure equivalent to between 6 and 8 on a pain level scale, similarly to instructions in previous work.\textsuperscript{5}

**Joint range of motion**

Passive hip flexion and extension ROM of the dominant limb were measured with a manual goniometer (Carci, São Paulo, BRA) using the standardized procedures outlined by Norkin and White.\textsuperscript{19} Hip flexion ROM was assessed in a supine position with the test knee flexed and the opposite knee extended (Figure 4A). A blood pressure cuff was placed under the lumbar spine and inflated to 60 mmHg, at which it was maintained for the duration of the measurement to ensure a stable lumbar spine.\textsuperscript{20} The test hip was

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**Figure 2.** The foam rolling procedure. A. starting point, B. end point.\textsuperscript{6}

**Figure 3.** The rolling massage procedure. A. starting point, B. end point.
In order to identify differences between different time points, 95% confidence intervals (CI) of the change scores from the greatest baseline measure were calculated. 95% CI of the difference between these change scores were then calculated in order to identify between-intervention differences. Normality of the differences was ensured using the Shapiro-Francia test. Rather than traditional null hypothesis statistical testing, 95% CI were used in order to prevent the dichotomous interpretation of the results, to increase the likelihood of correct interpretation, and to allow for a more nuanced and qualitative interpretation of the data. For differences with a 95% CI that includes zero, it cannot be concluded that the observed differences are not due to chance alone; in other words, the observation are statistically different from one another when the 95% CI of differences does not equal zero. Additionally, Cohen’s $d$ effect-sizes were calculated using the formula $d = \frac{M_d}{s_d}$, where $M_d$ is the mean difference and $s_d$ is the standard deviation of differences. This calculation differs slightly from traditional Cohen’s $d$ calculations, in that it better represents within-subject differences, whereas the traditional Cohen’s $d$ formula is better fit for between-subject comparisons. Cohen’s $d$ effect-sizes were defined as small, medium, and large for 0.2, 0.5, and 0.8, respectively. The combination of effect-sizes and 95% CI will therefore allow for a more nuanced and less polarizing interpretation of the results of the study.

In order to ensure that measures were greater than measurement error, minimum detectable change (MDC) scores were calculated at the 95% level. In order to calculate MDC, standard error of measurement (SEM) was calculated first, using the formula $SEM = SD_{test} \sqrt{1 - ICC}$, where $SD_{test}$ is the standard deviation of scores from the first test and ICC is the test-retest intraclass correlation coefficient. Then, MDC at the 95% level was calculated using the formula $MDC = 1.96(SEM)\sqrt{2}$. MDC is distinctly different from testing to see if the difference between pre and post intervention measurements differs from zero, as MDC strictly pertains to measurement error calculated from the reliability of measurement, while testing to see if changes differ from zero pertains to the change score and its variance relative to

**Figure 4.** Passive hip range of motion measurements. A = passive hip flexion; B = passive hip extension.
Intervention with RM produced statistical increases in hip flexion and extension ROM when compared to the baseline (Table 3). Moreover, it remained statistically increased for 10- and 20-minutes post intervention, for both hip flexion and extension, respectively, with large effect sizes. However, for both hip flexion and extension, it only exceeded MDC immediately post and 10-minutes after intervention.

FR was statistically superior in improving hip extension ROM as compared to RM immediately post intervention relative to the baseline values with large effect size, as well as 30-minutes post with medium effect size (Table 3). Greater statistical increases in hip flexion ROM were also achieved in the FR condition as opposed to RM immediately post intervention and at 10- and 30-minutes post intervention (Table 3) with medium effect sizes. No other differences were found between interventions, and none of the observed differences exceeded the MDC.

**DISCUSSION**

The purpose of this study was to investigate the acute effects of foam rolling and rolling massage of anterior thigh on hip range-of-motion in trained men. The main findings of this study were: 1) FR and RM resulted in increased hip flexion and hip extension ROM immediately after intervention as compared to the baseline (Table 3). Furthermore, it remained statistically increased for 10-, 20-, and 30-minutes post intervention, respectively, with large effect sizes, but did not exceed MDC at 30-minutes post intervention. Similarly, hip extension ROM was statistically greater after the FR treatment and remained statistically increased for 10-, 20-, and 30-minutes post intervention, respectively, with medium to large effect sizes (Table 3). However, it only exceeded MDC immediately following treatment.

**RESULTS**

ICCs for baseline ROM measures and MDCs are presented in Table 1.

The means and standard deviations of ROMs for each condition and time point are presented in Table 2.

Mean within- and between-condition differences with accompanying 95% CIs and effect sizes are presented in Table 3. Hip flexion ROM statistically increased immediately after intervention with FR as compared to the baseline (Table 3). Furthermore, it remained statistically increased for 10-, 20-, and 30-minutes post intervention, respectively, with large effect sizes, but did not exceed MDC at 30-minutes post intervention. Similarly, hip extension ROM was statistically greater after the FR treatment and remained statistically increased for 10-, 20-, and 30-minutes post intervention, respectively, with medium to large effect sizes (Table 3). However, it only exceeded MDC immediately following treatment.

**Table 1.** Intraclass correlation coefficients between the two baseline measures of range of motion and minimal detectable change for each measure of range of motion to ascertain reliability of baseline measures and assess whether the changes were greater than measurement error, respectively.

<table>
<thead>
<tr>
<th>Measure</th>
<th>ICC</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip flexion FR</td>
<td>0.712</td>
<td>0.376–0.882</td>
</tr>
<tr>
<td>Hip extension FR</td>
<td>0.609</td>
<td>0.206–0.834</td>
</tr>
<tr>
<td>Hip flexion RM</td>
<td>0.535</td>
<td>0.129–0.793</td>
</tr>
<tr>
<td>Hip extension RM</td>
<td>0.583</td>
<td>0.194–0.818</td>
</tr>
</tbody>
</table>

**Table 2.** Means and standard deviation for hip range-of-motion across conditions and time points. All results are expressed in degrees.

<table>
<thead>
<tr>
<th></th>
<th>Baseline mean</th>
<th>Post 0</th>
<th>Post 10</th>
<th>Post 20</th>
<th>Post 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR flexion</td>
<td>90.11 ± 6.91</td>
<td>112.00 ± 9.15</td>
<td>107.11 ± 11.52</td>
<td>101.00 ± 7.58</td>
<td>95.89 ± 6.63</td>
</tr>
<tr>
<td>FR extension</td>
<td>7.11 ± 3.77</td>
<td>15.89 ± 3.39</td>
<td>12.22 ± 2.73</td>
<td>10.56 ± 2.97</td>
<td>8.67 ± 2.00</td>
</tr>
<tr>
<td>RM flexion</td>
<td>92.56 ± 7.12</td>
<td>108.44 ± 9.27</td>
<td>103.44 ± 9.91</td>
<td>98.56 ± 8.91</td>
<td>91.89 ± 7.69</td>
</tr>
<tr>
<td>RM extension</td>
<td>7.22 ± 2.18</td>
<td>12.78 ± 2.92</td>
<td>11.33 ± 2.91</td>
<td>9.33 ± 2.91</td>
<td>7.78 ± 1.80</td>
</tr>
</tbody>
</table>

FR = foam rolling, RM = rolling massage; ‘Baseline mean’ = average of the two baseline scores, ‘post 0’ = immediately after intervention, ‘post 10’ = 10 minutes after intervention, ‘post 20’ = 20 minutes after intervention, ‘post 30’ = 30 minutes after intervention.
Both interventions resulted in statistically increased ROM for 30-minutes post intervention. Findings from previous studies investigating the time course of acute effects of self-massage on increases in ROM are unclear, as some have found ROM to be increased only immediately post intervention,\(^1\) while others have found increases for at least 10 minutes,\(^2,5,17\) but not 30 minutes following the intervention.\(^17\) The discrepancy between studies may be a function of many parameters, including muscle group treated, volume of the intervention, level of pressure, and method of testing ROM. Considering the MDC in our study, hip extension ROM following FR and flexion following RM increased ROM only immediately post intervention, while hip extension ROM following RM remained increased 10 minutes post intervention. The former results are in line with Škarabot et al.,\(^11\) while the latter are in agreement with other studies.\(^2,5,17\)

Interestingly, it was found that self-massage applied to the anterior thigh not only affects hip extension – as has been shown previously\(^4,6,30,31\) – but also affects hip flexion. This is a novel and important finding, as it suggests that the ROM effects of self-massage likely have a central component. Such a finding is in line with previous work by Aboodarda et al.,\(^13\) who found that self-massage applied to the calves not only

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**Table 3. Mean within- and between-condition differences in hip range-of-motion, 95% confidence intervals and effect sizes.**

<table>
<thead>
<tr>
<th></th>
<th>Post 0 - baseline</th>
<th>Post 10 - baseline</th>
<th>Post 20 - baseline</th>
<th>Post 30 – baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean difference</td>
<td>95% CI</td>
<td>d</td>
<td>Mean difference</td>
</tr>
<tr>
<td>FR flexion</td>
<td>21.89</td>
<td>18.72, 25.06*</td>
<td>3.4</td>
<td>17.00</td>
</tr>
<tr>
<td>FR extension</td>
<td>8.78</td>
<td>6.81, 10.74*</td>
<td>2.2</td>
<td>5.11†</td>
</tr>
<tr>
<td>RM flexion</td>
<td>15.89</td>
<td>11.98, 19.80*</td>
<td>2.0</td>
<td>10.88†</td>
</tr>
<tr>
<td>RM extension</td>
<td>5.56</td>
<td>4.45, 6.66*</td>
<td>2.5</td>
<td>4.11</td>
</tr>
<tr>
<td>FR vs. RM flexion†</td>
<td>6.00</td>
<td>0.91, 11.09*</td>
<td>0.6</td>
<td>6.11</td>
</tr>
<tr>
<td>FR vs. RM extension†</td>
<td>3.22</td>
<td>1.17, 5.27*</td>
<td>0.8</td>
<td>1.00</td>
</tr>
</tbody>
</table>

(*) illustrates statistically different as CI does not include 0; (†) illustrates values that did not exceed Minimum Detectable Change; FR = foam rolling, RM = rolling massage; ‘d’ = Cohen’s d; ‘baseline’ = average of the two baseline scores, ‘post 0’ = immediately after intervention, ‘post 10’ = 10 minutes after intervention, ‘post 20’ = 20 minutes after intervention, ‘post 30’ = 30 minutes after intervention.
increases pain pressure tolerance in the ipsilateral calf, but also the contralateral calf, suggesting central pain modulation may be at play. More recently, Kelly & Beardsley \textsuperscript{13} demonstrated a crossover effect, whereby foam rolling the ipsilateral calf not only increased ipsilateral dorsiflexion ROM, but also contralateral dorsiflexion ROM. These effects are similar to the non-local effects observed in stretching.\textsuperscript{32,33} Furthermore, it has been suggested that self-massage of the agonist can impede muscle activation of the antagonist,\textsuperscript{34} but it should be noted that it cannot be said for certain that the observed difference was real, since it did not exceed the MDC.\textsuperscript{35} Therefore, it appears that the effects of self-massage are not specific to the region(s) treated.

The ability for one to experience treatment effects in regions to where the treatment was not applied has important clinical applications. For example, if one has a wound to which pressure cannot be applied, but increased ROM is desired, such as following a proximal hamstrings repair,\textsuperscript{36} then self-massage applied to the quadriceps may be a viable option for increasing hip flexion ROM. The findings of this investigation and others\textsuperscript{13,15,32,33} evidence that non-local changes do indeed occur, which can allow for practitioners to improve their patients’ ROM without endangering the potentially-sensitive tissue surrounding the muscle of interest. Lastly, the choice of modality (i.e., FR or RM) may not be as important for maximal effectiveness.

In addition to the ROM findings, the results of this present study are also consistent with previous work by the authors of the present experiment.\textsuperscript{37,38} More specifically, it was found that self-massage applied to the agonist or antagonist musculature affected agonist performance during multiple sets of knee extensions. These effects were hypothesized to be attributable to a central opioidergic response, which could also account for the improvements in ROM observed in this present study.\textsuperscript{9} Specifically, in more noxious variations of massage therapy, such as self-massage, a descending inhibitory response is elicited via endogenous opioids and other neuropeptides acting on the periaqueductal grey and rostral ventromedial medulla.\textsuperscript{9} On a psychological level, such effects may be modulated by expectations,\textsuperscript{39} which have been shown to affect force inhibition/facilitation responses to stretching interventions.\textsuperscript{40} Furthermore, analgesia induced by techniques such as self-massage could have been mediated by autonomic nervous system (ANS) activity;\textsuperscript{41} that is, a shift from sympathetic to parasympathetic tone. The mechanism behind this ANS shift remains unclear, but it can be hypothesized that certain hormones and neuropeptides may be at play given that massage has been associated with changes in stress hormones\textsuperscript{42} (e.g., cortisol) and neuropeptides\textsuperscript{9} (e.g., endogenous opioids, oxytocin and endocannabinoids), and that the aforementioned hormones and neuropeptides that are associated with a sympathetic shift also play a role in descending modulatory pathways,\textsuperscript{43,44} which could account for changes in ROM. In essence, descending inhibition may have a role in stretch tolerance and, due to its diffuse nature, may explain the non-local effects observed in this study and others.\textsuperscript{13,15,32,33} However, despite the logical basis for the aforementioned neurophysiological mechanisms, the present investigation did not investigate them, and direct research into the mechanisms of self-massage are needed to further elucidate such mechanisms.

There are a number of limitations that should be taken into account when interpreting the findings in this study. Firstly, although the investigator was blinded as to which intervention was performed, the investigator was not blinded as to whether or not the participant performed an intervention. It is therefore possible that both the investigator and participant expected, and thus saw, improvements in ROM following each intervention. Moreover, goniometry was used to measure hip ROM, which is less objective than motion capture; however, because the changes exceeded the MDC, at least some of the observed changes are likely real. Secondly, the pace of rolling was not controlled for in both conditions, thereby reducing internal validity of the results due to the possibility of pace-dependent outcomes.\textsuperscript{6} However, not controlling for pace enhances ecological validity of the findings, as it is a better representative of the scenario in practice. Thirdly, participants in this study were males, and different results may be observed in females. Lastly, passive ROM was measured and improvements in passive ROM may not necessarily transfer to mobility in functional movement patterns.\textsuperscript{45} However, from a perspective of central mechanisms, the results are...
still relevant. Future studies in the area should try to expand these findings onto functional movement patterns. Notwithstanding these limitations, this work has important clinical and mechanistic implications, as it demonstrates that self-massage applied to the anterior thigh will not only increase hip extension ROM, but also hip flexion ROM.

CONCLUSIONS
The results of the present study indicate that FR and RM of the anterior thigh are equally effective at increasing hip flexion as well as hip extension ROM. These findings strongly suggest that the mechanisms for changes in ROM are at least partially central in nature, and further suggest that self-massage has a global effect. More data are needed to investigate the effects of foam rolling and roller massage on other joints and in other populations (e.g., rehabilitative).

REFERENCES
ABSTRACT

Study design: Case series

Background and purpose: The literature has emphasized the use of exercise as an intervention for individuals with lumbopelvic pain. However, there is limited information to guide clinicians in exercise selection for those with sacroiliac (SI) joint dysfunction. Altered function of the gluteus maximus has been found in those with SI joint dysfunction. The objective of this case series was to assess the effectiveness of an exercise program directed at increasing gluteus maximus strength in those with clinical tests positive for SI joint dysfunction.

Case descriptions: The eight subjects in this series presented with lumbopelvic pain and clinical evidence of SI joint dysfunction. Each subject underwent 10 treatments over five weeks consisting of five exercises directed at strengthening the gluteus maximus. Radiological assessment and clinical examination were performed to rule out potential concurrent pathologies. Visual analog pain scale, the Oswestry Disability Index, and strength assessed via hand held dynamometry were measured pre- and post-intervention.

Outcomes: A significant (p<0.001) weakness in gluteus maximus was noted when comparing the uninvolved and involved sides pre-intervention. After completing the strengthening exercise program over 10 visits, statistically significant (p<0.002) increases in gluteus maximus strength and function were found, as well as a decrease in pain. All subjects were discharged from physical therapy and able to return to their normal daily activities.

Discussion: The results of this case series support the use of gluteus maximus strengthening exercises in those with persistent lumbopelvic pain and clinical tests positive for SI joint dysfunction.

Key words: Hip, low back pain, rehabilitation, sacroiliac joint
BACKGROUND AND PURPOSE
Despite sacroiliac joint (SI) dysfunction being a well-documented clinical entity that can result in pain and loss of function, there is little research available to direct treatment interventions. This includes specific exercise selection. Previous authors have suggested that altered gluteus maximus muscle function can be associated with SI joint dysfunction. However, the effectiveness of an exercise program directed at increasing gluteus maximus strength in those with clinical tests positive for SI joint dysfunction has not been studied.

The SI joint provides the link for ground reaction forces between the lower extremities and trunk during weight-bearing activities. Proper activation of abdominal, leg, and back musculature allow for normal load transmission across the lumbopelvic region. Specifically, a relationship between the gluteus maximus and SI joint has been studied. Anatomical studies suggest the gluteus maximus can contribute to stabilizing the SI joint with muscle fibers being perpendicular to the joint surfaces. Additionally, activation of the gluteus maximus was found to increase compressive force across the SI joint. Clinical studies have shown individuals with SI joint dysfunction demonstrate abnormal gluteus maximus recruitment during weight bearing activities. Therefore it is hypothesized that weakness of the gluteus maximus can be related to abnormal loading of the SI joint and be a cause of the impairments associate with SI joint dysfunction.

There is evidence to suggest that exercises directed at improving gluteus maximus function should be included as an intervention in those with SI joint dysfunction. The aim of this study was to report the outcome of eight subjects with lumbopelvic pain and clinical tests positive for SI joint dysfunction who participated in an exercise program directed at increasing gluteus maximus strength. This work received approval from the Institutional Review Board of Santa Casa Hospital, São Paulo-SP, Brazil and all participants gave informed, written consent prior to participation.

CASE DESCRIPTION
The eight subjects were evaluated at baseline and after 10 treatment sessions. The mean age of the subjects was 33 years (range, 18-43 years), 4 females and 4 males, 6 were considered sedentary and 2 were active, with average pain duration of 13 months (range, 5-24 months). All subjects were recruited at Santa Casa Hospital. Evaluation consisted of an assessment of trunk and hip range of motion, visual analog scale (VAS) pain assessment and self-reported level of function using the Oswestry Disability Index. Gluteus maximus strength was measured with a hand-held dynamometer. Slump Test, Laseque straight-leg maneuver, Piriformis Test (buttock or sciatic pain during hip medial rotation), Grava Test (pain during hip adduction and abdominal contraction in a prone position), flexion-abduction and external rotation test (FABER), and the Scour Test were performed to rule out concurrent sources of symptoms.

Four clinical tests were used to assess for SI dysfunction, as described by McGrath et al. These tests included the SI compression, SI distraction, Squish, and Gaenslen. Subjects were considered to have SI dysfunction when at least three out of four of these tests were positive with pain provocation. The results of these tests are provided in Table 2. Only subjects with clinical evidence of SI dysfunction were included in the study. Moreover, all subjects included in this study had lumbopelvic pain.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Age (year)</th>
<th>Gender</th>
<th>Relevant History</th>
<th>Symptom duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18</td>
<td>Female</td>
<td>Sedentary / Student</td>
<td>5 months</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>Male</td>
<td>Recreational soccer player</td>
<td>1 year</td>
</tr>
<tr>
<td>3</td>
<td>27</td>
<td>Male</td>
<td>Run 3 times per week</td>
<td>1 year</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>Female</td>
<td>Sedentary / Teacher</td>
<td>2 years</td>
</tr>
<tr>
<td>5</td>
<td>38</td>
<td>Female</td>
<td>Sedentary</td>
<td>6 months</td>
</tr>
<tr>
<td>6</td>
<td>41</td>
<td>Female</td>
<td>Sedentary</td>
<td>1 year</td>
</tr>
<tr>
<td>7</td>
<td>43</td>
<td>Male</td>
<td>Sedentary / Driver</td>
<td>10 months</td>
</tr>
<tr>
<td>8</td>
<td>26</td>
<td>Male</td>
<td>Sedentary</td>
<td>2 years</td>
</tr>
</tbody>
</table>
study had unilateral lumbopelvic pain in the SI region for at least 12 weeks (chronic) and had no previous physical therapy treatment. Subjects with clinical and imaging evidence of any spinal or pelvic co-morbidity potentially responsible for pain radiating through the sacroiliac region, signs of lower limb length discrepancy, or with cognitive deficiency were excluded.

It is important to highlight that none of the subjects had SI joint degeneration, as evaluated by antero-posterior pelvic X-rays.

**Exercise Protocol for Gluteus Maximus Strength**

The subjects attended physical therapy two times per week for a total of 10 visits. Each visit lasted approximately 30 minutes. In the first five sessions, subjects performed the following exercises to strengthen the gluteus maximus: bilateral bridge, unilateral bridge, and non-weight-bearing hip extension in prone with the knee flexed at 90 degrees. In the next five sessions, abduction and external rotation in a quadruped (“fire hydrant” exercise) and weight-bearing hip extension (known as “deadlift” exercise) (Figure 1) were added. This exercise program was developed and based on previous electromyography studies.20,21 Each exercise was performed for 10 repetitions. Elastic resistance was added to the fire hydrant, hip extension in prone and deadlift exercises to allow each subject to perform at a 10-repetition maximum. The resistance for each

**Table 2. Results of clinical tests.**

<table>
<thead>
<tr>
<th>Tests</th>
<th>Subjects</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<tbody>
<tr>
<td>Slump</td>
<td></td>
<td>-</td>
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<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
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<tr>
<td>Lasegue</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Piriformis</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Grava</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>FABER</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>+</td>
<td>+</td>
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<td>+</td>
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<td>+</td>
</tr>
<tr>
<td>Distraction</td>
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<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Squish</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Gaenslen</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

**Figure 1.** Exercises of the gluteus maximus strengthening program. A) Bilateral bridge, B) Unilateral bridge, C) Hip abduction in quadruped, D) Hip extension in prone (with knee flexed), E) Dead lift.
effort was used. A pilot study was performed to assess reliability of this strength assessment. Eight healthy volunteers (four men and four women) were tested according to the protocol described above. The results of measuring muscle strength indicated good reliability, with intraclass correlation coefficients (ICCs 2.1) of 0.86.\textsuperscript{11,16}

A comparison between the pre- and post-intervention was performed using the paired t-test with p values set at 0.05. The software Statistical Package for Social Sciences (SPSS), version 19.0 was used for these analyses.

### OUTCOMES

The results of the strength assessments are provided in Table 3. Significant (p<0.001) gluteus maximus weakness was noted when comparing the uninvolved to involved sides. After completing the 5-week exercise program, a significant (p=0.002) increase in gluteus maximus strength on the involved side was found, ranging from 17%-29% (Table 3). No changes were observed on the uninvolved side in the pre-versus post-treatment analyses. Additionally, a significant (p<0.001) decrease in pain as noted on the VAS and a significant (p<0.001) increase self-reported function as noted with by the Oswestry (Table 4) were also identified when comparing pre- and post-intervention values. All subjects were discharged from physical therapy and able to return to their normal daily activities.

### DISCUSSION

The results of this case-series indicate that subjects with persistent pain in the lumbopelvic region and

![Figure 2. Position for gluteus maximus strength assessment.](image)

---

**Table 3.** Strength of gluteus maximus muscle in the involved and uninvolved side at baseline and re-evaluation (5-week post-treatment evaluation).

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Baseline (kg)*</th>
<th>Re-evaluation (kg)</th>
<th>Change (%)**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Uninvolved</td>
<td>Involved</td>
<td>Involved</td>
</tr>
<tr>
<td>1</td>
<td>19.6</td>
<td>15.5</td>
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<tr>
<td>2</td>
<td>24.8</td>
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<td>24.9</td>
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<tr>
<td>3</td>
<td>22.9</td>
<td>19.7</td>
<td>24.6</td>
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<td>4</td>
<td>14.7</td>
<td>12.1</td>
<td>15.4</td>
</tr>
<tr>
<td>5</td>
<td>16.9</td>
<td>13.9</td>
<td>17.3</td>
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<tr>
<td>6</td>
<td>15.4</td>
<td>13.1</td>
<td>17.0</td>
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<tr>
<td>7</td>
<td>23.9</td>
<td>20.5</td>
<td>25.1</td>
</tr>
<tr>
<td>8</td>
<td>26.3</td>
<td>22.3</td>
<td>26.1</td>
</tr>
</tbody>
</table>

* Statistically different between groups (p<.001)
** Statistically different post-treatment in the involved side (p=.002)
stabilized the SI joint, subjects in this study had a significant decrease in pain and improvement in function. Previous research has shown that exercises are effective in altering pain and functional disability in subjects with segmental lumbar instability and altered motor recruitment patterns. It has been hypothesized that delayed onset of the gluteus maximus may alter the compressive force on the SI joint and hinder mechanisms required for load transfer. Delayed onset of the gluteus maximus contraction has been identified in those with SI joint pain. Therefore it would seem appropriate that exercises should be directed at improving the gluteus maximus timing and function. While it is not known whether the gluteus maximus activation patterns were normalized, the subjects demonstrated an increase in strength and improved function.

In the treatment of those with low back pain, evidence supports the use of the joint mobilization and exercise. Identifying SI dysfunction can be difficult in subjects with low back pain. Furthermore, diagnosing the exact cause of SI joint pain is controversial. However, research suggests that SI dysfunction is present when three out of four tests (SI compression, SI distraction, squish, and Gaenslen) were positive. The results of the current case-series suggest that in those with lumbopelvic pain and clinical tests positive for SI joint dysfunction, exercise directed at strengthening the gluteus maximus should be included in the overall exercise program. When analyzing the strength assessment data of the subjects considered “active” (patients 2 and 3), there were no significant differences when compared to the sedentary subjects (others), which indicates a possible beneficial effect for both populations.

One of the limitations of this study was the small sample size, as is typical with case series research. However, even with only eight subjects significant differences in strength, VAS, and function were found. Considering the minimal clinically important differences (MCID) used to measure pain and function, all subjects presented clinically significant changes (Table 4): at least a reduction of two points on VAS scale, and a difference of six points on the Oswestry Disability Index questionnaire.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>VAS* Before</th>
<th>VAS* After</th>
<th>Oswestry* Before</th>
<th>Oswestry* After</th>
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<tr>
<td>1</td>
<td>10</td>
<td>1</td>
<td>80</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
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<tr>
<td>8</td>
<td>10</td>
<td>1</td>
<td>90</td>
<td>16</td>
</tr>
</tbody>
</table>

VAS= Visual analogue scale, 0-10 cm where 0 means “no pain” and 10 means “worst imaginable pain during last week”. Oswestry (0-100 points, higher score represents more incapacity). * Statistically different between groups for the VAS and Oswestry (p<.001).
Further research is needed using a longer follow-up period, larger sample size and include a multi-modal intervention program with mobilization and a comprehensive exercise program that includes gluteus maximus strengthening.

CONCLUSIONS
The results of this case series of eight subjects with clinical tests positive for SI joint dysfunction with gluteus maximus weakness demonstrated improvements in function, pain, and strength after completing a strengthening program. These results support the inclusion of gluteus maximus strengthening exercises in those with persistent lumbopelvic pain and clinical tests positive for SI joint dysfunction. Further research is needed to determine the short- and long-term effectiveness of this approach in the overall management of subjects with SI dysfunction.

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ABSTRACT

Background and Purpose: Secondary impingement syndrome (SIS) is a common complaint in the sporting population particularly among athletes engaging in overhead activities. While symptoms may be present at the shoulder with patients complaining of SIS, spinal alignment or dysfunction can influence scapular positioning and overall shoulder girdle function. As an adjunct therapy to traditional interventions for SIS, thoracic high-velocity low-amplitude (HVLA) thrusts have been utilized and correlated with patient reported decreases in pain. Mulligan Concept (MC) thoracic sustained natural apophyseal glides (SNAGs) are an emerging treatment intervention utilized to treat patients with shoulder pain and dysfunction as the evidence supporting an interdependent relationship between the thoracic spine and the shoulder is growing. The purpose of this case series was to investigate the effects of one MC thoracic SNAG treatment session on subjects classified with SIS, while utilizing a classification-based treatment protocol.

Case Descriptions: Seven subjects classified with SIS were treated utilizing a MC thoracic SNAG. The Numeric Rating Scale (NRS) was administered at initial evaluation, immediately following intervention, and at the 48-h follow-up to identify patient-reported pain during range of motion, manual strength testing, and special tests of the shoulder. Investigators collected the Shoulder Pain and Disability Index (SPADI) at initial evaluation and the 48-h follow-up to identify patient-reported dysfunction.

Outcomes: Following one MC thoracic SNAG treatment (3 sets of 10 repetitions), minimal clinically important differences (MCIDs) were reported utilizing the NRS. A decrease in pain during active shoulder abduction (ABD) was detected immediately post-treatment, and the NRS change scores for resisted external rotation (RER) and active ABD were statistically different and clinically important at the 48-h follow-up.

Discussion: Based on the results of this case series, thoracic SNAGs may influence short-term pain levels and shoulder mobility in the included subjects with SIS and support the concept of regional interdependence (RI) between the thoracic spine and glenohumeral joint. Continued exploration into the proposed benefits of the MC thoracic SNAG treatment as an adjunct therapy when treating patients complaining of SIS is warranted.

Key Words: Impingement syndrome, regional interdependence, intervention

Level of Evidence: 4 (Case Series)
BACKGROUND AND PURPOSE

Secondary impingement syndrome at the glenohumeral joint, accounts for up to 44%-65% of all shoulder related medical visits. Secondary impingement, defined as impingement secondary to instability in the shoulder, occurs mostly in athletes, under 35 years of age, and completing overhead activity. Commonly, the physical presentation of patients classified with SIS includes a slouched posture or kyphosis, which is indicated by an increase of thoracic spine flexion, resulting in decreased elevation of the glenohumeral joint. A kyphotic posture may predispose athletes who participate in overhead sports such as swimming, tennis, baseball, football, volleyball, or javelin prone to developing symptoms of SIS due to the added demands of sporting activities at the shoulder. Patients with SIS may also develop compensatory motor patterns in the glenohumeral joint and thoracic spine in order to protect painful tissue. Dysfunction of the thoracic spine may influence shoulder complex function, therefore treatment focused away from the local glenohumeral joint on the thoracic spine could result in changes in shoulder pain and function.

In response, clinicians and researchers alike have begun to utilize the regional interdependence (RI) model to treat patients classified with SIS as the available evidence is limited regarding which traditional treatment method (i.e., rest, non-steroidal anti-inflammatory drugs [NSAIDs], corticosteroid injections, therapeutic exercise, passive modalities, and manipulation) is recommended. Regional interdependence is defined as, “seemingly unrelated dysfunction in a separate region of the body that may contribute to the patient’s chief complaint.” Utilizing the RI model and treating the thoracic spine utilizing interventions such as high-velocity low-amplitude (HVLA) thrusts and sustained natural apophyseal glides (SNAGs) in clinical practice creates an expanded approach for treating SIS beyond the traditional local techniques.

Application of HVLA thrusts occurs as a Grade-5 manipulation at the end-range of joint motion performed on a bony prominence and distinguished from other forms of manual therapy by an audible “pop”. Comparatively, Mulligan Concept (MC) sustained natural apophyseal glides (SNAGs) is a spinal mobilization technique which combines elements of active physiological movement with an accessory glide directed along the facet joint plane that facilitates pain-free movement throughout osteokinematic range of motion. To date, only HVLA thrusts have been investigated as a treatment for SIS.

Boyles et al assessed the short-term effects of HVLA thrusts demonstrating positive short-term effects with statistically significant results at 48-hour follow-up for shoulder pain and disability index (SPADI) and NPRS values for Neer Impingement Test, Hawkins Test, resisted empty can, resisted internal rotation, resisted external rotation, and active abduction utilizing HVLA thrusts in the management of SIS. Subjects between 18 and 50 years of age, reported a 2 or greater pain rating on a 10-point Numeric Pain Rating Scale (NPRS) with either a positive orthopedic special test in Category 1 and reported a 2 or greater on NPRS in either Category 2 or any resisted test in Category 3 (Table 2).

Unlike posterior to anterior manipulative procedures such as HVLA thrusts, the advantage of a thoracic SNAG is the facilitation of the correct physiological motion while in weight-bearing. The benefit of the thoracic SNAG treatment to the clinician is the ability to directly affect the painfully restricted movement, even in the acute stage, by using a movement that would normally increase the patient’s symptoms but are now pain-free. The MC primary guidelines and concept stress the treatment should be pain free, immediate and long-lasting, referenced as the PILL concept. A clinician may incorporate a sub-therapeutic SNAG into their initial assessment and if the response matches the PILL concept, the SNAG is clinically indicated at the therapeutic level. Traditionally, researchers and clinicians alike have focused primarily on the painful arm movement rather than the RI theory that mobility of the thoracic spine may affect glenohumeral joint movement. Accordingly, the purpose of this case series was to investigate the effects of one Mulligan Concept thoracic SNAG treatment session on subjects classified with SIS, while utilizing a classification-based treatment protocol.
Description of Cases: Participant History and Systems Review

Two primary investigators who averaged 12 years of clinical experience, and had both completed three Mulligan Concept Upper Extremity courses that included practical training in the use of cervical and thoracic SNAGs were involved in this case series. Both investigators ensured standardization of all examination, outcome assessments, and treatment techniques performed through video recordings and communication. Investigators established a standard body position at the start of each shoulder motion measurement, and measured glenohumeral joint ROM utilizing the Clinometer application available on a smart phone, via both the android and iOS platforms. The same MC thoracic SNAG treatment protocol was utilized for all patients, although application of the protocol regarding force and direction were specific to each subject. In an attempt to isolate the possible effects of the MC thoracic SNAG, no other intervention (e.g., stretching, modalities, or home program) were applied, nor were modifications of activity imposed.

Seven consecutive patients (6 males, 1 female) representing three “in-season” sports (water polo, baseball, basketball) and one “off-season” sport (volleyball) (Table 1) ranging in age from 15-22 years (mean = 19±2.83) who presented to the clinic with complaints of SIS were included in this multi-center case series. All subjects denied an acute musculoskeletal injury to the shoulder within the previous 30 days or receiving prior treatment for the current presentation of shoulder pain. Each participant provided informed consent to use their patient case and data, and participant confidentiality was protected according to the United States’ Health Insurance Portability and Accountability Act (HIPPA).

Clinical Impression #1

Secondary Impingement Syndrome (SIS) is commonly addressed using treatments focused on reducing soft tissue (e.g., tendon, bursae) inflammation and increasing neuromuscular dynamics (e.g., strengthening, proprioception). As the subjects had not reported any previous treatment for the current presentation of shoulder pain and denied any acute musculoskeletal injury within the last 30 days, the cause of the subjects’ chief complaint was hypothesized to be a result of repetitive overhead activity. Further evaluation needed to be performed to determine whether the subjects could be classified with SIS versus a scapulothoracic restriction based on traditional evaluation techniques.

Examination

Investigators began the examination of each subject by administering the Numeric Rating Scale (NRS), Shoulder Pain and Disability Index (SPADI) outcome measures, as well as collecting patient-reported history relating to duration, mode of onset, distribution of symptoms, nature of symptoms, aggravating/relieving factors, and any prior glenohumeral joint treatments. Physical examination included glenohumeral joint ROM, cervical ROM, Spurling’s test, Cervical Distraction test, and special tests for the shoulder. The subject self-reported pain utilizing the NRS was reported during the completion of the following orthopedic special tests: Neer impingement test, Hawkins impingement test, active shoulder abduction, and resisted muscle tests for external rotation (RER), internal rotation (RIR), and empty can (REC). For the purpose of this study, due to secondary impingement syndrome not fitting the traditional definition of impingement syndrome, investigators defined SIS in subjects reporting a combination of weakness during resisted muscle testing, decreased activity of the rotator cuff muscles, crepitus, stiffness within the glenohumeral joint which may result in loss of activity and sleep.

<table>
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<tr>
<th>Table 1. Patient Demographics</th>
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<tr>
<td>Gender</td>
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<td>Sport</td>
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<td>Age</td>
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disturbances, or pain associated with arm elevation above the height of the shoulder while being internally rotated. Inclusion in the study occurred if participants met the classification-based inclusion criteria established by Boyles et al. (Table 2). Participants were excluded from the study if they met any of the exclusion criteria listed in Table 3. After consent was obtained, each patient was assessed to determine the vertebral level for treatment by the clinician superficially palpating for spinous process tenderness at T1-T7 vertebral levels, followed by the patient performing active trunk extension with hands over head to elicit pain over the thoracic spinous processes while the clinician superficially palpated to determine the level of vertebral hypomobility (Figure 1). The mobility of the vertebrae was judged to be normal, hypomobile or hypermobile. Interpreting the mobility was based on the clinician’s perception and experience of rating mobility of a spinal segment. The matched level of spinous process tenderness and hypomobile segment was deemed the initial treatment level (Table 4). The clinician completed a single sub-therapeutic dose of the thoracic SNAG, at the established treatment level (the determined hypermobile segment). After identifying the painful or restricted level the clinician placed one arm around the patient’s chest above the established treatment level, while placing the ulnar border of the mobilizing (treatment) hand over the thoracic spinous process of the determined level and performed a single thoracic SNAG using a cephalad glide applied parallel to the facet joint plane (i.e. toward the patient’s eyes) (Figure 1). The patient actively performed one repetition of trunk extension returning to the starting point while the clinician continued to apply the glide. The subject then reported whether an immediate pain-free

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**Table 2. Inclusion Criteria (Boyles et al., 2009)**

<table>
<thead>
<tr>
<th>Category 1</th>
<th>≥ 2 NRS</th>
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<tbody>
<tr>
<td></td>
<td>Neer’s Impingement Sign</td>
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<td></td>
<td>Hawkins Impingement Sign</td>
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<td>Category 2</td>
<td>≥ 2 NRS</td>
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<td></td>
<td>Active Shoulder Abduction</td>
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<td>Category 3</td>
<td>≥ 2 NRS</td>
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<td>Resisted Internal Rotation</td>
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<td>Resisted External Rotation</td>
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<td>Empty Can</td>
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† = Required to have NRS of ≥2 on either test in Category 1 and an NRS of ≥2 with one test in Category 2 or 3

**Table 3. Exclusion Criteria**

- Primary complaint of neck or thoracic pain
- Demonstrated neurological deficit
- Positive Spurling’s test
- Received shoulder mobilization or thoracic manipulation for current shoulder pain within the last 30 days
- Received cortisone injection into the shoulder joint within the last 30 days

**Table 4. Thoracic SNAG Treatment Level**

<table>
<thead>
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<th>Patient #1</th>
<th>T7</th>
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<tr>
<td>Patient #2</td>
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<td>Patient #3</td>
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<td>Patient #5</td>
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<tr>
<td>Patient #6</td>
<td>T6</td>
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response was achieved. A subject report of an immediate pain-free response indicated the treatment level was determined. In the event the patient did not report a pain-free effect to the single sub-therapeutic application, the clinician adjusted (e.g., redirected angle and/or intensity) the thoracic SNAG and performed a second application. Inability to elicit a pain-free response at the originally assessed level caused the clinician to move to the next vertebral level directly adjacent to the originally assessed segment and provide another single sub-therapeutic thoracic SNAG. A maximum of three consecutive vertebral levels was assessed, and the treatment level was determined as the level in which the sub-therapeutic dosage of the thoracic SNAG the patient reported the pain-free effect.

Clinical Impression #2
Based on the ROM measurements, results of special tests, and patient-reported history, the investigators developed the working clinical diagnosis of SIS as a result of thoracic restriction. As the subjects’ complaints were consistent with the examination results and traditional treatments had yet to be administered, investigators focused treatment on the thoracic region in an attempt to use a RI treatment approach. It was theorized that utilizing MC thoracic SNAGs could assist in resolving any underlying positional fault of the thoracic spine that may have been contributing to their decreased mobility at the glenohumeral joint resulting in a clinical presentation of SIS.

OUTCOME MEASURES
To evaluate the effect of treatment for SIS, patient-reported outcome measures were utilized to assess perceived levels of pain (NRS) and functional disability (SPADI) as well as impairment based outcomes (i.e., active shoulder ROM) to measure shoulder function. Investigators utilized minimal clinically important differences (MCIDs) and minimal detectable change (MDC) to interpret patient-reported outcomes measures including the benefits derived from treatment, the impact upon the patient, and the implications for clinical management of the condition. Outcome measurements were collected at the initial evaluation, immediately post-treatment, and 48-hours post-treatment. A description of each outcome measure is listed in Table 5.

INTERVENTION
Treatment began at the vertebral level determined during the patient evaluation and sub-therapeutic thoracic SNAG assessment (Table 4). The investigator provided verbal instructions for the patient to move into trunk extension and provide over-pressure at the end-range of motion while the investigator maintained the transverse glide for a set of 10 repetitions (Figure 1). After the patient clearly understood treatment parameters and the importance of a pain-free treatment, each patient was treated therapeutically. Upon completion of the first set of 10 repetitions, the patient rested for one minute. The clinician then re-applied the thoracic

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<th>Table 5. Description of Outcome Measures</th>
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<td><strong>Outcome Measure</strong></td>
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<td>Numeric Rating Scale (NRS)</td>
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<tr>
<td>Shoulder Pain and Disability Index (SPADI)</td>
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SNAG at the previously identified level for a total treatment of 3 sets of 10 repetitions with one-minute rest between sets. Total treatment time was less than five minutes.

Immediately following the thoracic SNAG treatment, patients were re-evaluated for pain levels using the orthopedic special tests, resisted muscle tests, and ROM to examine the effects of one treatment of thoracic SNAGs. After completing treatment, all patients resumed normal sport activity. Patients returned to the clinic 48-hours after initial treatment for follow-up with the same provider. Outcomes collection of pain levels (NRS) for orthopedic special tests, function (SPADI), and ROM measurements to assess short term effects on pain and function were conducted. No treatment/examination was conducted at the follow-up and the patient was considered to have completed the study at this time. One patient (N=1) was excluded from the study after failing to return for the 48-hour post-treatment follow-up due to illness unrelated to treatment.

**DATA ANALYSIS**

All data was analyzed using SPSS version 22.0 (SPSS Inc., Chicago, IL, USA). One-way repeated measures analysis of variance (RM-ANOVA) tests were conducted to evaluate the effect of MC SNAGs on the NRS, and shoulder ROM across time. Mean differences from the initial visit scores and 95% confidence intervals (CIs) were calculated for the NRS, and shoulder ROM for post-treatment and at 48-hour follow-up. Significant changes were further analyzed with Bonferroni post hoc testing. Prior to data analysis, normality of distribution was assessed and the alpha level was set at p < .05. Effect size differences were computed with partial eta squared ($\eta^2_p$). A small effect size is $\eta^2_p = 0.02$; medium effect size is $\eta^2_p = 0.13$; large effect size is $\eta^2_p = 0.26$.28

**OUTCOMES**

**Numeric Rating Scale (NRS)**

Application of Mulligan Concept thoracic SNAGs did not result in statistically significant improvements in pain (NRS) over time for Hawkins impingement test [Wilks’ Lambda = .453, F (2, 4) = 2.415, p < .05, $\eta^2_p = .547$, power = .257] or Neer impingement test [Wilks’ Lambda = .724 F (2, 4) = .763, p < .05, $\eta^2_p = .276$, power = .112]. (Table 6). The mean changes in NRS scores for Hawkins from initial visit to post-treatment (M = 0.00, 95% CI [3.65 - 3.65], p = .05), and from initial visit to 48-hour follow-up visit (M = .667, 95% CI [.511 - 1.84], p = .05) were not significant. Overall effect size ($\eta^2_p$) for pain was 0.55.

However, statistically significant improvements in pain (NRS) during resisted shoulder ROM did occur with resisted external rotation (RER) over time [Wilks’ Lambda = .180, F (2, 4) = 9.08, p < .05, $\eta^2_p = .820$, power = .715]. The mean changes in NRS for

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<th>Table 6. Statistical and Clinical Outcomes for Pain (NPRS) from Baseline to Post-Treatment and 48-hour Follow-up</th>
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<td><strong>Initial Evaluation</strong></td>
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<td>NRS</td>
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NRS = Numeric Rating Scale; MCID = Minimal Clinically Important Difference; EC = empty can; IR = internal rotation; ER = external rotation; ABD = abduction; * = Statistically significant $p <= .05$ ** = achieved MCID
RER from initial to post-treatment (M = 1.58, 95% CI [.621 – 2.54], p = .05), and from initial visit to 48-hour follow-up visit (M = 3.50, 95% CI [.550 – 6.45], p = .05 were significantly different. Although resisted internal rotation (RIR) over time [Wilks' Lambda = .246, F (2, 4) = 6.13, p < .05, η² = .754, power = .549] did demonstrate a large effect size, there was not a statistically significant difference.

**Shoulder Pain and Disability Index (SPADI)**
A paired samples (dependent) t-test was used to compare the mean baseline SPADI score to the 48-hour follow-up SPADI score after a single Mulligan Concept thoracic SNAG. The mean initial visit SPADI was 23.06 (+/-6.62) and the 48-hour follow-up visit was 16.28 (+/-10.19). A statistically significant decrease from the initial visit SPADI was achieved (t(5) = 3.25, p=0.05) however this value was not clinically significant (Table 7).

**Range of Motion (ROM)**
Mulligan Concept thoracic SNAGs failed to produce statistically significant changes in overall shoulder ROM for all measured motions over time. However, shoulder external rotation (ER) [Wilks' Lambda = .512, F (2, 4) = 1.90, p < .05, η² = .488, power = .212], and flexion (FLEX) [Wilks' Lambda = .482, F (2, 4) = 2.14, p < .05, η² = .518, power = .233] did demonstrate moderate effect sizes (Table 8).

**DISCUSSION**
In this multi-site case series, two practitioners of MC utilized thoracic SNAGs to attempt to decrease pain and improve disability at the glenohumeral joint in subjects initially classified with SIS. The Investigators developed this case series based on a report by Boyles et al,2 however due to low power in our study, identifying statistically significant differences was not possible. Based on the results of this case series, the use of thoracic SNAGs in patients classified with SIS may have an impact on short-term pain and disability. However, the changes observed did not reach the level of clinically meaningful difference. One possible reason why clinically significant change was not realized was that subjects reported pain and

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<th>Table 7. Statistical and Clinical Outcomes for Disability (SPADI) from Baseline to 48-hour Follow-up</th>
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<tr>
<td><strong>Initial Evaluation</strong></td>
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<td>SPADI</td>
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SPADI = Shoulder Pain and Disability Index; MCID = Minimal Clinically Important Difference; *Statistically significant different, p = .05

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<tr>
<th>Table 8. Statistical and Clinical Outcomes for Shoulder Range of Motion (ROM) from Baseline to Post-Treatment and 48-hour Follow-up</th>
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<td><strong>Initial Evaluation</strong></td>
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<td>ROM</td>
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<td>Shoulder FLEX</td>
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<td>Shoulder EXT</td>
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<td>Shoulder ABD</td>
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<td>Shoulder IR</td>
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ROM = Range of Motion; MDC = Minimal Detectable Change; IR = internal rotation; ER = external rotation; ABD = abduction; FLEX = flexion; EXT = extension; * = achieved MDC
dysfunction within 30 days of onset of symptoms, whereas Boyles et al.2 subjects had been experiencing shoulder pain for longer periods of time. This may explain the relatively low initial NRS and SPADI scores which could have resulted in a floor effect.

Additional factors why clinically significant change was not realized include the decision to treat the patient at a single thoracic level which differs from Boyles et al.2 who treated three different levels of the spine with HVLA, and the decision to treat subjects with a manual therapy intervention that does not fall under the category of manipulation. It is possible the single location was not the optimal treatment level and may illustrate the need to treat subjects with SIS using a multi-level intervention versus a single-level treatment approach. Likewise, a treatment intervention utilizing thoracic SNAGs in conjunction with a glenohumeral MWM may produce greater results for patients who do not respond favorably to the thoracic SNAGs alone. The evaluation of thoracic SNAGs in isolation from local interventions such as manual therapy directed at the glenohumeral joint may explain the lack of clinically significant differences that occurred during this case series. Pain associated with SIS may be a result of a local response to injury which may necessitate a local treatment intervention as suggested by Lewis4 and Teys29 who reported that for patients with shoulder pain, posteriorly directed pressure applied to the region of the humeral head led to an immediate increase in shoulder elevation range of motion and associated decrease in pain when compared with a sham and a control technique.

Boyles et al.2 did not report ROM values, therefore no comparison between this study and the results found by Boyles et al.2 could be achieved (Table 8), however several explanations for an immediate change of ROM are proposed. First, the application of thoracic SNAGs may improve thoracic mobility indirectly leading to improved shoulder range of motion. Otoshi et al.30 suggest that a reduction in thoracic kyphosis can lead to an improvement in shoulder ROM, and manual therapy that includes thoracic spine interventions may provide decreases in self-reported pain measures and disability in patients with SIS. Second, an increase in shoulder ROM may be a result of decreased neuromuscular inhibition. Cleland et al.31 demonstrated an increase in lower trapezius muscle strength immediately following thoracic manipulation. Lastly, a hypothesized hypoalgesic effect may contribute to the reduction of shoulder pain leading to an increase in shoulder range of motion.

Other research conducted regarding ROM and the shoulder include various research studies conducted to determine the effect of several stretching protocols aiming to improve glenohumeral internal rotation deficit (GIRD), a possible precursor to SIS. For example, one investigation utilizing a sleeper stretch demonstrated an average 12.4° increase in subjects over a four-week static stretching program.32 Similarly, use of sleeper stretches produced an increase of 3.1° in IR after one treatment session.33 In a collegiate baseball population, a four-week stretching-plus-mobilization protocol demonstrated an increase of 19° in IR in subjects.34 Linter et al.35 reported IR increases however, those increases were only achieved after a three-year IR stretching program. Shoulder ROM improvements associated with stretching protocols are found with static stretching, but the findings also suggest the improvements required repetitive application of the stretching protocols targeted to specific musculoskeletal tissues over extended time frames.

**LIMITATIONS AND FUTURE RESEARCH**

Limitations of this study include a lack of a control group or randomization of patients, and that only short-term follow-up was conducted. A limitation inherent to all case series research is a small sample size and relatively specific patient population. Despite these limitations, the results of this case series demonstrate the potential to reduce pain and disability in patients classified with SIS. Continued investigation utilizing a cohort study format is needed to determine if the observed total mean changes for shoulder IR, ER, and FLEX ROM in this study from a single MC thoracic SNAG treatment challenge the efficacy of static stretching protocols. Also, cohort studies comparing immediate results of Mulligan Concept thoracic SNAGs versus thoracic manipulation and Mulligan Concept thoracic SNAGs combined with a glenohumeral MWM would be beneficial in determining the effectiveness of the thoracic SNAG technique. Additional research is also necessary to determine the effectiveness of a single...
treatment versus the cumulative effects of multiple thoracic SNAG treatments on multiple spinal segments when warranted.

CONCLUSION
The present case series is the first to investigate the use of thoracic SNAGs for the treatment of SIS. Based on the increases seen in shoulder internal and external rotation and shoulder flexion (ROM), as well as decreases in pain (NRS) with resisted external rotation (RER), the thoracic spine treatment intervention demonstrated in this case series, appears to benefit patients classified with SIS which supports the RI model. Although additional studies with larger sample sizes are needed to establish the clinical value of utilizing a single treatment session thoracic SNAG to treat patients complaining of SIS, this case series provides an initial framework for a clinical model utilizing manual therapy through regional interventions for patients with SIS.

REFERENCES


ABSTRACT

Background and Purpose: Early sport specialization (ESS) refers to intense training year round in a specific sport starting at a young age with no or limited participation in other sports. This approach to training is highly controversial; recent literature suggests that this type of specialized training could be a contributing source to overuse injuries in youth athletes. The purpose of this case report was to describe a patellofemoral articular cartilage defect of the knee in a preadolescent skier due to overuse and repetitive microtrauma as a result of ESS.

Study Design: Case Report

Case Description: A healthy 11-year-old male competitive alpine skier presented with recurrent swelling of his right knee and persistent anterior knee pain while skiing without evidence of any specific history of injury or traumatic event. The patient failed a conservative treatment regimen including rest and formal physical therapy focused on generalized knee strengthening. Magnetic resonance imaging was ordered and revealed an articular cartilage defect of the medial patellar facet. The patient was treated with an arthroscopic debridement of his articular cartilage defect.

Outcome: At 12 weeks postoperatively, the patient presented with a normalized gait pattern, no evidence of knee effusion, full knee range of motion and patellar mobility symmetric to his contralateral limb, and no patellar crepitation or painful palpation on physical exam. The patient was released to begin return to sport progression at 12 weeks, and was cleared for full activities/returned to competitive skiing at 15 weeks postoperatively. At 16 weeks postoperatively, he won an international alpine ski race in Europe for his age group.

Discussion: Cartilage injuries and osteochondral defects are very common in adolescent athletes and often go undiagnosed. Allied healthcare professionals must be educated on the known causes of recurrent knee effusions and how early sport specialization may result in overuse injuries to knee joint cartilage.

Level of Evidence: 4

Key Words: Anterior knee pain, early sport specialization, overtraining, overuse injuries
INTRODUCTION

It is estimated that 27 million U.S. youths participate in team sports, and approximately 60 million participate in some type of organized athletics.1 Most adolescents have taken to specializing in one sport as opposed to participation in multiple sport disciplines. Early sport specialization (ESS) refers to intense training year-round in a specific sport starting at a young age. This approach to training is highly controversial; recent literature suggests that this type of specialized training may increase the rate of acute injuries, overuse injuries, and ultimately lead to decreased sports participation.2-4

Sports which require high velocity movement and change of direction demands, for example alpine skiing, can lead to lower extremity overuse injuries.5,6 Anterior knee pain (AKP) is a common complaint in youth athletes.7 This complaint is usually diagnosed as patellofemoral pain and treatment commonly consists of nonoperative physical therapy, with a rehabilitation emphasis placed on strengthening quadriceps and generalized hip musculature. However, many conditions can cause AKP and swelling, especially after physical activity. AKP commonly results from irritation of the medial suprapatellar plica. Many youth athletes in repetitive jump/landing sports will develop patellar tendinopathy, Osgood-Schlatter disease, or Sinding-Larsen-Johansson disease—which often can mimic or even coincide with cartilage injuries. Osteochondritis dissecans (OCD) of the knee can also cause idiopathic AKP and swelling with activity.9 Osteochondritis dissecans of the knee is an injury to the subchondral bone and articular cartilage that usually develops in young athletes from overuse or acute trauma.9,10 Patients with an OCD lesion may present with no prior history of injury and often times a benign physical exam. While rest is indicated, most of the time OCD lesions continue to cause recurrent knee swelling (due to the intraarticular nature of this lesion, and altered mechanics resulting in intraarticular effusion) which may differ from other extraarticular knee pathology (i.e. patellar tendinopathy, Osgood-Schlatter's disease). Unfortunately, OCD lesions are often unrecognized on diagnostic imaging, such as plain radiographs and magnetic resonance imaging. This presents a major challenge for clinicians when diagnosing and treating potential cartilage injuries of the knee.

With recurrent knee effusions and AKP that does not respond to rest or conservative treatment, clinician’s must rule out cartilage injuries as the source of pathology. The purpose of this case report was to describe a patellofemoral articular cartilage defect of the knee in a preadolescent skier due to overuse and repetitive microtrauma as a result of ESS.

SUBJECT PRESENTATION AND EXAMINATION

Verbal informed consent from both the subject and parents were obtained prior to publication. A healthy 11-year-old male (height: 160.0 cm; weight: 40.8 kg) competitive alpine skier presented with recurrent swelling of his right knee and persistent AKP while skiing without evidence of any specific history of injury or traumatic event. Of note, the athlete was a competitive skier who competed six days per week during the season and trained year-round, specializing in downhill ski racing. The athlete first disclosed his pain presentation to his parents and coaching staff after skiing practice. The parents subsequently referred the athlete to physical therapy and was prescribed a 2-week rest period with no skiing. After four weeks of generalized knee strengthening, the athlete (and his parents) presented for further orthopaedic evaluation due to recurrent knee effusions despite conservative rehabilitation. The patient presented with a history of recurrent knee effusions over a period of six weeks. While interviewing the patient, he denied any specific injury or fall that he could attribute to his knee pain and swelling. The patient presented with a slight limp causing an asymmetrical gait pattern that was non-painful. On physical exam, the patient had full knee range of motion with 2+ moderate effusion and tenderness to palpation over the medial aspect of the patella.

INTERVENTIONS

Radiographs were obtained and revealed an anatomic variant, a bipartite patella, but no other acute bone abnormalities (Figure 1). Magnetic resonance imaging (MRI) was ordered and revealed an articular cartilage defect of the medial patellar facet (Figure 2A). The patient then underwent a diagnostic
did not continue to delaminate and cause recurrent effusions and pain with activity (Figure 2C). A chondroplasty was performed because the size, depth, and location of the lesion were not suitable for a cartilage resurfacing procedure (i.e. Osteoarticular Autograft Transplantation) or cellular based repair (i.e. Autologous Chondrocyte Implantation). No other intraarticular pathology was noted during the arthroscopic evaluation. The patient started formal physical therapy 24 hours after the procedure.

Postoperatively, the patient was allowed to weight bear as tolerated with the use of crutches for two weeks. Physical therapy initially focused on edema control, range of motion, and quadriceps activation exercises with a generalized progression from muscular endurance to strength and hypertrophy. A major emphasis was placed on rest from skiing and sports activities and allowing the patient's knee pain and swelling to subside before increasing activity. The focus of this case report is on diagnosis and relationship of ESS to AKP, not intervention, therefore, interventions are presented generally. At 12 weeks postoperatively, the patient presented with a normalized gait, no knee effusion, full knee range of motion, patellar mobility symmetric to his contralateral limb, and no patellar crepitation or painful palpation on physical exam. The patient was released to begin return to sport progression at 12 weeks, and was cleared for full activities with a return to competitive skiing at 15 weeks postoperatively. At 16 weeks postoperatively, he won an international alpine ski race in Europe for his age group.

DISCUSSION

Early sports specialization is common in the United States due to the theoretical consensus that early specialization in one sport is the recipe for creating superior athletes. However, not only has this theory been contradicted in terms of athlete and individual success, but there is growing evidence that this focus on one sport with excessive repetition of set movements and stressors can lead to unique pathology through overuse, even in the absence of acute trauma (Table 1).

Jayanthi et al performed a case controlled study on 1,190 athletes 7 to 18 years of age who were separated into two groups: injury and no injury. They
into tight articulation. As the skier maneuvers over bumps and around course gates, repetitive microtrauma in the patellofemoral joint can lead to chondral injuries, especially in young athletes. This case report is an example of this potential relationship between patellofemoral chondral damage and ESS in alpine skiing. However, the assumption of this cause and effect relationship cannot be validated.

Youth injuries due to overuse in all sports range from 46% to 54%, with recent data suggesting that these numbers are increasing. Concerns for the rise in overuse injuries in young athletes are the increasingly popular trend of early single-sport specialization. However, some believe that overuse injuries are often under-reported in the current literature because most of the injury definitions have focused on time loss from sport. The American Orthopaedic Society for Sports Medicine (AOSSM) consensus statement defined early sports specialization according to 3 criteria: 1) participation in intensive training and/or competition in organized sports greater than eight months per year; 2) participation in one sport to the exclusion of participation in other sports; and 3) involving prepubertal children (grade 7 or roughly age 12 years old). In this case report, the athlete satisfies the criteria of ESS because of his single sport specialization, prepubertal age, and intensive ski competition > eight months per year. This is possible due to his unique ski academy in which he participates in on-snow training and competition in the United States (late October to April) and internationally (June to August). A recent position statement from the American Medical Society for

<table>
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Specific sports have been correlated with specific overuse injury patterns. Due to the biomechanics involved with throwing a baseball, and the tendency for ESS in the baseball culture, there have been studies that discuss the correlation between ESS in baseball with elbow and shoulder injuries. To date, there have not been any cases reported on the correlation between alpine skiing and patellofemoral chondral injuries. The relationship of skiing and injury to the patellofemoral joint is explained by the repetitive forces on the knee during sustained knee flexion, which brings the patella and trochlea

| Table 1. Categorization of risk factors for overuse injury. Adapted from DiFiori et al. Reprinted with permission. |
Sports Medicine describes the importance of recognizing specific risk factors for overuse injury among youth athletes in order to deploy prevention strategies (Table 1). In order to decrease the risk of overuse injuries in young athletes associated with early sport specialization, the AOSSM consensus statement recommends the following: A) children who participate in more hours per week than their age, or more than 16 hours per week in intense training, and who are specialized in sport activities should be closely monitored for indicators of burnout, overuse injury, or potential decrements in performance due to overtraining; B) all youth (including inactive youth) can benefit from periodized strength and conditioning (e.g., Integrative Neuromuscular Training [INT]) to help them prepare for the demands of competitive sport participation; and C) youth who specialize in a single sport should plan periods of isolated and focused INT to enhance diverse motor skill development and reduce injury risk factors. In order to decrease the risk of future knee problems associated with ESS and skiing in this athlete, both the parents and the athlete were educated on the detrimental effects of single sport specialization at a young age. In addition, both the physical therapist and school athletic trainer were contacted and a team approach was implemented regarding a safe but efficient return to sport progression.

LIMITATIONS
The findings in this case report appear to be educational and representative of ESS; however, there are inherent limitations. While this overuse injury pattern may be representative of a larger group of individuals, it is still only a single case and therefore results cannot be directly extrapolated. It is also possible that the lesion could have developed from a source other than skiing. Furthermore, because the aim of this study was to describe the epidemiology of an injury presentation, and not evaluate the details or outcomes of treatment, there is not long-term follow-up to report.

CONCLUSIONS
With the presentation in this case report and the increasing incidence of ESS in youth athletes, allied health care professionals should consider patellofemoral chondral injury in the competitive skier with persistent AKP and recurrent effusions. This case report may provide insight to the detrimental consequences of overuse and skeletal immaturity associated with ESS in young skiers. However, future studies are needed to further identify injury risk factors and long-term outcomes within a larger group of similar patients.

REFERENCES


