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ABSTRACT

Background: ACL injuries are common in sports, which has resulted in the development of risk screening and injury prevention programs to target modifiable neuromuscular risk factors. Previous studies which have analyzed single-leg cutting tasks have reported that the anticipation status of the task (pre-planned vs. unanticipated) has a significant effect on the mechanics of the knee.

Hypothesis/Purpose: The purpose of this systematic review is to assess the effect of anticipation on the mechanics of the knee in the sagittal, frontal, and transverse planes during tasks which athletes frequently perform during competition.

Study Design: Systematic Review

Methods: The following databases were searched using relevant key words and search limits: Pub Med, SPORTDiscus, CINAHL, and Web of Science. A modified version of the Downs and Black checklist was used to assess the methodological quality of the articles by two independent reviewers.

Results: 284 articles were identified during the initial database search. After a screening process, 34 articles underwent further review. Of these articles, 13 met the criteria for inclusion in this systematic review.

Conclusions: It appears that tasks which do not allow a subject to pre-plan their movement strategy promote knee mechanics which may increase an athlete’s risk of injury.

Clinical Relevance: Clinicians involved in the development and implementation of ACL injury risk screening and prevention programs may want to consider incorporating tasks which do not allow time for pre-planning. These unanticipated tasks may more closely mimic the demands of the sports environment and may promote mechanics which increase the risk of injury.

Level of Evidence: Level 1b

Key Words: Anterior cruciate ligament, decision-making, knee biomechanics
INTRODUCTION
Each year, there are as many as 200,000 anterior cruciate ligament (ACL) injuries in the United States alone, with the majority occurring in young athletes.1 Unfortunately, the authors of a recent systematic review, which included a meta-analysis, determined that only 63% of athletes will return to their prior level of function and only 44% will return to competitive sports participation following an ACL reconstruction.2 This is not the only reason for concern, as athletes who have experienced an ACL injury also demonstrate accelerated degenerative changes of the knee even when they have undergone a successful surgical reconstruction.3 As a result of the high incidence of ACL injury and the potential long-term impact, ACL injury prevention programs which target modifiable neuromuscular risk factors have been developed.4-6 A recent systematic review was conducted to assess the effectiveness of these programs.7 Fortunately, this report indicated that three of the eight programs evaluated resulted in a significant reduction in the incidence of ACL injury. However, the potential for these programs to have a meaningful impact on ACL injury rates may still be limited as even the most effective of these programs would require 70 athletes to participate in order to prevent a single non-contact ACL injury, based on the number needed to treat metric. The authors also discussed the large degree of variability in the training components included in these programs. The limited effectiveness and significant variability in ACL injury prevention programs may be due to an incomplete understanding of the important neuromuscular risk factors.8-10 This creates what has been described as the “ACL injury enigma” as it has been highlighted that an injury cannot be prevented if it is not completely understood.11

The identification of biomechanical risk factors for ACL injury has been the result of a combination of studies which have predominantly involved human cadaver specimens,12-16 biomechanical analyses,17 or musculoskeletal modeling.18-20 This work has identified mechanics in the sagittal, frontal, and transverse planes which contribute to ACL injury risk.21 Understanding these mechanics has allowed for the identification of conditions or circumstances which may promote the risk of ACL injury. For example, both central and peripheral fatigue have been found to be factors which promote mechanics associated with an increased risk of ACL injury.22 This is consistent with the observation that the majority of ACL injuries occur at the end of a half or the end of a game when athletes are fatigued.23-25 It appears that assessing key biomechanical variables can provide insight into the risk of ACL injury.

The majority of ACL injuries are non-contact in nature and often occur in sports such as basketball and soccer26 which involve a relatively quick response to an external stimulus such as a ball, teammate, or opponent which cannot be anticipated. In these cases, an athlete is afforded limited time to identify the relevant stimulus and perform the neurocognitive processing required to respond with a motor plan which will allow them to successfully complete a task without putting themselves at risk of being injured.27 Interestingly, it has been previously reported that relatively poor performance on a test of neurocognitive processing is associated with an increased risk of non-contact ACL injury.28 Due to the fact that the majority of ACL injuries occur in sports which require landing and cutting in response to unanticipated stimuli and the fact that an athlete’s neurocognitive processing appears to play a role in regard to their risk of injury, researchers have begun to investigate the effect of a task’s anticipation status (pre-planned vs. unanticipated) on the mechanics of the lower extremity.27,29-31 Understanding the role that anticipation plays in regard to ACL injury risk is not just of interest to researchers trying to understand the ACL enigma, it is also of great importance to clinicians involved in developing risk-screening and injury prevention programs. If unanticipated conditions promote injury risk in comparison to trials which allow for pre-planning, it is important that these types of unanticipated tasks are integrated into these programs.

Studies investigating the effects of anticipation have used a variety of tasks, subject groups, and methodologies and have also included various dependent variables. This makes a systematic review on this topic of great importance in order to provide an unbiased overview which can help to guide future research and also inform clinicians who are interested in preventing ACL injuries. Therefore, the purpose of this article is to systematically review the literature regarding the effect of anticipation on the mechanics
of the knee in the sagittal, frontal, and transverse planes during tasks which athletes frequently perform during competition.

**METHODS**

A literature search was performed using the databases, key words and search limits provided in Table 1. Articles which assessed the effect of anticipation on the mechanics of the knee during a single-leg cutting tasks were included in this review. Only studies which included a single-leg land-and-cut or run-and-cut task were included because these movements are common in sports and ACL injuries typically occur during tasks of this nature. Some studies also included a crossover cutting task. However, these were not included in this review as this activity is uncommonly performed during sports. The authors also chose not to include studies which implemented a training program to alter cutting mechanics as the current review was only intended to describe ACL injury risk and studies that included training did not allow for the delineation of the effects of anticipation independently of any training effects. Additional hand searching was conducted throughout the article review process and a search using the Cited Reference Search tool provided by the Web of Science database was also performed.

Once the literature search was complete, each article title and abstract was screened to determine if they were appropriate for inclusion in this systematic review. The methodological quality of each article was assessed using items from a version of the Downs and Black checklist which was previously modified for use in non-randomized biomechanical studies. This modified version includes 13 of the 27 items from the original checklist which was developed for use in randomized clinical trials. The wording of some of the questions was also altered in order to provide clearer scoring criteria to improve the consistency among raters. Two reviewers independently evaluated each article. Their scores were compared and a third reviewer was involved in the case of any discrepancies. A data extraction form, developed specifically for this review process, was provided to each reviewer involved in evaluating the articles in order to ensure consistency in identifying the key details (e.g. subject group(s), methods, task, outcomes) which needed to be highlighted within each study. This helped the reviewers determine if an article was appropriate for inclusion in this review and also allowed for analysis of the potential influence of additional factors (i.e. subject group, task) on the results of a study.

Due to the heterogeneity of the tasks, methodology, and outcomes assessed in the studies, it was determined that a meta-analysis was not appropriate. The focus was specifically on the biomechanical variables (joint angles and moments) of the knee as these are thought to have the most relevance to ACL injury. All moments are expressed as externally applied moments as this was the most commonly utilized convention among the articles included.

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<td>CINAHL (EBSCO)</td>
<td>[knee OR anterior cruciate ligament OR lower extremity] AND [anticipation OR decision making] AND [biomechanics OR kinematics OR kinetics]</td>
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<tr>
<td>Web of Science</td>
<td>[ACL OR anterior cruciate ligament OR knee] AND [anticipation OR decision making] AND [biomechanics OR kinetics OR kinematics]</td>
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When summarizing the results of the studies, the focus was on the peak angles and moments as these were most commonly reported. Studies that only looked at muscle activation patterns via electromyography were not included as this was outside the scope of this review.

RESULTS

Search Results
The initial database search resulted in the identification of 310 articles, with an additional 35 articles identified using the Cited Reference Search tool and through hand searching. After duplicates were removed, 236 articles remained. The titles and abstracts were screened which resulted in the exclusion of 201 of these articles. The remaining 35 articles where read in full and evaluated for possible inclusion in the review. Thirteen of these articles met the criteria and were included. A flow diagram is provided in Figure 1 in accordance with the PRISMA Statement.39 This figure also includes the reasons for article exclusion. The primary reasons why articles were excluded were 1) they did not include a single-leg cutting task, 2) they did not directly compare pre-planned and unanticipated trials, and 3) they implemented a training program. One study met all of the criteria for inclusion in this review, but was excluded because subjects were required to carry loads ranging from 6-40 kg during the trials in order to simulate military field operations.40

A summary of the key details of the studies which were included in the current review are provided in Table 2. This includes the participant characteristics, task, and outcomes of interest. The consensus scores for the modified Downs and Black checklist are provided in Table 3. Both the overall scores and the scores for each individual criterion are presented.37

Sagittal Plane Mechanics
The authors of four of the seven studies included in this review, which analyzed the effect of anticipation on the sagittal plane knee angles, reported a statistically significant increase in the peak knee flexion for the unanticipated trials in comparison to the pre-planned trials.27,30,41,42 The authors of the three remaining studies reported no significant differences.29,31,43 None of the authors reported a reduction in the knee flexion angle in the unanticipated condition. The effect of anticipation on the sagittal plane moments was fairly inconsistent. The authors of two studies reported a significant increase in the external knee flexion moment in the unanticipated condition,30,43 Khalid et al44 reported a significant decrease, the authors of three studies reported no significant difference between the conditions,29,31,41 and Besier et al27 reported an increase in the unanticipated condition during a run-and-cut at 30°, but a significant decrease when the angle of the cut was performed at 60°.

Frontal Plane Mechanics
The authors of each of the studies included in the current review reported the effect of anticipation on the mechanics (knee angles and/or moments) of the knee in the frontal plane. The authors of three of the studies included in this review reported a significant increase in the peak knee abduction angle when trials were unanticipated,30,41,42 while the authors of three additional studies reported no significant difference.29,31,45 The authors of two studies, which both included NCAA Division I athletes, reported a significant interaction between the effects of fatigue and anticipation on the peak knee abduction angles during a lateral cutting task, as the increase in the peak knee abduction angles for the unanticipated condition became more prominent as the subjects progressed through a general fatigue protocol.20,43
The authors of six of the included studies reported a significant increase in the peak knee abduction moment for the unanticipated condition, while Cortes et al. reported a significantly lower peak knee abduction moment in the unanticipated condition, and Brown et al. reported that the effect of anticipation was not significant. Kipp et al. also reported no significant effect of anticipation on the peak knee abduction moment in either a group of recreational athletes or a group of NCAA Division I athletes. However, they also performed a principal components analysis on the knee moment waveforms and compared the effects of anticipation between the two groups of athletes and found a significant interaction (group x condition) for the fourth retained principal component. This interaction indicated that the magnitude of the abduction moment during early stance (~20%) increased for the unanticipated trials in the recreational athlete group, but not for the group of NCAA Division I athletes. Similar to the results reported for the peak knee abduction angles, McLean et al. also reported a significant

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<td>Cortes (2011)</td>
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<td>Park (2011)</td>
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<td>Lee (2013)</td>
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<td>Run-and-cut at 45°, stimulus presented 450 ms</td>
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<td>Weinhandl (2013)</td>
<td>20 female recreational athletes</td>
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<td>Sagittal, frontal, and transverse angles, sagittal, frontal, and transverse moments</td>
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<td>Kim (2014)</td>
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<td>13 male amateur soccer players</td>
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<td>Khalid (2015)</td>
<td>6 male soccer players, 6 female soccer players</td>
<td>Run-and-cut at 45°, adjusted timing of stimulus to subject</td>
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interaction between fatigue and anticipation as the increase in the peak knee abduction moment in the unanticipated condition became more prominent as subjects progressed through a fatigue protocol.

Transverse Plane Mechanics

The effect of anticipation on the mechanics of the knee in the transverse plane was less commonly analyzed than the effects in the sagittal and frontal planes. However, the authors of four of the studies included in this review reported a statistically significant increase in the peak knee internal rotation angles for the unanticipated trials,10,30,42,43 while the authors of two studies reported that anticipation had no effect on the transverse plane kinematics of the knee.29,31 Also, the authors of four of the included studies reported an increase in the peak internal rotation moment of the knee for the unanticipated condition,27,31,43,44 while the authors of two studies reported the opposite effect.30,47

DISCUSSION

In general, anticipation had a prominent effect on the mechanics of the knee during the cutting tasks, which would likely result in an increase in the risk of an ACL injury. This finding was consistent with observational studies whose authors have reported that the majority of injuries occur during a landing and cutting task12,51 performed while competing in sports such as basketball and soccer which do not allow for pre-planning.26,52

The implications of the effects of anticipation on the mechanics of the knee in the sagittal plane were difficult to ascertain. An increase in the external knee flexion moment would likely require a greater internal knee extension torque, mainly from the quadriceps musculature. This could potentially increase the risk of injury as force from the quadriceps has been shown to increase ACL strain by promoting anterior translation of the tibia relative to the femur.12,13 In fact, DeMorat et al.12 reported that the application of a single quadriceps force of 4500 N at 20° of knee flexion resulted in a rupture of the ACL in over half of the cadaver specimens they included in their analysis. However, many have begun to question how this cadaver work translates to sports-related tasks as the authors of multiple musculoskeletal modeling studies have reported that sagittal plane mechanics alone cannot produce forces which are high enough to rupture the ACL during landing and cutting.53,54 This is primarily due to the large posteriorly directed ground reaction force vector during the initial landing phase which effectively limits the force which is transmitted to the ACL, as this vector passes behind the knee joint and limits anterior translation of the tibia. Also, the increase in the knee flexion angle reported in the unanticipated trials would most likely counteract the increase in the force produced by the quadriceps. This is due to the fact that the hamstring musculature becomes more effective at assisting the ACL in limiting the anterior translation of the tibia as the knee flexion angle
increases. However, Weinhandl et al used a musculoskeletal modeling approach to estimate the forces acting on the ACL and reported that anticipation significantly increased ACL loading (combined sagittal, frontal, and transverse plane forces). Interestingly, the increase in the ACL force was primarily due to an increase in the loading in the sagittal plane. It seems that further analysis is required in order to truly understand how the sagittal plane mechanics of the knee contribute to ACL injury risk.

In the frontal plane, the effects of anticipation were relatively consistent as the results of multiple studies demonstrated an increase in the peak knee abduction angle and peak knee abduction moment. This is concerning as these mechanics have been previously shown to increase ACL strain and have also been reported to prospectively predict ACL injury when observed during a land-and-jump task. The frontal plane mechanics of the knee for the unanticipated trails also appear to be influenced by the athletes’ level of fatigue. In fact, some have proposed that unanticipated tasks, performed when an athlete is fatigued, represent the “worst case scenario” in regard to ACL injury risk. The effects of fatigue appear, at least in part, to affect central control mechanisms (suprapinal and spinal components) as McLean et al utilized a single-leg progressive fatigue protocol and found an interaction between the effects of anticipation and fatigue for the frontal plane mechanics of the knee. The nature of the interaction indicated that the difference between pre-planned and unanticipated trials became more prominent with fatigue. Interestingly, they also found similar results in the non-fatigued limb. The authors concluded that this inter-limb crossover supports the premise that the effects of fatigue are centrally mediated. While the effects of central fatigue can occur anywhere in the nervous system from the cerebral cortex to the neuromuscular junction, future studies would likely benefit from attempting to more precisely explain the mechanism behind the relationship between fatigue and anticipation. This is important as combating the effects of fatigue at the spinal level would likely require different intervention approaches than at the supraspinal level.

Similar to the frontal plane, anticipation was reported to have significant effects on the mechanics of the knee in the transverse plane. The most consistent finding was an increase in the internal rotation moment in the unanticipated condition. This is also concerning as Flemming et al found that applying an internal rotation torque to the knee increased the ACL strain in a group of 11 subjects who had a transducer implanted arthroscopically into their ACL. It has also been reported that the effects of loading in the frontal and transverse planes can have a combined effect which may result in ACL strains which are high enough to result in a rupture of the ligament. In regard to ACL injury risk, it appears that the most prominent effects of anticipation may occur in the frontal and transverse planes of motion.

From a research perspective, the results of this systematic review indicate that when performing a study to investigate possible risk factors for ACL injury, the demands of the task must be carefully considered, as anticipation appears to be a significant independent risk factor and may interact with other risk factors for ACL injury. Also, if incorporating an unanticipated task, it is important to consider the timing of the stimulus provided, as there appears to be a cutoff point (between 600-800 ms) in regard to the presentation of the stimulus to the time in which the subject must complete the task (i.e. cut), where knee joint kinematics and kinetics are affected. Times which are greater than this threshold are thought to allow participants time to successfully develop a motor plan which will not increase their risk of injury. However, the specific cutoff point may depend on the complexity of the task and the subject sample (recreational vs. elite athletes). Finally, some have advocated for the implementation of stimuli which better reflect the sports environment in an effort to improve the ecological validity. While most studies used a relatively simple stimulus (e.g. alternating colors, arrows, etc.) to direct movement, others have begun to incorporate different stimuli which may more closely mimic sport participation. For example, Lee et al compared a traditional arrow stimulus to a stimulus which required subjects to respond to a video of a soccer defender and found that while both significantly influenced knee mechanics, the game-like soccer simulation had a more prominent effect. While this is certainly a worthwhile endeavor, all
of the methods used to assess the effects of anticipation are still relatively controlled in comparison to the demands of the sports environment as most involve only two or three choices. Finally, studies that include a run-and-cut task should be carefully designed to control for the approach speed as two of the studies reported significant differences between the pre-planned and unanticipated trials.\(^{27,41}\)

For professionals interested in ACL risk screening and injury prevention, the results of this review support the integration of tasks that specifically target central control mechanisms. Authors have previously proposed the use of decision-making tasks,\(^{27,45}\) neurocognitive training,\(^{45}\) virtual reality training,\(^{31,43}\) and metal imagery\(^{43}\) as approaches which could potentially allow athletes to reduce their risk of injury in the dynamic sports environment. The potential for training is supported by the findings of Kipp et al\(^{45}\) where recreational athletes demonstrated greater differences between their pre-planned and unanticipated trials than NCAA Division I athletes. These authors proposed that this is likely due to the fact that the NCAA Division I athletes had improved their ability to perform in dynamic conditions as they may have more exposure to tasks which do not allow for pre-planning. However, it is impossible to determine from their cross-sectional design whether the elite athletes improved performance under unanticipated conditions was experience-driven or whether their innate ability had contributed to them reaching their athletic status. Nonetheless, intervention studies do support the fact that the effects of anticipation may be modifiable with appropriate training.\(^{34-36}\) Current training programs typically involve exposing athletes to unanticipated run-and-cut or land-and-cut tasks, similar to those included in the studies which have analyzed the effects of anticipation. The basic premise of this approach is that this training can improve an athlete’s neurocognitive processing within a relatively controlled environment and that the effects of this training will translate into improvements in motor control within the sports environment. Training studies have not typically involved any type of progression. However, altering the timing of the stimulus and/or increasing the number of response options seem like viable options. Other approaches which target neurocognitive processing should also be investigated (e.g. mental imagery, choice reaction tasks, dual task training) as these interventions would likely be very easy and relatively inexpensive to implement on a wide scale.\(^{46}\) Developing programs which do not require trained personnel and costly equipment may play a key role in reducing the rate of ACL injury. This is an area of research that certainly merits further study.

This systematic review does have some limitations, which need to be carefully considered. First, as with all systematic reviews there is a significant risk of publication bias, as studies demonstrating statistically significant differences in outcomes are more likely to be published. No attempt was made to contact the authors of the studies in this review in order to address this limitation. Second, while the methodological quality of the articles included in this review was assessed using a previously modified version of the Downs and Black checklist, no articles were excluded based on quality. Unfortunately, there is not a well-developed checklist to evaluate the methodological quality of studies which are not randomized control trials. While the authors of this paper do have experience using these types of rating systems, there is no training program available to ensure consistency as there is with other scales. Further development of tools to assess the methodological quality of non-randomized trials, including the Downs and Black checklist, appears warranted. Finally, while this review only analyzed the effects of anticipation on the mechanics of the knee, the mechanics of the hip and the ankle may also be affected\(^{28,41,47}\) and may contribute to the risk of ACL injury.

It is also important to note that a similar systematic review, which included a meta-analysis, was recently performed by Brown et al.\(^{61}\) However, these authors only included articles which assessed a run-and-cut task where the approach speed was between 3.0 to 5.5 m/s in an attempt to allow for a comparison among studies. However, in doing this they excluded any study which used a land-and-cut task. The articles that Brown et al excluded provided valuable information within the current review and landing and cutting is also a common task involved in sports. As a result, they only included three of the thirteen articles that were included in the current review.
They also did not address how anticipation can interact with fatigue and how there appears to be some experience-driven adaptations. Both of these factors have important implications for both researchers and clinicians and should be included in a review of this nature. Finally, their systematic review was limited in regard to their analysis of the effects occurring in the frontal and transverse planes by only including a single study which analyzed the effect of anticipation on frontal and transverse plane kinematics.

CONCLUSION
In conclusion, the results of this systematic review indicate that anticipation has a significant effect on the mechanics of the knee in the sagittal, frontal, and transverse planes during cutting tasks. It appears that tasks which do not allow an athlete to pre-plan their movement promote mechanics which may increase the risk of ACL injury. This has important implications for both researchers and clinicians involved in the development of ACL risk screening and injury prevention programs. Researchers must carefully consider the demands of the tasks they include in their protocols and clinicians may benefit from implementing activities which involve cutting in response to a stimulus that cannot be anticipated.

REFERENCES


ABSTRACT

Background: Although many authors have studied the prognostic factors that may contribute to anterior knee pain, synthesis of the existing evidence has not been performed.

Purpose: The purpose of this systematic review is to summarize and examine existing prognostic models in patients with anterior knee pain that first present to physical therapists (primary care setting).

Design: Systematic review

Method: For this review Pubmed, Embase and Cinahl databases were searched and published papers that reported prognostic models for patients with anterior knee pain that first present to physical therapists (primary care setting) were selected. The authors extracted and summarized the univariate and multivariate predictors and evaluated which predictors consistently appeared to be relevant to pain, function, or recovery.

Results: Nine studies were included. The quality scores of these studies ranged from 9 to 17 positive items out of 21 items included in the assessment for quality. None of the prognostic models were validated internally or externally. Four studies were considered to be of sufficient quality. The authors of these four studies found 14 different predictors significantly related to pain intensity of which seven with limited evidence. Fifteen different predictors were found that were related to function of which seven with limited evidence. Furthermore, strong evidence was found that baseline pain intensity, pain coping and kinesiophobia are of no predictive value for pain, and activity related pain, pain coping and kinesiophobia are of no predictive value for function at follow up.

Conclusions: Because of the low quality of a number of studies and the heterogeneity of the examined variables and outcome measures of most of the studies, only limited evidence for seven predictors related to pain and seven predictors related to function in patients with anterior knee pain in a primary care setting was found.

Level of Evidence: 1b

Keywords: anterior knee pain, patellofemoral pain, physical therapy, prediction, prognostic models, primary care setting.

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INTRODUCTION
Anterior knee pain, also known as patella femoral pain syndrome, is a condition that occurs most commonly in active young adults and adolescents, often leading to functional impairments.\(^1\)\(^,\)\(^2\) It is characterized by pain in the anterior part of the knee during and after several physical activities (e.g. bodyweight loading of lower extremities) such as walking, stair climbing/descent, squatting, and sitting with the knees flexed.\(^3\) In athletically active men and women the prevalence of anterior knee pain is reported to be 25%.\(^4\)\(^,\)\(^5\) The cumulative incidence of anterior knee pain is reported as 9.7/100 athletes and 1.1/1000 athletic exposures.\(^6\) Females are over two times more likely to develop anterior knee pain compared to males.\(^7\) Despite the high prevalence of AKP in young people, there is no consensus in the literature concerning its pathogenesis, prognosis, and treatment.\(^8\)\(^,\)\(^9\)\(^,\)\(^10\)\(^,\)\(^11\) In a random sample of patients with anterior knee pain, 30-50% of the patients still suffered from symptoms after several years.\(^8\)\(^,\)\(^12\)

Knowledge of prognostic factors is essential for physical therapists in order to make treatment decisions.\(^13\)\(^,\)\(^14\)\(^,\)\(^15\) Some authors have shown that several conservative treatment strategies are effective but most of their studies are small and were conducted in a mixed population of patients with anterior knee pain.\(^16\) This makes it difficult to judge which patients will benefit most from a specific treatment option. Clinical prognostic models may provide important input for more specific treatment decisions. These models combine a number of patient characteristics in order to predict prognosis, and they may be used by the physical therapist to advise the patient or tailor treatment to the need of the patient.\(^17\)

In the past decades, many prognostic models have been developed for patients that first present to physical therapy (primary care setting), including several concerning the prognosis of anterior knee pain. The available prediction models are not yet ready for application in clinical practice because of their preliminary stage of development.\(^18\)\(^,\)\(^19\)\(^,\)\(^20\) These anterior knee pain models vary with regard to patient populations, outcome measures, and relevant prognostic factors, which hampers the generalizability and implementation of these models in clinical practice. Therefore, the primary aim of this study was to summarize and examine existing prognostic models in patients with anterior knee pain that first present to physical therapists (primary care setting). The secondary aim was to develop a new prognostic model to be used and validated in primary care physical therapy.

METHODS
Data sources and searches
An extensive search of the databases Pubmed, Embase and Cinahl was performed in 2012 and an additional search conducted in January 2015. The search was based on a previously derived and validated search strategy.\(^19\) The specific search strategy is published; see also Appendix A for details.\(^19\) In addition, the reference lists of the identified studies were screened to detect potentially relevant studies.

Study selection
Studies were selected that included prognostic models concerning patients with anterior knee pain or subgroups of patients with anterior knee pain.\(^19\) A prognostic model (or prediction model) is defined as a model that combined at least two characteristics typical based on multivariable analyses.\(^17\) The authors selected studies that were relevant for physical therapists in primary care, published in English, conducting a multivariable analysis and using Patient Related Outcome Measures (PROMS) such as: pain, function or recovery. Randomized controlled trials (RCT’s), case studies, retrospective cohort studies and studies that aimed to develop a questionnaire were excluded.\(^19\) RCT’s and case studies use strict inclusion and exclusion criteria, which limits generalizability, retrospective cohort studies have a high risk of bias and therefore limited evidence and questionnaire studies use a different design and purpose.

Four review authors were involved in the study selection process (AV, MH, LO and GP). First, two review authors independently screened all references found with the initial search on title and abstract. Next, two review authors independently screened the full texts of the potential eligible articles based on the selection criteria. In case of disagreement consensus was achieved or a third independent review author was contacted.
Data extraction
Data extraction included patient characteristics, country and setting in which the study was executed. Also data on the number of predictors used in the univariable analyses as well as the multivariable analyses were extracted. Data extraction included also the reasons why the chosen predictors were selected for the analyses and whether predictor variables were dichotomized. The authors scored which predictors were univariably significant and/or multivariably significant related to the outcome measures and which predictors were presented in the final prognostic models. Next, data on all outcome measures used and the follow-up period were extracted. In addition, authors examined if predictors and outcome measures were measured in a standardized, valid and reliable way; meaning, had the authors of each study measured what was supposed to be measured (valid) and were the measurements consistent (reliable). Finally, the performance of the prognostic models was assessed and the authors determined whether the models were validated.

Outcome measures
The PROMS pain, function and recovery (as defined in the original studies) were considered as the outcome measures of interest for the current systematic review, as these are common and important complaints in patients with anterior knee pain consulting physical therapists.21

Methodological quality assessment
There was no uniform criteria list available for use in assessing the methodological quality of studies on prognostic models. Therefore, a criteria list (previously developed by Oort et al.19) was used, which was developed based on several existing criteria lists for assessing the quality of prognostic studies in general [Appendix B]. This list consists of 21 items in six domains. All items were scored as ‘positive’, ‘negative’ or ‘unclear’.

Two review authors independently assessed each included study (GP, LO or AV). They discussed disagreements until consensus was achieved. If necessary, they utilized a third review author (LO or AV) to resolve the disagreement. Consistent with other systematic reviews, the authors decided to use a summary score to get an overall impression of the study quality.22,23,24,25 To select studies of sufficient quality, the score of 70% or higher of the maximum score, (15 positive items out of the 21 items of the score list) was chosen for the study to be considered of sufficient quality; all other studies were considered low quality studies. To evaluate the robustness of these conclusions a sensitivity analysis was performed on the choice of cut-off point (a score of 14 or 16 positive items instead of 15 out of 21) to determine whether that changed the conclusion based on the studies with sufficient quality.

Performance assessment
The performance of a prediction model is described by four parameters: explained variation (R²), discrimination, calibration and clinical usefulness.17,26 When the included studies reported at least one of these four parameters, we scored the item ‘performance’ in the criteria list as positive.

The R² is an overall measure to quantify how well the data fits a statistical model, in other words if enough relevant predictors are included in the model. The higher the R², the better the model fits the data and the most relevant predictors are included in the model.17 Discrimination refers to the extent in which a model is able to distinguish patients with an outcome from patients without this outcome. The most commonly used performance measure to indicate the discriminative ability of prognostic models is the area under the curve (AUC), or C-statistics.27,26 Model calibration can be described by use of a calibration plot (e.g. a slope), a classification table or the Hosmer-Lemeshow goodness-of-fit test (H-L).17,26 Finally, clinical usefulness can be described by measures like accuracy, sensitivity, specificity and positive and negative predictive value.22

Data Synthesis and Analysis
Currently, there are no valid methods available to quantitatively pool multivariable prognostic models that contain different predictors (e.g. a meta-analysis). Therefore, a level of evidence synthesis was performed (Table 1) taking the quality of the studies into consideration.28,29,30 Only the results of the analyses of the studies with sufficient quality, i.e. studies with a score of 15 positive items out of the 21 items of the score list were presented.
RESULTS

Study selection
Nine studies fulfilled the selection criteria (Figure 1). Appendix C provides the study characteristics of all nine included studies.

Three studies utilized patients recruited from a military population. Four studies examined patients who were treated in specific clinics and two studies have been conducted in primary care. The sample size of the studies varies between 30 and 74 patients, except in one study (n = 310).

OUTCOME MEASURES

Pain. All studies measured pain intensity as an outcome; seven studies used the Numerical Rating Scale...
(NRS)\(^{33,34,37}\) or the Visual Analogue Scale (VAS)\(^{31,32,35,38}\) and two studies\(^{36,39}\) the Kujala pain score. The validity and reliability of these measurement instruments have been previously reported and are good.\(^{40,41}\)

**Function.** Six studies measured function as an outcome\(^{31,32,35,37,39}\): using either the Kujala score (also called the Anterior Knee Pain Scale (AKP)), the Activity of Daily Living Scale (ADLS), the Functional Index Questionnaire (FIQ), or the Lysholm and Tegner functional knee scores. The validity and reliability of these instruments are good and the outcomes of the different measurement instruments are comparable.\(^{42,40,43,44,45}\)

**Other.** Other outcome measures included the use of a rating scale for subjects' impression of the change (recovery) and physical activity limitations questionnaires.

**Methodological quality assessment**

The number of positive items ranged from 9\(^{38}\) to 17\(^{31,37}\) out of 21 items (Table 2). All studies scored positive on ‘inclusion and exclusion criteria’, ‘prospective design’, ‘all prognostic factors described used to develop the model’, ‘standardized or valid measurements’ and ‘clinical relevant outcome measures’. Two items on which all studies scored negative or unclear were: ‘internal validation’ and ‘external validation’. One study did not describe ‘clinical performance measures’.\(^{39}\) One study scored positive on ‘sufficient number of subjects per variable’.\(^{31}\) Finally, two studies did not provide a clear presentation of the data of all predictors.\(^{38,30}\) Four studies were considered as of sufficient quality.\(^{31,32,36,37}\)

For the sensitivity analysis, with 14 positive items the same four studies were found of sufficient quality. However with a cut-off of 16 positive items just three studies remained of sufficient quality.\(^{31,32,37}\)

**Performance assessment**

Five studies presented the explained variance by calculating the R\(^2\), which ranged from 0.05 to 0.60 (Appendix C).\(^{31,32,35,36,37}\) One study presented the discriminative power by calculating the Area Under the Curve (AUC).\(^{31}\) Three studies presented the clinical usefulness by reporting sensitivity, specificity and likelihood ratios.\(^{34,35,38}\) One study did not use any of the performance measures.\(^{15}\)

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**Data synthesis and Analysis**

**Univariable analysis**

In total, 190 predictors were univariably assessed; 11 predictors were evaluated in more than one study. Only ‘pain at baseline’ was univariably analyzed in all studies but appeared only univariably significantly related to pain at follow-up in four studies.\(^{31,33,36,37}\) Duration of symptoms\(^{31,33,34,35,36,38}\) and age\(^{31,33,34,35,36,37,38}\) were also frequently assessed univariably, and both were significantly related to pain and function; gender was evaluated in five studies.\(^{31,33,35,37,39}\)

In the four studies of sufficient quality\(^{31,32,36,37}\), 29 predictors were found that were univariably significantly related to pain or function, of which 27 were considered unique, meaning they were only evaluated in one study. Four predictors were evaluated in more than one study. Twenty-six predictors were univariably significantly related to pain as well as function. Each included study used their own cut-off points for inclusion of potential predictors in the multivariable analysis and there were hardly any agreements between these chosen cut-off points.

**Multivariable analysis**

Table 3 presents the overview of the predictors related to pain and function in the studies of sufficient quality and additional low quality studies as a result of the multivariable analyses. Predictors only assessed in low quality studies (quality score of 14 positive items or less) are not presented in this table. Because only one study assessed recovery as outcome (N=1)\(^{31}\), analysis of recovery as an outcome is not presented in this table.

**Pain.** Of the 29 univariably significant predictors 14 were multivariably significantly related to pain in at least one study of sufficient quality (Table 3). Seven out of these 14 predictors were found in only one high quality study. ‘Duration of symptoms’ was the only significant predictor found in a study of sufficient quality\(^{31}\) as well as a low quality study\(^{30}\) however ‘duration of symptoms’ was not significantly related to pain in another low quality study.\(^{33}\)

‘Pain at baseline’ was univariably significant related to pain at follow-up in four studies, but in none of the studies after multivariate analysis.

**Function.** Of the 27 univariably significant predictors 15 were significantly related to function in at
Table 2. *Criteria list of methodological quality developed by Oort et al*[^19]

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<td>17</td>
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<td>11</td>
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</table>

For definitions criteria and operationalization of the criteria see Appendix B

+ positive score on a item
- negative score on a item
# Total score: sum of all positive scores
Table 3. Predicting variables and their level of evidence after multivariable analysis

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<th>Predictors</th>
<th>Predictors</th>
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<td>0</td>
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</table>
least one study of sufficient quality (Table 3). Pain at baseline was examined in all studies of sufficient quality but was only significantly related to function in one of these studies.

**Levels of evidence**

**Association**

Limited evidence was found for seven predictors to be related to pain (frequency of pain\(^{36}\), Catastrophizing (PCS)\(^{32}\), anterior knee pain score (AKPS)\(^{31}\), Fear avoidance (FABQ-PA, FABQ-W)\(^{37}\), magnetic resonance imaging (MRI)\(^{36}\) and recruitment\(^{33}\)).

Furthermore limited evidence was found for seven predictors to be related to function (Catastrophizing (PCS)\(^{32}\), Anxiety (HAD)\(^{32}\), AKPS\(^{31}\), FABQ-PA\(^{37}\), MRI\(^{36}\), gastrocnemius length\(^{37}\) and the Functional Index Questionnaire knee score (FIQ)\(^{31}\)).

**No association**

Strong evidence for no predictive value for pain at follow up was found for three variables (baseline pain intensity, pain coping, and kinesiophobia). Also strong evidence for no predictive value was found for three variables related to function at follow-up (i.e. ‘activity related pain’, ‘pain coping’ and ‘kinesiophobia’).

Moderate evidence was found for five predictors for not being related to pain (triple jump test, muscle length [Quadriceps, Hamstrings and Soleus], ADLS, bilateral symptoms and step test) and for three predictors for function (triple jump test, muscle length [Quadriceps, Hamstrings and Soleus] and ADLS).

<table>
<thead>
<tr>
<th>Predictors</th>
<th>Pain Level of Evidence to be of predictive value related to pain</th>
<th>Function Level of Evidence to be of predictive value related to function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low quality studies</td>
<td>Studies of sufficient quality</td>
<td>Studies of sufficient quality</td>
</tr>
<tr>
<td>(N=5)(^{33,34,35,38,39})</td>
<td>(N=4)(^{31,3,2,36,37})</td>
<td>(N=4)(^{31,3,2,36,37})</td>
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<td>Depression (HAD)</td>
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<tr>
<td>Sporter</td>
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<td>Quality of movement</td>
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<td>Single legged jump test</td>
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</tr>
<tr>
<td>Allocated preferred treatment</td>
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</table>

MRI= Magnetic resonance imaging; CSA= Cross sectional area; AKP= Anterior Knee Pain Scale; FABQ-PA= Fear Avoidance Belief questionnaire-Physical Activity; FABQ-W= Fear Avoidance Belief questionnaire-Work; FIQ=Functional Index Questionnaire; HAD=Hospital Anxiety and Depression score; CSQ=Coping Strategies Questionnaire; TSK=Tampa Scale Kinesiophobia; ADLS=Activities of Daily Living Scale; BMI=Body Mass Index

0: a study with no association between the predictor and the outcome measure

+: a study with a significant association between the predictor and the outcome measure

When there is notified 0,0,0,+, it is meant that there are 3 studies without a significant relationship with the outcome measure and one study with a significant relationship
Limited evidence was found for nine predictors for not being a predictor for pain (BMI, muscle length gastrocnemius, anxiety (HAD), depression (HAD), FIQ, being an athlete, quality of movement, working state and single legged jump test) and for eight predictors for not being a predictor for function (BMI, anxiety (HAD), FABQ-W, being an athlete, quality of movement, recruitment, work type and allocated preferred treatment).

Methodological considerations
A summary score was used to report overall study quality. However, this is not recommended by Hayden et al who indicate that to judge overall quality (or risk of bias), one could describe studies with a low risk of bias as those in which all, or the most important (as determined a priori), of the six important bias domains (study participation, study attrition, prognostic factor measurement, outcome measurement, study confounding and statistical analysis and reporting) are rated as having low risk of bias. No difference in the conclusions was found following the recommendations of Hayden et al compared to using the established summary score. The same four studies remained of sufficient quality.

Classifying prognostic models with regard to levels of evidence (e.g. strong, moderate, limited evidence or inconclusive) is under discussion. However, the authors believe that the quality of the study likely influences the selection of most relevant predictors. For prognostic models it is unclear at the moment, which methodological quality items are of greatest relevance. As it is important to avoid compensation for less important items and because studies with high quality scores were expected to select the most important predictors, authors decided to use a level of evidence approach despite the earlier discussion.

Strengths and limitations
The decision to base the conclusions of this review on studies with sufficient quality may have influenced the selection of the most relevant predictors. On the other hand we chose this cut-off because including studies of low quality might have led to the erroneously selection of predictors based on studies with major methodological problems. For example, it is advised that the number of candidate variables to develop a prognostic model should not exceed a tenth of the study population in the smallest outcome group as this easily leads to an incorrect estimation of the predictors in the model. However, most of the studies included (7 out of 8) did not comply with this rule. Furthermore, researchers dichotomize the predictors with the aim of making the final model more feasible in daily practice, but this may lead to loss of information (with regard to the measurement scale range and precision of outcome predictions) and a loss of statistical power.

DISCUSSION
Main findings
A wide variety of potential predictors were found (n=193) that were related to pain or function in nine studies of patients with AKP or PFP. Out of 193 predictors, just 34 unique predictors were significantly related to pain or function, of which 19 predictors in four studies were found in studies of sufficient quality. Too few studies assessed recovery, so the authors were unable to generate evidence on this outcome measure. Only limited evidence was found for several predictors because most of the predictors were assessed in just one study of sufficient quality. This limits the strength of the current conclusions. Furthermore the authors were unable to derive a single, multiple factor prediction model for pain or function in patients with anterior knee pain because of the variety in predictors.

Comparison with the literature
This is the first review on prognostic models in patients with anterior knee pain. All studies used pain intensity and/or function as outcome measures. Remarkably, the predictor 'baseline pain intensity' was evaluated in all studies but was not related to pain intensity or function at follow-up. This might indicate that focusing on decreasing the baseline pain intensity as a treatment goal might not be relevant in patients with anterior knee pain. This can be explained when viewed in relationship to cognitive-behavioral theory. This theory indicates that patients should view pain in general as a common condition that can be self-managed, rather than as a serious condition that needs careful protection. The patients should not be guided by pain, but rather, should focus on the activities they are able to perform.
four out of eight studies the predictors were dichotomized before entering the regression analysis.33,34,38,39

This systematic review was limited to English-language articles and did not consider grey literature (the kind of material that is not published in easily accessible journals or databases, including things like abstracts of research presented at conferences, unpublished theses, and so on); therefore, some studies have been missed. However, an extensive search has been performed in accordance with the directives for systematic reviews, so authors assume that the articles that were potentially missed would not have majorly altered any of the findings.

The most important limitation is the heterogeneity of the included studies. A wide variety of potential predictors were found; there was hardly any overlap between studies in the choice of predictors for the analysis and therefore in the final set of predictors. This heterogeneity resulted in inconclusive evidence for most predictors. Furthermore only two of the studies of sufficient quality evaluated psychological factors, however these factors were not the same in both studies.32,36 This means that authors were unable to draw conclusions on the possible predictive value of psychological predictors.

Recommendations for future studies
Based on the current results, the authors would recommend the development and validation of a new prognostic model for patients with anterior knee pain (i.e. including variables such as: frequency of pain, catastrophizing, anterior knee pain score, fear avoidance (FABQ-PA and FABQ-W), MRI, recruitment, anxiety, gastrocnemius length and the FIQ-score). Regardless of how the model is developed, it is essential for its potential applicability that the performance and validity of a model is evaluated. Ideally more than one performance measure should be used. Only one study used more than one performance measure.30 Moreover, none of the studies validated their final prognostic models. Therefore the presented prognostic models, in their current form, are not yet suitable for use in daily clinical care.

Furthermore, in authors’ opinion, the methodological quality of future studies can easily be improved. Methodological flaws frequently occurring in these studies can in future be resolved by making small changes in the study methodology. Many reports are available with guidelines how to develop a high quality prognostic model.18,17

CONCLUSION
Clinicians have to base their treatment strategy on determinants relevant for the prognosis. Based on the current results clinicians do not need to consider pain or activity related pain for treatment decisions, as they appear to be unrelated to decrease in pain or increase in function in patients with anterior knee pain. However clinicians should consider catastrophizing, a high score on the FABQ, HAD, AKP, FIQ, gastrocnemius length and a high frequency of pain for their treatment decisions because these variables are significantly related to the outcome measures pain and/or function in patients with anterior knee pain that first present to a physical therapist.

REFERENCE


APPENDIX A: THE COMBINATION OF KEYWORDS THAT WERE USED FOR MEDLINE DATABASE SEARCH


Afterwards the inclusion procedure, selection of studies with regard to patellar complaints were based on the keywords: patellofemoral, patellar femoral, patellar femoral pain syndrome, patellar, anterior knee pain, patella femoral, patellaafemoral, knee pain, patellar arthritis, patella arthritis, patello arthritis, patellar injury, patella injury.
### APPENDIX B

**METHODOLOGICAL ASSESSMENT OF STUDIES ABOUT PROGNOSTIC MODELS, DEVELOPED BY OORT ET AL.**

#### Criteria list

<table>
<thead>
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<th>Criteria</th>
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<td><strong>Study design</strong></td>
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</tr>
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<tr>
<td>b) Source population</td>
<td>+ / - / ?</td>
</tr>
<tr>
<td>c) Inclusion and exclusion criteria</td>
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<tr>
<td>d) Prospective design</td>
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<tr>
<td><strong>Study attrition</strong></td>
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<tr>
<td>e) Number of drop-outs</td>
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<tr>
<td>f) Information given on method how they deal with missing data</td>
<td>+ / - / ?</td>
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<td>g) All prognostic factors described used to develop the model</td>
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<tr>
<td>h) Standardized or valid measurements</td>
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<tr>
<td>i) Linearity assumption studied</td>
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<tr>
<td>j) No dichotomization of prognostic variables</td>
<td>+ / - / ?</td>
</tr>
<tr>
<td>k) Data presentation all prognostic factors</td>
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<tr>
<td><strong>Outcome measures</strong></td>
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<td>l) Description of outcome measures described</td>
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</tr>
<tr>
<td>m) Standardized or valid measurements</td>
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</tr>
<tr>
<td>n) Data presentation of most important outcome measures</td>
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<td><strong>Analysis</strong></td>
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<tr>
<td>o) Presentation of univariate crude estimates</td>
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<tr>
<td>p) Sufficient numbers of subjects per variable</td>
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</tr>
<tr>
<td>q) Selection method of variables explained</td>
<td>+ / - / ?</td>
</tr>
<tr>
<td>r) Presentation of multivariate estimates</td>
<td>+ / - / ?</td>
</tr>
<tr>
<td><strong>Clinical performance / validity</strong></td>
<td></td>
</tr>
<tr>
<td>s) Clinical performance</td>
<td>+ / - / ?</td>
</tr>
<tr>
<td>t) Internal validation</td>
<td>+ / - / ?</td>
</tr>
<tr>
<td>u) External validation</td>
<td>+ / - / ?</td>
</tr>
</tbody>
</table>
Methodological assessment of studies about prognostic models.

Operationalization of items.

Study participation

a) Inception cohort: **positive** when patients were identified at an early uniform point (inception cohort) in the course of their complaints (e.g. first point at which symptoms were first noticed or first consultation at physiotherapy practice). **Also positive** in case of a heterogeneous population (survival cohort) for which subgroups of patients were identified and analysed (first episode of complaints or first consultation at physiotherapy practice). **Negative** when no inception cohort was used.

b) Source population: **positive** when population was described in terms of sampling frame (primary care, general population, physiotherapy practice) and recruitment procedure (place and time-period of recruitment and type of methods used to identify the sample). **Negative** when not both of these features are given. **Also negative** when it is likely that the recruitment procedure led to selection of participants that are systematically different from eligible non-participants.

c) Inclusion and exclusion criteria: **positive** when criteria were formulated for at least 4 out of 5 of the (for the study) most relevant characteristics, mostly:
   1. Age
   2. Sex
   3. Relevant co-morbidity
   4. Duration of complaints
   5. Type of complaints

   **Negative** when ≤3 criteria were formulated. **Also negative** when it is likely that the criteria used for inclusion/exclusion led to selection of participants that are systematically different from eligible non-participants.

d) Prospective design: **positive** when a prospective design was used. **Also positive** in case of a historical cohort of which the determinants (prognostic factors) are measured before the outcome was determined. Negative if a historical cohort is used, considering prognostic factors at time zero which are not related to the primary research question for which the cohort is created or in case of an ambispective design.

Study attrition

e) Drop-outs: **positive** when total number of drop-outs (loss to follow-up) was ≤20%. **Also positive** when appropriate procedures were used to deal with missing values (e.g. use of multiple imputation). **Negative** when the total number of drop-outs exceeds the 20% cut-off point and no appropriate procedures were used to deal with missing values.

f) **Positive** if method is described. **Negative** if not.

Prognostic factor measurement

g) Clinical relevant potential prognostic factors: **positive** when the article describes at least one of the following factors at baseline:
   6. Physical/disease factors (e.g. severity of pain, range of motion, duration of complaints, localization of complaints)
   7. Psychosocial factors (e.g. live events, anxiety, depression)
   8. Sociodemographic factors, other than gender and age (e.g. employment status, occupation, co-morbidity)

   **Negative** when the article does not describe at least one of the factors mentioned above at baseline.

h) Standardized or valid measurements: **positive** if at least one of the factors of g), excluding age and gender, are measured in a standardized, valid and reliable way.
i) **Positive** if studied (and accounted for if necessary) or not relevant (in case of no continuous predictors used), **negative** if not.

j) **Positive** if prognostic variable isn't dichotomized or dichotomization is sensible to do. **Negative** if prognostic variable is dichotomized.

k) Data presentation of most important prognostic factors: **positive** when frequencies, percentages or mean (and standard deviation or CI), or median (and Inter Quartile Range) are reported for all prognostic factors in the final model. In all other cases: **negative**.

Outcome

l) Clinical relevant outcome measure(s): **positive** if at least one clinical relevant outcome criteria for recovery is reported. In all other cases: **negative**.

m) Standardized or valid measurements: **positive** if one or more of the main outcome measures are measured in a standardized, valid and reliable way. In all other cases: **negative**.

n) Data presentation of most important outcome measures: **positive** if frequencies, percentages or mean (and standard deviation/CI), or median (and Inter Quartile Range) are reported for one or more of the main outcome measures for the most important follow-up measurements. In all other cases: **negative**.

Analysis

o) Univariate crude estimates presented: **positive** if univariate crude estimates (RR, OR, HRR) between prognostic factors separately and outcome are provided. **Negative** if only p-values or wrong association values (Spearman, Pearson, sensitivity) are given, or if no tests are performed at all.

p) Sufficient numbers of subjects per variable: **positive** if it is mentioned (or easy derivable) that the number of cases (and non-cases) in the multivariate analysis was at least 10 times the number of independent variables that were put in the multivariate analysis. In all other cases: **negative**.

q) **Positive** if references are used to explain the selection method of variables. **Also positive** if an appropriate rationale is given. **Negative** if not.

r) Multivariate estimates presented: **positive** if multivariate estimates (with CI or p-values) are presented of all prognostic factors that are part of the final clinical prediction rule. **Negative** if not.

Clinical performance/validity

s) Performance measurement: **positive** if the study provides information about performance measurement (e.g. discrimination, calibration, explained variance). In all other cases: **negative**.

t) Internal validation: **positive** if appropriate techniques are used to assess internal validity of the prognostic model (e.g. cross-validation or bootstrapping). In all other cases: **negative**.

External validation: **positive** if the prognostic model is tested in a different population. **Negative** if not.
### Appendix C. Characteristics of the included studies

<table>
<thead>
<tr>
<th>Author, Publication Year</th>
<th>N, Quality (Q), Setting, Country</th>
<th>Number of Univar. Variab.</th>
<th>Number of Multivar. Variab.</th>
<th>(Number of) Prediction variables</th>
<th>Outcome Follow-up</th>
<th>Performance</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collins Kent* 2012</td>
<td>N=310 Primary care Australia and the Netherlands</td>
<td>-</td>
<td>17</td>
<td>Pain (Four variables) -Symptom duration -Recruitment -Activity related pain -AKPS Function AKPS: (Three variables) -Symptom duration -Pain intensity -AKPS Function FIQ: (Five variables) -Symptom duration -AKPS -pain intensity -female gender -FIQ</td>
<td>Pain; -VAS/NRS Function; -AKPS -FIQ Follow-up: 3 and 12 months</td>
<td>Explained Variation ($R^2$): Pain: 0.260*/<em>0.237</em> AKP: 0.330*/<em>0.317</em> FIQ: 0.273*/<em>0.235</em> Area Under the Curve (AUC): Pain: 0.790/0.736# AKP: 0.675/0.304# FIQ: 0.611/0.563#</td>
<td>3 month follow-up 12 month follow-up Cut off measurement instruments for respectively: Pain is 60, AKP is 80 and FIQ is 14;</td>
</tr>
<tr>
<td>Doménech Mar* 2014</td>
<td>N=47 Orthopaedic Clinic Spain</td>
<td>-</td>
<td>7</td>
<td>Pain -Catastrophizing (PCS) Function: (Two variables) -Catastrophizing -Anxiety</td>
<td>Pain; -VAS Function; -Lysholm Follow-up: 6 months</td>
<td>Explained Variation ($R^2$): Pain: 0.49 Function: 0.58</td>
<td></td>
</tr>
<tr>
<td>Iverson* 2008</td>
<td>N=49 Military Population Texas</td>
<td>41</td>
<td>40</td>
<td>Pain (Five variables) -Difference in hip internal rotation &gt; 14° -Ankle dorsiflexion &gt; 16° -Navicular drop &gt; 3 mm -No stiffness with sitting -Squatting most painful</td>
<td>Pain; -NRS Recovery: -GRCQ Follow-up: Same day after treatment</td>
<td>Pain: Sn: 0.36-0.73 Sp: 0.63-0.93 1.R+: 1.9-4.9 1.R-: 0.4-0.7</td>
<td>No performance measures of the model, only of the predictors separate</td>
</tr>
<tr>
<td>Leshner* 2006</td>
<td>N=50 Military Population Texas</td>
<td>28</td>
<td>6</td>
<td>Pain (Two variables) -Tibial angulation -Patellar tilt test</td>
<td>Pain; -NRS Recovery: -GRCQ Follow-up: Same day after treatment</td>
<td>Pain: Sn predictors: 0.53-0.88 Sn model 0.53 Sp predictors: 0.51-0.75 Sp model 0.88 1.R+ predictors: 1.8-2.1 1.R+ model 4.4 1.R- predictors: 0.24-0.63 1.R- model 0.53</td>
<td>Performance measures of the model and of the predictors separate</td>
</tr>
<tr>
<td>Natri* 1998</td>
<td>N=49 Clinic Finland</td>
<td>19</td>
<td>19</td>
<td>Pain -Patellar crepitation Function: Lysholm (Three variables) -Bilateral symptoms -Patellar apprehension</td>
<td>Pain; -VAS$^1$ Function; -Lysholm -Tegner Follow-up:</td>
<td>Pain: -VAS: $R^2$: 0.16 Function: -Lysholm: $R^2$: 0.60 -Tegner: $R^2$: 0.52</td>
<td>Determinants at follow-up are measured at 6 months and are predicting the outcome at 7 years</td>
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</table>
### Appendix C. Characteristics of the included studies (continued)

<table>
<thead>
<tr>
<th>Author, Publication Year</th>
<th>N, Quality (Q), Setting, Country</th>
<th>Number of Univar. Variab.</th>
<th>Number of Multivar. Variab.</th>
<th>(Number of) Prediction variables</th>
<th>Outcome Follow-up</th>
<th>Performance</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patryn 2012</td>
<td>N=40 Q=15/21&lt;sup&gt;*&lt;/sup&gt; Orthopaedic surgeon Belgium</td>
<td>21</td>
<td>4</td>
<td>Pain: (Three variables) - CSA total quadriceps - Avg PT Ecc 60 - Frequency of pain Function: (Three variables) - CSA total quadriceps - Avg Peak Torque, Ecc 60°/sec - Frequency of pain</td>
<td>6 months and 7 years Pain: - Kujala Function: - Kujala Follow-up: - 7 weeks</td>
<td>Pain: R&lt;sup&gt;2&lt;/sup&gt;: 0.54/0.46 Function: R&lt;sup&gt;2&lt;/sup&gt;: 0.54/0.46</td>
<td>R&lt;sup&gt;2&lt;/sup&gt; / adjusted R&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Piva 2008</td>
<td>N=74 Q=17/21&lt;sup&gt;*&lt;/sup&gt; Primary Care Physical therapist Pittsburgh USA</td>
<td>18</td>
<td>8</td>
<td>Pain: (Six variables) - Age - Sex - Height - Weight - Change in FABs-PA - Change in FABs-W</td>
<td>Pain: - NRS Physical function: - ADLS Follow-up: - 8 weeks</td>
<td>Pain: R&lt;sup&gt;2&lt;/sup&gt;: Model 1: 0.05 Model 2: 0.33 Model 3: 0.43 Function: R&lt;sup&gt;2&lt;/sup&gt;: Model 1: 0.12 Model 2: 0.37</td>
<td>Model 1 for pain and function: age, sex, height, weight Model 2 for pain and function: age, sex, height, weight, FABs-PA Model 3 for function: age, sex, height, weight, FABs-PA, gastrocnemius length</td>
</tr>
<tr>
<td>Sutlive 2004</td>
<td>N=45 Q=11/2&lt;sup&gt;4&lt;/sup&gt; Military Population Texas</td>
<td>24</td>
<td>8</td>
<td>Pain: (Six variables) - Forefoot alignment - Great toe extension - Navicular drop test - Calcaneal stance - 90/90 SLR-test - Difficulty walking</td>
<td>Pain: -VAS Recovery GRCQ Follow-up: - 3 weeks</td>
<td>Pain: Sn: 0.13 - 0.71 Sp: 0.48 - 0.97 I.R.: 1.4 - 4.0</td>
<td>No performance measures of the model, only of the predictors separate</td>
</tr>
<tr>
<td>Witvrouw 2001</td>
<td>N=30 Q=9/21&lt;sup&gt;4&lt;/sup&gt; University Hospital Belgium</td>
<td>39</td>
<td>39</td>
<td>Pain: (Two variables) - Reflex response time Vastus Medialis Oblique - Duration of symptoms</td>
<td>Pain: - Kujala Function: Kujala Follow-up: - 5 weeks and 3 months</td>
<td>No performance measures</td>
<td></td>
</tr>
</tbody>
</table>

VAS= Visual Analogue Scale; NRS= Numerical Rating Scale; AKPS= Anterior Knee Pain Scale; FIQ= Functional Index Questionnaire knee; GRCQ= Global rating of Changes Questionnaire; CSA= Cross sectional area; FABs-PA= Fear Avoidance Beliefs-Physical Activities; FABs-W= Fear Avoidance Beliefs-Work; ADLS= Activity of Daily Living Scale; Sn= Sensitivity; Sp= Specificity; LR+ (positive Likelihood Ratio); LR- (negative Likelihood Ratio); R<sup>2</sup> (Explained Variation)

<sup>*</sup> Study with sufficient quality

<sup>4</sup> Study with low quality
ABSTRACT

Background: Hip flexor tightness is theorized to alter antagonist muscle function through reciprocal inhibition and synergistic dominance mechanisms. Synergistic dominance may result in altered movement patterns and increased risk of lower extremity injury.

Hypothesis/Purpose: To compare hip extensor muscle activation, internal hip and knee extension moments during double-leg squatting, and gluteus maximus strength in those with and without clinically restricted hip flexor muscle length.

Design: Causal-comparative cross-sectional laboratory study.

Method: Using a modified Thomas Test, female soccer athletes were assigned to a restricted (>0° of sagittal plane hip motion above the horizontal; n=20, age=19.9 ±1 years, ht=167.1 ±6.4 cm, mass=64.7 ±8.2kg) or normal (>15° of sagittal plane hip motion below horizontal; n=20, age=19.4 ±1 years, ht=167.2 ±5.5 cm, mass=61.2 ±8.6 kg) hip flexor muscle length group. Surface electromyographic (sEMG) activity of the gluteus maximus and biceps femoris, and net internal hip and knee extension moments were measured between groups during a double-leg squat. Isometric gluteus maximus strength was assessed using handheld dynamometry.

Results: Individuals with restricted hip flexor muscle length demonstrated less gluteus maximus activation (p=0.008) and a lower gluteus maximus : biceps femoris co-activation ratio (p=0.004). There were no significant differences (p>0.05) in hip or knee extension moments, isometric gluteus maximus strength, or biceps femoris activation between groups.

Conclusions: Female soccer athletes with hip flexor muscle tightness exhibit less gluteus maximus activation and lower gluteus maximus : biceps femoris co-activation while producing similar net hip and knee extension moments. Thus, individuals with hip flexor muscle tightness appear to utilize different neuromuscular strategies to control lower extremity motion.

Level of Evidence: 3

Keywords: ACL Injury, Electromyography, Hamstring Injury, Musculoskeletal Injury, Neuromuscular Control,
INTRODUCTION:
Lower extremity injuries represent a significant burden in sports and physical activity, contributing to a majority of time loss from participation and disability.1-7 Furthermore, lower extremity injuries contribute to decreased athletic performance and overall team success.8 However, a majority of lower extremity and lumbo-pelvic-hip complex injuries, including hamstring injury,7 groin injury,9 ankle sprains,10 anterior cruciate ligament rupture,11-14 and low back pain,15,16 have been shown to be preventable and are attributable to modifiable biomechanical risk factors.17 Restricted hip flexor muscle length or “tightness” assessed via hip extension range of motion (ROM)18 has been identified as a risk factor for various lower extremity musculoskeletal injuries,15,16,19-23 and thus should be examined further as a modifiable factor linked to sport-related injury.

Furthermore, restricted hip flexor muscle length is theorized to decrease neural drive to the hip extensor musculature. Specifically, reciprocal inhibition of the gluteus maximus, secondary to “overactivity” of the hip flexor muscle group has been implicated to occur and lead to lower extremity injury.24-27 Reciprocal inhibition is theorized to lead to an increased reliance on the secondary hip extensor muscles, such as the hamstrings and hip adductors to produce hip extension torque,28 clinically referred to as “synergistic dominance”.29 Dependency on secondary hip extensors may provoke greater tissue stress in the hamstring and hip adductor musculature, thus resulting in a higher risk of soft tissue injury.30-32 However there is a dearth of literature that validates clinical theory of restricted hip flexor muscle length as an underlying factor inciting altered lower extremity neuromuscular control.

Therefore, the purpose of this study was to compare lower extremity strength, muscle activation and biomechanics between individuals with and without limited hip flexor muscle length. The primary hypothesis of this study was that individuals with restricted hip flexor length would exhibit less hip extension strength, greater internal knee extension moment, and lesser internal hip extension moment compared to individuals with normal hip flexor length during the descent phase of a double-leg squat (DLS). The secondary hypothesis of this investigation was that individuals with restricted hip flexor length would also display depressed gluteus maximus activation and elevated biceps femoris activation compared to those with normal hip flexor length during the descent phase of a DLS.

METHODS
Participants
The investigators conducted a causal-comparative study involving forty female soccer athletes who demonstrated “restricted” (n = 20) or “normal” (n = 20) hip flexor length. All participants, regardless of group assignment, played soccer at the NCAA Division I varsity or the highest the competitive intercollege club level for one hour or more at least twice a week, had no history of lower extremity, spine, abdominal, vestibular, or mild traumatic brain injury in the last three months that limited them from sport of physical activity participation for greater than three consecutive days. A priori power analyses revealed that 20 participants per group would result in an estimated power of 0.80 to observe significant differences of at least 20% in muscle activity, biomechanics, and strength between the normal and restricted groups.33-35

Hip extension ROM of the dominant limb was assessed by the lead investigator (MM), a certified athletic trainer, using the modified Thomas test assessed using a digital inclinometer (Model# 12-1057, Fabrication Enterprises Inc. - Baseline Evaluation Instruments, White Plains, New York) aligned parallel to a line connecting the anterior superior iliac spine and the superior pole of the patella (Figure 1).18,36-38 Inclinometer values greater than 0° (+) indicate that the thigh was positioned above the horizontal and relatively flexed (Figure 1a).18 Inclinometer values below 0° (-) indicate that the thigh was below the horizontal and relatively extended (Figure 1b).18 Inclusion criteria for the normal group was defined as hip extension ROM >15° below the horizontal.
Inclusion criteria for the restricted group was defined as hip extension ROM > 0° above the horizontal.

**Experimental Procedures**

Before participation, all study procedures were explained to each subject, and informed consent was obtained as approved by the Institutional Review Board at The University of North Carolina at Chapel Hill. Participants’ height (cm) and mass (kg) were recorded using a digital scale and stadiometer. Prior to testing, participants completed a warm-up on a stationary cycle ergometer at a self-selected pace for five minutes at a rate of perceived exertion of 5/10.

**Maximal Volitional Isometric Contraction Assessment**

A surface electromyography (sEMG) system (Delsys Bangloni 8, Inc., Boston, Massachusetts): inter-electrode distance = 10 mm; amplification factor = 1,000 (20–450 Hz); CMMR @60 Hz > 80 dB; input impedance > 1015 Ω/pF) was used to record activity as sampled at 1,000 Hz from the gluteus maximus and biceps femoris of the dominant limb during maximal volitional contractions (MVIC). Electrodes for the biceps femoris were placed approximately 1/3rd the distance between the ischial tuberosity and lateral popliteal crease, while those for the gluteus maximus were placed approximately 1/3rd the distance between the second sacral vertebrae and the greater trochanter. A reference electrode was placed at the tibial tuberosity on the dominant leg.

Dominant limb peak isometric force and sEMG measures were concurrently collected for the gluteus maximus with the knee flexed 90° (Figure 2a) by the lead investigator (MM). Hip extension strength data were obtained via a handheld digital dynamometer (Lafayette Manual Muscle Tester, Model #01163, Lafayette, Indiana). Isometric hip extension strength pilot testing revealed excellent intra-rater reliability (ICC(3,k) = 0.98) and a low standard error of the measure (SEM = 0.48 N). Isometric force (N) and sEMG activity were collected for five seconds for each of three trials. For the biceps femoris, participants maximally flexed their knee against the investigator-applied force to the posterior shank at the level of the medial and lateral malleoli (Figure 2b). sEMG data were collected for five seconds for each of three trials.

**Biomechanical Assessment Preparation & Assessment**

A TrackStar (Ascension Technologies Inc. Burlington, Vermont, USA) electromagnetic motion analysis system controlled by The Motion Monitor v8.0 software (Innovative Sports Training Inc. Chicago, Illinois, USA) was used to sample hip and knee kinematic data at 100 Hz during the DLS. Electromagnetic sensors were secured to the participant’s dominant limb shank and thigh, and the apex of the

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Figure 1. Modified Thomas Test assessment of hip extension ROM to assess hip flexor muscle length; (1a.) – restricted >0° above the horizontal, (1b.) – normal >15° below the horizontal.
sacrum. Medial femoral epicondyle, lateral femoral epicondyle, medial malleolus, lateral malleolus, left anterior superior iliac spine, right anterior superior iliac spine bony landmarks were digitized using a 15 cm stylus attached to an electromagnetic sensor. The knee and ankle joint centers were defined as the centroids between the medial and lateral femoral condyles and medial and lateral malleoli. The Bell method was used to approximate the hip joint center. A non-conductive force plate (Bertec 4060-NC, Columbus, Ohio, USA) sampled center of pressure and ground reaction force data at 1,000 Hz.

A right-handed global coordinate system was defined for all segments (+x-axis= anterior direction, +y-axis= leftward direction and +z-axis= superior direction). Sagittal plane joint motion was defined as the motion of the distal segment relative to the proximal segment using a Cardan angle rotation sequence with the first rotation about the y-axis of the joint.

Muscle activation, kinematic, and kinetic data were collected during the descent phase of the DLS to simulate hip and knee flexion deceleration neuromuscular control during sport participation. Subjects performed the five DLS repetitions barefoot with their feet shoulder width apart, toes pointed straight ahead, and arms extended over-head. Squat velocity was controlled via a metronome (60 beats per minute). Participants achieved at least 60° of knee flexion confirmed with a goniometer and motion capture knee kinematics. Participants were instructed to descend for two beats, ascend for two beats, and then pause for one beat between squats and then repeat. Prior to assessment, participants were required to perform between five and seven consecutive practice trials of squatting at the appropriate depth and cadence for familiarization.

Data Reduction
Peak isometric force (N) for each gluteus maximus MVIC trial was averaged across the three testing trials and normalized to the participant's body weight (×BW).

Raw sEMG data were exported into a custom MatLab v2012a program (MathWorks, Natick, Massachusetts, USA) and then passively demeaned, band-pass (10-350 Hz) and notch filtered (59.5-60.5 Hz - 4th order Butterworth digital filter), and smoothed using a 25 ms root mean squared sliding window. sEMG data were normalized as a percentage of MVIC (%MVIC). Mean sEMG amplitudes were calculated during the descending phase for each trial of the DLS, defined as the period from initiation of knee flexion until peak knee flexion. Muscle co-activation ratios were calculated during the descending phase for gluteus maximus and biceps femoris muscle activation by dividing the mean gluteus maximus activity by the

**Figure 2.** (2a.) – Gluteus maximus MVIC & strength assessment, (2b.) – Biceps femoris MVIC assessment.
mean biceps femoris activity (gluteus maximus : biceps femoris). A ratio of 1.0 indicates balanced muscular activation; ratios less than 1.0 indicate greater activation of biceps femoris relative to the gluteus maximus.

All kinematic data were low-pass filtered at 10 Hz (4th order low-pass Butterworth digital filter). Kinematic and kinetic data were combined via an inverse dynamics solution to yield net internal hip and knee extension moments (Nm). Peak moments were identified during the descending phase of each squat trial, normalized to the product of the body weight and height (BW×Ht), and averaged across trials. Internal hip and knee extension moment data are reported as positive values for ease of interpretation.

**STATISTICAL ANALYSES**

Separate independent samples t-tests were performed to compare hip extension ROM, gluteus maximus strength, gluteus maximus activation, biceps femoris activation, gluteus maximums : biceps femoris co-activation ratio, and peak hip and knee extension moments between the restricted and normal groups (α = 0.05).

Statistical outliers were defined as variables with values more than three standard deviations from the group means. Examination of sEMG data identified outliers in biceps femoris (n=8) and gluteus maximus (n=5) sEMG data. The total number of subjects utilized in analyses of sEMG data is presented in Table 1. No statistical outliers were identified for internal moment or strength data.

**RESULTS:**

**Inclusion Criteria Verification**

There was a significant difference in hip extension ROM (p < 0.001, d = 2.18) between the restricted (12.85° ± 5.05) and normal (-19.52° ± 9.19°) groups, with no significant group differences in age, height, or mass (Restricted: age = 19.9 ± 1 years, ht = 167.1 ± 6.4 cm, mass = 64.7 ± 8.2 kg, Normal: age = 19.4 ± 1 years, ht = 167.2 ± 5.5 cm, mass = 61.2 ± 8.6 kg, p > 0.05).

**Muscle Activation**

Descriptive statistics, p-values, and effect sizes are presented for all DLS muscle activation data in Table 1. The restricted group demonstrated significantly less average gluteus maximus activation compared to the normal group during the descent phase of the DLS (60% less relative activation). The restricted group also displayed a significantly lower gluteus maximus : biceps femoris co-activation ratio than the normal group, indicating 2.6 times more biceps femoris activation relative to gluteus maximus activity in the restricted compared to the control group. However, biceps femoris EMG amplitude normalized to MVIC did not differ between groups.

**Muscle Strength & Joint Moments**

There were no significant differences between the restricted and normal groups in hip extension strength or internal hip and knee extension moments during the DLS. Descriptive statistics, p-values, and effect sizes for these data are presented in Table 2.

**DISCUSSION**

This is the first study to compare gluteal muscle strength, primary hip extensor muscle activation, and lower extremity biomechanics between individuals with restricted and normal hip flexor muscle length during a controlled functional movement. The current findings revealed that muscle activation amplitude of the gluteus maximus was significantly less in the restricted group compared to the normal group, resulting in a significantly lower gluteus maximus : biceps femoris co-activation ratio. However,
The amplitude was more than 2 times greater than the biceps femoris. In contrast, the restricted group demonstrated a gluteus maximus : biceps femoris co-activation ratio of 0.88, indicating relatively greater activity of the biceps femoris. These findings suggest that individuals with restricted hip flexor length achieve comparable hip extension moments via a decreased activation of the primary hip extensor muscle (gluteus maximus) and relatively greater activation of the secondary or synergistic hip extensor muscles (biceps femoris) compared to individuals with normal hip flexor length.

Hip extension strength did not differ between the restricted and normal groups. Gluteal muscle strength has been observed to influence activation of the gluteal musculature, as weaker individuals display greater muscle activation compared to stronger individuals during the same standardized task.44 Since muscle strength was similar, it is possible the differences in muscle activation were primarily due to differences in hip flexor muscle length between groups. Hip flexor muscle tightness may facilitate reciprocal inhibition and / or an abnormal resting muscle length of the gluteus maximus musculature underlying the observed lower gluteus maximus : biceps femoris co-activation ratio in the restricted group.

The current findings indicate that limited hip flexor muscle length does not directly alter internal hip and knee extension moments. However, the observed muscle activation strategy in individuals with limited hip flexor muscle length suggests that these individuals exhibit relatively greater reliance on hamstrings musculature versus gluteus maximus to eccentrically control hip flexion during a controlled functional movement. The requirement for greater hamstrings muscle co-activation may impart greater stress on the hamstrings, thus clinicians should be more cautious when treating individuals with restricted hip flexor length.

| Table 2. Net normalized internal hip & knee extension moments (Nm/NBW/mHT) during the descent phase of a double-leg squat, & isometric gluteus maximus strength (N/NBW) |
|-------------------------------------------------|------------------|------------------|-----------------|------------------|
|                                                  | Restricted       | Normal           | p               | Cohen's d        |
|                                                  | Mean (SD)        | Mean (SD)        | 95% CI          | 95% CI          |
| Hip Extension Moment                             | 0.091 (0.021)    | 0.096 (0.03)     | [0.082, 0.1]    | 0.580            | 0.19             |
| Knee Extension Moment                            | 0.072 (0.038)    | 0.073 (0.073)    | [0.055, 0.089]  | 0.360            | 0.02             |
| Gluteus Maximus Strength                         | 0.39 (0.21)      | 0.4 (0.14)       | [0.298, 0.482]  | 0.730            | 0.06             |
controlled motion to identify the effects of a specific ROM limitation on lower extremity hip and knee neuromuscular control.

It should also be noted that muscle strength was assessed via a maximal voluntary isometric contraction, yet the hip extensor musculature often functions in both a concentric and eccentric manner during more demanding functional tasks. Furthermore, the study methodology evaluated hip extension strength of the gluteal muscle mass, and did not isolate hamstring muscle strength. Thus the comparison of clinical hip extension strength between groups is primarily focused on gluteal strength.

Collectively, it is unclear if the strength measures, though clinically relevant, adequately reflect the functional demands of the hip extensors. Finally, this study’s methodology did not assess the activation of the primary hip flexor muscles, iliacus, and psoas major. Thus, it is not possible to determine if there was truly greater activation of the hip flexor muscles, which may have produced reciprocal inhibition of the gluteus maximus muscle in the restricted group. Future research should consider these limitations.

CONCLUSIONS

In conclusion, individuals with restricted hip flexor muscle tightness displayed hip and knee extension moments similar to those with normal muscle length, but they achieved these moments with decreased gluteus maximus activation and greater relative hamstring co-activation (reduced gluteus maximus : hamstrings co-activation ratio). This decrease in gluteus maximus activation may be due to reciprocal inhibition of the gluteus maximus, which resulted in compensatory greater levels of relative hamstrings co-activation to achieve the same internal hip extension moment. These findings suggest that hip flexor muscle tightness may be an important factor to consider in hamstring and ACL injury prevention programs. The findings of this study provide rationale for clinicians to consider implementing a treatment paradigm aimed at increasing hip extension range of motion and gluteal muscle strength. Achieving or maintaining normal hip flexor muscle length may decrease the potential for an inhibitory effect of the shortened hip flexors on gluteal neuromuscular control.
REFERENCES


ABSTRACT

Background: Although the dynamic balance has been proposed as a risk factor for sports-related injuries, few researchers have used the Y balance test to examine this relationship. The purpose of this study was to determine if the Y Balance Test (YBT) is a valid test for determining subjects susceptible to soft tissue injury among soccer players on a professional team.

Study Design: Prospective cohort

Methods and Measures: Prior to the 2011 football (soccer) season, the anterior, posteromedial and posterolateral YBT reach distances and limb lengths of 74 soccer players were measured. Athletes' physiotherapists documented how many days the players were unable to play due to the injuries. After normalizing for lower limb length, each of the reach distances, right/left reach distance difference and composite reach distance were examined using odds ratios and logistic regression analysis.

Results: Logistic regression models indicated that players with a difference of equal or greater than 4cm between lower limbs in posteromedial direction were 3.86 more likely to sustain a lower extremity injury (p = 0.001). Results indicate that players who had lower scores than the mean in each reach direction, independently, were almost two times more likely to sustain an injury.

Conclusions: The results suggest that YBT can be incorporated into physical examinations to identify soccer players who are susceptible to risk of injury.

Key Words: Balance/postural stability, injury prevention, lower extremity

Level of evidence: 2b
INTRODUCTION

Typically, sports and exercise are considered to have a long-term health benefits. However, there are certain health risks, such as injury, that should be taken into consideration. Injury prevention in sports is very important, and a lot of investigative time and effort is spent in this realm. Prevention is important given the fact that athletes do not wish to miss competitions or training for their sports.

A number of different tools have been created that are designed to pinpoint the athlete’s predisposition to or risk for injuries. In addition, health professionals and coaches should work with athletes to attempt to reduce the number of injuries as much as possible. The objective of the prevention process is not to completely eliminate injuries, but rather to reduce them and keep them at an acceptable level.

The risk of injury is a combined measurement of incident probability and the consequences of an adverse effect. The risk factor is a situation that offers a predisposition to an adverse event. The estimation and evaluation of the risk level is called “risk assessment”. If the activity risk level combined with the individual risk level is considered too high, preventive measures must be applied in order to decrease the risk.

Risk factors can be divided into two groups: intrinsic and extrinsic. Intrinsic factors include medical history, age, physical conditioning, and performance measures such as balance and functional movements. Extrinsic factors include the weather, temperature, and altitude. Both types of factors should be considered when examining risk.

Injuries can be divided in two types, contact injuries, caused by contact with a fellow athlete or an object while participating in competition or training, and non-contact injuries which are often caused by intrinsic factors such as neuromuscular disorders, being unfit, training overload, etc. Non-contact injuries are often the focus of prevention initiatives, and managing identified risk factors plays an important part.

Well-designed prevention programs with neuromuscular and proprioceptive training components have been suggested to reduce injury risks. There is evidence regarding the efficiency of training prevention programs for the reduction of some injuries in adults and teenagers in sports which involve pivoting. Many authors have shown that interventions that include balance exercises are very efficient in injury risk reduction as well as performance improvement after an injury. Changes in proprioception and neuromuscular control are considered to be responsible for these effects.

Poor balance, altered motor control, or lack of neuromuscular control have all been described as predictors of injury risk in the lower limbs of athletes. Poor dynamic balance is considered an intrinsic risk factor. The implementation of an injury prevention program that includes balance and neuromuscular control in soccer athletes has been shown to reduce both injury incidence and health care costs. However, in order to implement an injury prevention program athletes at risk must be identified. Several methods or measures have been proposed to assess injury predisposition, including injury history, body mass index, hop testing, and isokinetic testing. One of the most promising is the evaluation of the dynamic balance using the Y Balance Test (YBT).

The YBT has been shown to be able predict lower extremity injury in university basketball players, and to identify those with chronic ankle instabilities. In addition, the YBT improves with training sessions and is a good test to evaluate whether or not the athlete can return to practicing sports. Hertel et al and Plisky et al reduced the number of reach directions to three from the original eight proposed by the creators of the Star Excursion Balance Test, anterior, posteromedial, and posterolateral.

The YBT is a functional test that requires strength, flexibility, neuromuscular control, stability, range of movement, balance, and proprioception. This test is a good solution for functional testing because of its speed, efficiency, portability, consistency, and objectivity. It can be performed on multiple surfaces. In less than three minutes/subject one can perform a standard protocol with high inter and intra-evaluator reliability (95% CI: 0.88 –0.99 p<.01). This fact makes it possible to test many athletes during the pre-season. When the results of the YBT are asymmetrical or fail to meet expected norms (for gender, sport, experience level) a neuromuscular system
disorder may be present. However, it is important to remember that the YBT is only a test, and is not an assessment of the cause of the disorder.

According to Plisky et al\(^3\) a greater than four centimeter difference in the anterior reach direction between the legs suggests that an athlete has 2.5 times greater risk of injury. The YBT could be useful to identify athletes that are vulnerable to injuries. Side to side differences in performance of the YBT is considered an intrinsic risk factor for injury. The YBT has been shown to have significant differences in performance between genders, types of sports, and competition levels. In a study of 598 athletes, high school basketball player's scores were much worse than those found in the university players.\(^16\)

For these reasons, it is of interest to test players at the beginning of the preseason and study the number of injuries that subsequently occur throughout the season in order to determine injury risk. Considering the fact that all the studies to date have been carried out in the United States, it is important that similar same studies be conducted worldwide. Therefore, the purpose of this study was to determine whether the preseason YBT scores were able to predict injury in Spanish professional soccer players.

**METHODS**

**Subjects and Setting:**
Athletes from a professional soccer club that has six teams, two professional and four amateur were followed during the 2011-2012 season. All the subjects were males and of the 101 players who were a part of the six teams, 74 participated in the study. Thirteen players left the club before the study was completed. Fourteen players were excluded due to human errors in recording injury dates by the responsible physiotherapists' who served as data collectors. The Institutional Board of Jaume I University, approved the study. Written consent was obtained from players, parents or guardians prior to participation in the study. The rights of the subjects were protected throughout the study.

**Questionnaire:**
During the 2011-2012 season, each teams physiotherapist collected players' baseline and injury data: name and age, date of any sustained injury, days not played due to injury, games missed, injured body part(s), type of injury, medical diagnosis, date of relapse, and whether it was a contact or non-contact injury.

**YBT-LQ Protocol**
The YBT is a functional test that requires strength, flexibility, neuromuscular control, balance, stability, and range of motion (ROM). The lower quarter version of the YBT (YBT-LQ) was performed barefoot. A YBT Kit (Perform Better, West Warwick, Rhode Island) was used, which consists of three connected cylindrical tubular plastic bars marked in half centimeter increments. Each bar has a moveable indicator plate, which the subject moves by pushing with their foot/toes without bearing weight on the indicator.

Prior to the test, players performed a warm-up on an exercise bicycle for three minutes. The players were then allowed to have six practice trials on each leg in each of the three reach directions prior to formal testing. The player was instructed to stand on the leg (which was being evaluated) in the center of the platform with the most distal end of the longest toe just behind the red line. While maintaining single-leg stance, the player was instructed to reach with the free limb in the anterior direction for three trials (Figure 1), followed by three trials in posteromedial direction (Figure 2) and then three trials in posterolateral direction (Figure 3), all named in relation to the stance foot, per YBT-LQ protocol.

The player was instructed to push the distance indicator as far as possible towards the direction that was being evaluated. The player was monitored by the researcher during testing, and was not allowed to move the indicator by kicking it or accelerating the indicator at the end of the push. The maximal reach distance was recorded at the most distal point reached by the foot in the proximal edge of the indicator and was measured to the half centimeter. The trial was discarded and repeated if the player (1) Lost his balance during the exercise (reaching the maximal point and coming back at the initial position), (2) Lifted the heel of the foot that was on the platform. The entire surface of the foot must have remained in contact with the platform throughout the entire duration of the movement, (3) The foot did
not maintain contact with the distance indicator while the indicator was in motion (e.g., the indicator was kicked), (4) The distance indicator was used to maintain posture (e.g., the athlete supported their weight on the movement indicator), or (5) a loss of balance occurred during the return to the starting position once the distance had been marked. The greatest of the three trials for each reach direction was used for analysis. Also, the greatest reach distances for each of the directions were summed to yield a composite reach distance, which was normalized to limb length for analysis of the overall performance on the test.

Subjects’ limb length was measured before doing the test. They were placed in supine on a table with their hips and knees flexed. Subjects then lifted the pelvis and returned it passively to the table. The examiner then stretched the lower limbs passively into extension, in order to balance the pelvis. The subject’s right leg was measured in centimeters, with a tape measure, from the bottom edge of the anterior superior iliac spine to the distal edge of the medial malleolus. One researcher measured the subjects’ limb length and explained the test procedures, and the other researcher collected data during the test and made sure that all test movements were performed correctly.

**Injury Surveillance Protocol**
All injury data were recorded on a table by the physiotherapist responsible for the injured player. Several details were recorded including: name, injury date, the date of recovery, and the body side and area. The number of missed days and matches were also recorded. A medical assessment was carried out, determining the type of injury (contact or non-contact) and whether it was sustained during a match.
or a training session, and both of these details were recorded. Lastly, it was determined whether there was a violation of soccer rules that had occurred when the injury was sustained.

For the purposes of this study, an injury was defined as an event that caused at least one training day to be missed. A missed day was defined as the day following the moment the injury was sustained. Missed days ended when the subject was discharged from medical services (that day exclusive) and was able to return to training with the team. According to Ekstrand and Fuller, injuries can be divided into minimal (1-3 missed days), mild (4-7 missed days), moderate (8-28 missed days) or severe (more than 28 missed days).

### Statistical Methods

Means and standard deviations were calculated for the baseline characteristics, YBT reach distance, and limb length. As reach distance is associated with limb length, reach distance was normalized to limb length in order to allow for comparison between players. To express reach distance as a percentage of limb length, the normalized value is calculated by using the formula: reach distance divided by limb length, multiplied by 100. Composite reach distance is calculated using the formula: the sum of the three reach directions divided by three times the limb length, multiplied by 100. For right/left reach distance difference, a cutoff point of 4.0 cm in each direction was selected a priori and used to classify a player at increased risk for injury based on the results of Olmstead et al.

Crude odds ratios and 95% confidence intervals were calculated for total lower limb injuries, and those that were contact and non-contact. This was accomplished by comparing the proportion of individuals at risk of injury (reach distance difference between right and left leg in the same direction ≥ 4cm) without risk of injury (reach distance difference between right and left leg in the same direction < 4cm) and comparing the proportion of individuals at risk of injury (more days off during the season that the average of the sample) without risk of injury (less days off than the average of the sample). An alpha level of $p < .05$ was used to determine statistically significant differences. All data were analyzed using R for Windows, Version 2.14.

### RESULTS

Seventy-four subjects were included, who were on average $20.89 ± 5.31$ years old. From September 1 to April 30, a total of 1874 training sessions were missed, with a mean of $25.32 (± 36.7)$ missed days per player. Of the total of subjects, 34 (45.95%) were from one of the two professional teams (age, $25.38 ± 4.76$) and 40 (54.05%) were from amateur teams (age, $17.07 ± 1.07$). Total missed training sessions were 880 in professionals and 994 in non-professional subjects. All participants were from the same organization. Baseline characteristics including age, number of missed days and mean of missed days per players are shown in Table 1.

The results for YBT test performance at the beginning of the season are displayed in Table 2. These are actual distances reached by the subjects, without normalization. In anterior direction, the mean reach
for all subjects was 55.74 ± 5.56 cm. Professionals reached 57.20 ± 6.02 cm and amateurs 54.5 ± 4.87 cm. In PM direction, mean reach for all subjects was 107.38 ± 7.37 cm, and professionals reached 106.91 ± 8.46 cm while amateurs reached 107.77 ± 6.39 cm. In the PL direction mean reach scores were 104.70 ± 8.50 cm, professionals reached 104.32 ± 8.69 cm while amateurs reached 105.01 ± 8.42 cm. The composite reach distance was 267 ± 18.52 cm for all the subjects; 268.44 ± 20.62 cm in professionals and 267.28 ± 16.78 cm in amateurs.

Normalized reach distances (direct reach distance divided by limb length and multiplied by 100) results are displayed in Table 2. The anterior direction mean for all subjects was 62.71 ± 5.14%. Professionals reached 61.53 ± 5.59% and amateurs reached 63.71 ± 4.57%. In PM direction, the sample mean was 119.85 ± 8.79%, professionals reaching 116.03 ± 8.04%, and amateurs, 123.10 ± 8.14%. In PL direction, the normalized reach for all subjects was 117.17 ± 9.72%, 113.29 ± 8.00% for professionals, and 120.46 ± 9.94% for the amateurs. With regard to composite normalized reach results, the sample mean was 99.91 ± 6.87%. In professionals the mean composite, normalized reach distance result was 96.95 ± 6.09% while in amateurs it was 102.42 ± 6.54%.

Injury risk according to the difference between absolute reach distances is shown in Tables 3, 4, 5, and 6.
and according to normalized reached distance compared with the total average is presented in Tables 7, 8, 9 and 10. Regarding the injury risk, results in Tables 3, 4, 5 and 6 dichotomize differences between limbs as equal, lesser than, or greater than 4cm different in each direction and the number of injury risk subjects (high injury risk as previously defined as having more missed days than the average). The only significant odds ratio (OR) was between PM direction and non-contact injuries, with an OR of 3.86 (95% CI: 1.46 – 10.95). (Table 4) Although not statistically significant, the OR of 2.10 (95% CI: 0.74 – 6.0) was found in the difference between limbs in anterior reach distances and injury risk in contact injuries. With regard to total injuries, the OR was 0.50 (CI 95% CI: 0.2 – 1.4), and in non-contact injuries the OR of 0.48 (95% CI: 0.2 – 1.4).

Injury risk according to the normalized reach distances, are presented in Tables 7, 8, 9 and 10. There were no significant OR’s although there were scores where some type of relation may have existed. When anterior direction scores were examined with injury risk in contact injuries in table 7, the OR was 1.89 (95% CI: 1.46 – 10.95). (Table 4) Although not statistically significant, the OR of 2.10 (95% CI: 0.74 – 6.0) was found in the difference between limbs in anterior reach distances and injury risk in contact injuries. With regard to total injuries, the OR was 0.50 (CI 95% CI: 0.2 – 1.4), and in non-contact injuries the OR of 0.48 (95% CI: 0.2 – 1.4).

### Table 3. Risk as related to anterior direction reach difference between limbs

<table>
<thead>
<tr>
<th>Anterior direction difference*</th>
<th>Total (n=77)</th>
<th>n at risk</th>
<th>% injured</th>
<th>OR</th>
<th>(95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total injuries</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;4cm</td>
<td></td>
<td>53</td>
<td>38.00</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>≥4cm</td>
<td></td>
<td>21</td>
<td>55.00</td>
<td>0.50</td>
<td>(0.2, 1.4)</td>
</tr>
<tr>
<td><strong>Non-contact injuries</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;4cm</td>
<td></td>
<td>53</td>
<td>50.00</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>≥4cm</td>
<td></td>
<td>21</td>
<td>33.00</td>
<td>0.48</td>
<td>(0.2, 1.4)</td>
</tr>
<tr>
<td><strong>Contact injuries</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;4cm</td>
<td></td>
<td>53</td>
<td>31.00</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>≥4cm</td>
<td></td>
<td>21</td>
<td>48.00</td>
<td>2.10</td>
<td>(0.74,6.0)</td>
</tr>
</tbody>
</table>

Abbreviations: OR=odds ratio
* Between right and left reach distances.

### Table 4. Risk as related to posteromedial direction difference between limbs

<table>
<thead>
<tr>
<th>Anterior direction difference*</th>
<th>Total (n=77)</th>
<th>n at risk</th>
<th>% injured</th>
<th>OR</th>
<th>(95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total injuries</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;4cm</td>
<td></td>
<td>47</td>
<td>47.00</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>≥4cm</td>
<td></td>
<td>27</td>
<td>57.00</td>
<td>1.42</td>
<td>(0.50, 3.73)</td>
</tr>
<tr>
<td><strong>Non-contact injuries</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;4cm</td>
<td></td>
<td>47</td>
<td>34.00</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>≥4cm</td>
<td></td>
<td>27</td>
<td>67.00</td>
<td>3.86**</td>
<td>(1.46, 10.95)</td>
</tr>
<tr>
<td><strong>Contact injuries</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;4cm</td>
<td></td>
<td>47</td>
<td>38.00</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>≥4cm</td>
<td></td>
<td>27</td>
<td>29.00</td>
<td>0.168</td>
<td>(0.24,1.84)</td>
</tr>
</tbody>
</table>

Abbreviations: OR= odds ratio.
* Between right and left reach distances.
**p=0.001

Injury risk according to the normalized reach distances, are presented in Tables 7, 8, 9 and 10. There were no significant OR’s although there were scores where some type of relation may have existed. When anterior direction scores were examined with injury risk in contact injuries in table 7, the OR was 1.89 (95% CI: 0.72 – 5.13). In Table 8, PM direction was examined with injury risk in non-contact injuries,
The results show that athletes with a side-to-side difference equal to or greater than 4cm in PM direction have a 3.86 greater probability of suffering a non-contact injury than those who did not. Plisky et al\textsuperscript{13} showed that high school basketball players with decreased normalized reach distance in PM direction were significantly associated with lower extremity injury (p<.05). In addition, although there were no significant differences, there were indications that players who have low scores in anterior direction have nearly two times the possibility of a contact injury (OR 1.89) similar to the findings of Plisky et al\textsuperscript{13}.

The results of the current research did not agree with the findings of Plisky et al who suggested that and the OR was 2.14 (95% CI: 0.85 – 5.33). In contrast, in Table 9, PL direction with total injury risk provided an OR of 2.41 (95% CI: 0.96 – 6.26). When only with non-contact injuries were considered, the OR was 2.18 (95% CI: 0.87 – 5.67). When the composite results are normalized, and related to an injury risk in total injuries Table 10 shows the OR of 1.93 (95% CI: 0.77 – 4.96), while when joined with injury risk in non-contact injuries only, the OR was 2.24 (95% CI: 0.89 – 5.86).

**DISCUSSION**

The aim of this study was to determine if YBT could be used as a predictor of lower extremity injury in soccer players. The results show that athletes with a side-to-side difference equal to or greater than 4cm in PM direction have a 3.86 greater probability of suffering a non-contact injury than those who did not. Plisky et al\textsuperscript{13} showed that high school basketball players with decreased normalized reach distance in PM direction were significantly associated with lower extremity injury (p<.05). In addition, although there were no significant differences, there were indications that players who have low scores in anterior direction have nearly two times the possibility of a contact injury (OR 1.89) similar to the findings of Plisky et al\textsuperscript{13}.

The results of the current research did not agree with the findings of Plisky et al who suggested that

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**Table 5.** Risk as related to posterolateral direction difference between limbs

<table>
<thead>
<tr>
<th>Characteristic. Posterolateral direction difference*</th>
<th>Total (n=77)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n at risk</td>
</tr>
<tr>
<td><strong>Total injuries</strong></td>
<td></td>
</tr>
<tr>
<td>&lt;4cm</td>
<td>46</td>
</tr>
<tr>
<td>≥4cm</td>
<td>28</td>
</tr>
<tr>
<td><strong>Non-contact injuries</strong></td>
<td></td>
</tr>
<tr>
<td>&lt;4cm</td>
<td>46</td>
</tr>
<tr>
<td>≥4cm</td>
<td>28</td>
</tr>
<tr>
<td><strong>Contact Injuries</strong></td>
<td></td>
</tr>
<tr>
<td>&lt;4cm</td>
<td>46</td>
</tr>
<tr>
<td>≥4cm</td>
<td>28</td>
</tr>
</tbody>
</table>

Abbreviations: OR=odds ratio.
\* Between right and left reach distances.

**Table 6.** Risk as related to composite reach difference between limbs

<table>
<thead>
<tr>
<th>Characteristic. Composite Result difference*</th>
<th>Total (n=77)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n at risk</td>
</tr>
<tr>
<td><strong>Total injuries</strong></td>
<td></td>
</tr>
<tr>
<td>&lt;12cm</td>
<td>55</td>
</tr>
<tr>
<td>≥12cm</td>
<td>19</td>
</tr>
<tr>
<td><strong>Non-contact injuries</strong></td>
<td></td>
</tr>
<tr>
<td>&lt;12cm</td>
<td>55</td>
</tr>
<tr>
<td>≥12cm</td>
<td>19</td>
</tr>
<tr>
<td><strong>Contact Injuries</strong></td>
<td></td>
</tr>
<tr>
<td>&lt;12cm</td>
<td>55</td>
</tr>
<tr>
<td>≥12cm</td>
<td>19</td>
</tr>
</tbody>
</table>

Abbreviations: OR= odds ratio.
\* Sum of all three reach distances
Gender, competitive level, and type of sport are purported to affect YBT performance. Nevertheless, the current results demonstrated that those in the current study who had differences of greater than 4 cm in the PM direction had almost a four-fold greater possibility of suffering a non-contact injury in a lower limb. These results demonstrate a difference of greater than 4 cm in ANT direction between limbs implied having 2.5 greater possibility of injury. When comparing results between this study and the Plisky et al study, the athletes sport of preference differed; and although basketball can be compared to football (soccer) in some aspects, there are several performance based differences which may account for the differences in study outcomes.

### Table 7. Risk injury using normalized anterior reach distance average for total sample

<table>
<thead>
<tr>
<th>Normalized anterior direction*</th>
<th>n at risk</th>
<th>% injured</th>
<th>OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total injuries</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;62.71</td>
<td>36</td>
<td>0.44</td>
<td>1</td>
</tr>
<tr>
<td>≤62.71</td>
<td>38</td>
<td>0.55</td>
<td>1.54 (0.62, 3.91)</td>
</tr>
<tr>
<td>Non-contact injuries</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>&gt;62.71</td>
<td>36</td>
<td>0.44</td>
<td>1</td>
</tr>
<tr>
<td>≤62.71</td>
<td>38</td>
<td>0.47</td>
<td>1.13 (0.45, 2.83)</td>
</tr>
<tr>
<td>Contact injuries</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>&gt;62.71</td>
<td>36</td>
<td>0.28</td>
<td>1</td>
</tr>
<tr>
<td>≤62.71</td>
<td>38</td>
<td>0.42</td>
<td>1.89** (0.72, 5.13)</td>
</tr>
</tbody>
</table>

Abbreviations: OR= odds ratio
**P=0.001
Note: 62.71=normalized anterior direction average for the entire sample
* Normalized reach distance is reach distance divided by limb length multiplied by 100

### Table 8. Risk injury using normalized posteromedial reach distance average for total sample

<table>
<thead>
<tr>
<th>Normalized posteromedial direction*</th>
<th>n at risk</th>
<th>% injured</th>
<th>OR (95% CI)</th>
</tr>
</thead>
<tbody>
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<td>Total injuries</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;119.85</td>
<td>38</td>
<td>0.45</td>
<td>1</td>
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<tr>
<td>≤119.85</td>
<td>36</td>
<td>0.56</td>
<td>1.54 (0.62, 3.91)</td>
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<td>Non-contact injuries</td>
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<td>≤119.85</td>
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<td>2.14** (0.85, 5.33)</td>
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<tr>
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<td>36</td>
<td>0.27</td>
<td>0.53 (0.20, 1.38)</td>
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Abbreviations: OR= odds ratio
**P=0.001
Note: 119.85=normalized posteromedial direction average for the entire sample.
* Normalized reach distance is reach distance divided by limb length multiplied by 100
the OR was 1.93 (95% CI: 0.77 – 4.96) while when the composite result was related to injury risk in non-contact injuries only, the OR was 2.24 (95% CI: 0.89 – 5.86), and both were statistically significant. The injury risk in those with a composite reach distance less than the average of the sample were approximately two times more likely to sustain an injury. If composite scores lower than the average can be considered as having poorer balance, these

that there is a relationship between non-contact injuries and the reaching difference in the PM direction between lower limbs, which may indicate that body balance is essential for performance stability, and is important with regard to non-contact injury but does not directly relate to contact injury.

In reference to the composite result of normalized directions in Table 10, when related to total injuries, the OR was 1.93 (95% CI: 0.77 – 4.96) while when the composite result was related to injury risk in non-contact injuries only, the OR was 2.24 (95% CI: 0.89 – 5.86), and both were statistically significant. The injury risk in those with a composite reach distance less than the average of the sample were approximately two times more likely to sustain an injury. If composite scores lower than the average can be considered as having poorer balance, these

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results affirm the findings of McGuire et al. who showed that poor balance had a relationship with high lower limb injury risk. Regarding the differences in the results compared with other studies, it is important to note that only the results of the YBT were examined as a predictor of injury, and there are many other variables such as previous injury, biomechanics, coordination or strength which have a considerable amount of influence and may serve to raise the risk of injury.

There are several limitations to the current study. First of all, an injury was defined if it incapacitated a player, rendering them unable to practice sport. There is an intrinsic factor that was not measured, the tolerance to pain by the player in minor injuries, which may have impacted their ability to practice. The second limitation is that several members of the staff registered injuries and there is a possibility that minor injuries went unnoticed. An additional limitation was that the side of the injury and dominant leg were not taken into account. An injury was only registered as an injury without attempting to relate to a specific reach score for a limb, instead only relating injury to difference in LE scores on the YBT. Plisky et al. used the same methods for recording and examination of injury in their previous research.

CONCLUSION
The results of the current study indicate that subjects with inequalities between right and left lower limbs equal to or greater than 4 cm have an almost four-time greater likelihood of missed days in a season due to a non-contact injury. Moreover, athletes with lower composite scores than the sample average have greater possibility of having more missed days. As a result, the YBT should be considered a useful tool in detecting injury susceptible subjects. The YBT could therefore be useful during pre-season testing and when attempting to determine when the player is able to return to sport after an injury. Future research should be conducted in order to expand the YBT database for additional sports by gender and competitive level. More research is needed with the aim of determining whether the YBT is an efficient test for injury prediction or can be used as a test that provides information regarding return to sport decisions.

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ABSTRACT

Background: Foot orthotics are commonly utilized in the treatment of patellofemoral pain (PFP) and have shown clinical benefit; however, their mechanism of action remains unclear. Patellofemoral joint stress (PFJS) is thought to be one of the main etiological factors associated with PFP.

Hypothesis/Purpose: The primary purpose of this study was to investigate the effects of a prefabricated foot orthotic with 5° of medial rearfoot wedging on the magnitude and the timing of the peak PFJS in a group of healthy female recreational athletes. The hypothesis was that there would be significant reduction in the peak patellofemoral joint stress and a delay in the timing of this peak in the orthotic condition.

Study Design: Cross-sectional

Methods: Kinematic and kinetic data were collected during running trials in a group of healthy, female recreational athletes. The knee angle and moment data in the sagittal plane were incorporated into a previously developed model to estimate patellofemoral joint stress. The dependent variables of interest were the peak patellofemoral joint stress as well as the percentage of stance at which this peak occurred, as both the magnitude and the timing of the joint loading are thought to be important in overuse running injuries.

Results: The peak patellofemoral joint stress significantly increased in the orthotic condition by 5.8% (p = .02, ES = 0.24), which does not support the initial hypothesis. However, the orthotic did significantly delay the timing of the peak during the stance phase by 3.8% (p = .002, ES = 0.47).

Conclusions: The finding that the peak patellofemoral joint stress increased in the orthotic condition did not support the initial hypothesis. However, the finding that the timing of this peak was delayed to later in the stance phase in the orthotic condition did support the initial hypothesis and may be related to the clinical improvements previously reported in subjects with PFP.

Level of Evidence: Level 4

Keywords: Biomechanics, knee, patellofemoral pain

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Conflict of Interest Disclosure: None

IRB approval: The procedures utilized in this study were approved by the Institutional Review Board at the University of Wisconsin-Milwaukee.

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INTRODUCTION

Patellofemoral pain (PFP) is the most common running-related injury treated within a sports medicine setting. In fact, it is twice as common as the next most frequently reported condition (iliotibial band syndrome). Unfortunately, in many cases it can persist and limit sports participation and impair function years after the initial diagnosis. It has also been proposed to be a risk factor in the development of patellofemoral osteoarthritis. As a result, developing effective treatment options and optimizing current management approaches is of great interest to clinicians involved in the treatment of PFP. This topic has particular relevance to the female recreational athlete as the incidence of PFP has been reported to be two times higher in females in comparison to males of similar activity levels, although the exact reason for this discrepancy remains unclear.

PFP is a complex condition, with contributing factors proximal, local, and distal to the knee joint. Increased patellofemoral joint stress (PFJS) is one of the most commonly accepted etiological factors in the development of PFP. An increase in PFJS can occur due to an increase in the patellofemoral joint reaction force, a reduction in the contact area between the patella and the femur, or some combination of these two factors.

Alterations in the frontal and transverse plane kinematics of the hip and knee are thought to impact the mechanics of the patellofemoral joint. This may lead to a reduction in the patellofemoral contact area which may ultimately increase PFJS. Cadaver studies have confirmed the fact that manipulating the position of the tibia and the femur in the frontal and transverse planes can have a significant effect on the patellofemoral joint contact area. It has also been reported that females with PFP demonstrate increased hip adduction and internal rotation and increased knee external rotation during running, in comparison to healthy subjects.

The behavior of the foot has been theoretically linked to PFJS as excessive pronation is thought to alter the mechanics of the knee and hip in the frontal and transverse planes. As a result of the possible link between the mechanics of the foot and the etiology of PFP, foot orthotics designed to limit excessive pronation via relatively conservative degrees of medial rearfoot wedging (4-6°), are often used in the management of PFP. Clinically, these types of orthotics have been shown to have a positive effect in regards to pain and function and may have similar effects to a multimodal physical therapy intervention (i.e. joint mobilization, patellar taping, quadriceps strengthening, and patient education) in the early management of PFP.

While it appears that some patients with PFP may benefit from the use of a foot orthotic, there is less evidence to support the theoretical basis behind their proposed mechanism of action. Several researchers have investigated the effects of a foot orthotic on the kinematics of the knee and hip during running and have reported small and inconsistent effects in the frontal and transverse planes. It has also been consistently reported that a foot orthotic significantly increases the magnitude of the knee abduction moment. This does not support their use in the management of PFP as increased loading in the frontal plane has been found to increase the risk of developing PFP in both retrospective and prospective analyses. There appears to be little consensus regarding the mechanism of action behind the positive clinical effects of a foot orthotic in patients with PFP, which makes providing clear recommendations regarding orthotic design and prescription challenging. Until a clearer understanding of the mechanism of action of a foot orthotic is established, it is unlikely that this intervention will reach its peak efficacy.
The primary purpose of this study was to investigate the effects of a prefabricated foot orthotic with 5° of medial rearfoot wedging on the magnitude and the timing of the peak PFJS in a group of healthy female recreational athletes. The peak PFJS was chosen because this has been shown to be greater in subjects with PFP during walking and running and is thought to be a primary contributor in the development of PFP. The effects of the orthotic on the timing of this peak was also analyzed as the importance of considering the temporal characteristics of joint loading has also been previously highlighted. It was hypothesized that the peak PFJS would be significantly less and would occur later in the stance phase with the application of the foot orthotic. These results may help to explain the mechanism of action of a foot orthotic in the management of PFP and may be of interest to those involved in orthotic prescription and design.

METHODS

This cross-sectional study included 18 female subjects between the ages of 18-45 years old, who ran with a rearfoot strike pattern, and were considered recreationally active based on the Tegner Activity Level scale score of greater than or equal to five out of ten. Exclusion criteria included: 1) any medical condition which would limit physical activity, 2) any previous history of lower extremity surgery, 3) any lower extremity injury in the previous six months which limited training, or 4) a history of orthotic use. The decision to include healthy runners is based on a previous study which reported that the effects of a medially-wedged foot orthotic on the mechanics of the knee are similar between subjects with and without PFP. Therefore, it seems that healthy subjects can serve as a model for the mechanical effects which can be expected in a group with PFP. Female subjects were included in this study because of the greater incidence of PFP in this group in comparison to males and the fact that previous studies which have used a similar modeling approach to estimate PFJS during running have also included females. This allowed for the comparison of the results of this analysis to studies which have included a similar subject group. The study received approval by the institutional review board at the University of Wisconsin – Milwaukee and all subjects provided informed consent to participate. All necessary measures were implemented in order to ensure that the rights of the subjects included within the study were protected.

During a single testing session, three-dimensional kinematic data were collected at 200 Hz with a ten-camera Eagle system (Motion Analysis, Inc., Santa Rosa, CA), and ground reaction forces (GRF) were synchronously recorded at 1000 Hz using an AMTI force plate (OR6-5; Advanced Mechanical Technology Inc., Watertown, MA). All trials were performed in standard laboratory footwear (NBA-801; New Balance, Brighton, MA) which had no heel counter in order to allow for direct observation of the rearfoot. The orthotic was prefabricated, three-quarter length, and had a 5° medial rearfoot wedge (L3060 Basic Foot Orthosis; Freedom Prosthetics and Orthotics, Houston, TX).

Retroreflective markers were placed on the left and right ASIS and PSIS in order to track the motion of the subject’s pelvis. Additional, four-marker clusters were placed on the right thigh, leg, and calcaneus in order to track the subject’s thigh, leg, and foot. A standing calibration was recorded with additional calibration markers placed on the most superior aspect of the left and right iliac crests, as well as on the greater trochanters, right lateral and medial femoral epicondyles, right lateral and medial malleoli, and the right first and fifth metatarsal heads. These markers were removed following a three-second static standing trial. The participants then performed running trials with (Orthotic) and without (Baseline) the orthotic, with the order of the conditions being randomized. Subjects were allowed practice trials in order to accommodate to the orthotic. They then completed 10 successful running trials down a 15-m runway at a speed of 4.0 m/s (±5%) in each of the two conditions with their running speed monitored with two photoelectric timing gates positioned along the runway.

The raw three-dimensional coordinate and force data were filtered using a 4th-order, zero lag, recursive Butterworth filter with a cutoff frequency of 12 Hz and 50 Hz, respectively. Right-handed Cartesian local coordinate systems for the pelvis, thigh, shank, and foot segments of the stance leg were defined to describe the position and orientation of each segment. Three-dimensional joint angles were calculated using a joint
coordinate system approach. The joint center of the knee was estimated by finding the midpoint between the medial and lateral femoral epicondyles while the ankle joint center was estimated by finding the midpoint between the medial and lateral malleoli. The hip joint centers were estimated to be located at 25% of the distance from each of the greater trochanter markers. Joint kinetics were calculated using a Newton-Euler approach with previously estimated body segment parameters. The calculation of the joint angles and moments during the stance phase was performed with Visual3D software (C-Motion, Inc., Rockville, MD) with initial contact and toe off determined when the vertical GRF exceeded and fell below 20 N, respectively. All data were time normalized to 101 data points to reflect the percentage of the stance phase.

Next, the patellofemoral joint stress (PFJS) was calculated using custom written Matlab code (MathWorks, Inc., Natick, MA). The model used to estimate the PFJS was initially developed by Brechter and Powers in order to compare PFJS between groups with PFP and a healthy control group during walking. However, it has also been used extensively to estimate PFJS during running. The inputs required to estimate PFJS are the internal net knee extension moment and the knee flexion angle. The first step is to calculate the effective moment-arm (r) of the quadriceps musculature using a non-linear equation (Equation 1) provided by Salem and Powers which was fit to the data from van Eijden et al.

\[
\begin{align*}
 r(m) &= 8.0e^{-5}x^3 - 0.013x^2 + 0.28x + 0.046 \\
 x &= \text{knee flexion angle}
\end{align*}
\]

Next, the estimated quadriceps force (QF) was calculated by dividing the net knee extension moment (\(M_{\text{ext}}\)) by the effective moment arm (r) (Equation 2).

\[
\begin{align*}
 QF(N) &= \frac{M_{\text{ext}}(Nm)}{r(m)}
\end{align*}
\]

A constant (k) described by Brechter and Powers (Equation 3) was used to calculate the patellofemoral joint reaction force (PFJRF) (Equation 4).

\[
\begin{align*}
 k &= \frac{4.62e^{-01} + 1.47e^{-03}x - 3.84e^{-05}x^2}{1-1.62e^{-02}x + 1.55e^{-04}x^2 - 6.98e^{-07}x^3} \\
 x &= \text{knee flexion angle}
\end{align*}
\]

The patellofemoral joint contact area (PFJCA) was calculated as a function of the knee flexion angle using data from Connolly et al and an equation (Equation 5) which has previously been used for running trials.

\[
\begin{align*}
 PFJCA(\text{mm}^2) &= 0.0781x^2 + 0.6763x + 151.75
\end{align*}
\]

Patellofemoral joint stress (PFJS) was calculated by dividing the patellofemoral joint reaction force by the patellofemoral joint contact area (Equation 6) with the PFJS in units of millipascals (MPa).

\[
\begin{align*}
 PFJS(\text{MPa}) &= \frac{PFJRF(N)}{PFJCA(\text{mm}^2)}
\end{align*}
\]

The primary dependent variables of interest were the ten-trial mean peak PFJS and the mean percentage of stance in which this peak occurred (time to peak). Secondary dependent variables were the peak knee flexion angle, peak knee extension moment, peak PFJRF, and the peak PFJCA. These secondary dependent variables were tested once it was determined that the orthotic had a statistically significant effect on the PFJS, allowing for the assessment of which factor(s) (PFJRF, PFJCA, or some combination of both) promoted the difference in PFJS. Paired t-tests were used to compare each of these variables between the Baseline and Orthotic trials. The alpha level for all tests was set at \(p < .05\). Effect sizes were reported as Cohen’s d, which is the difference between the means of the conditions (Baseline, Orthotic) divided by the average of the standard deviations from both these conditions. All statistical tests were performed using SPSS (v22, SPSS, Inc.).
RESULTS
The subjects' mean (SD) age, mass, and height were 23.7 (6.0) years, 61.65 (12.72) kg, and 1.65 (0.07) meters, respectively.

There was a significant increase in the peak PFJS and a significant delay in the timing of this peak (Figure 1 and Table 1). This peak increased by 5.8%, and the timing of this peak was delayed by 3.8% in the orthotic condition. The increase in stress was associated with an increase in the PFJRF, while the contact area was not different between conditions (Figure 2 and Table 1). The contact area was a function of the knee angle, which was not different between conditions, and the joint reaction force was a function of the increased knee extension moment (Figure 3 and Table 1).

DISCUSSION
The primary purpose of this study was to investigate the effects of a prefabricated foot orthotic on the magnitude and the timing of the peak PFJS in a group of healthy female recreational athletes. The hypothesis for this study was that the peak PFJS would be significantly reduced and would occur later in the stance phase with the application of the foot orthotic. The results did not support the hypothesis in regards to the magnitude of the PFJS as the subjects in this study demonstrated a statistically significant increase in the orthotic condition. However, the results did support the hypothesis that there would be a statistically significant shift in the timing of the peak PFJS to later in the stance phase in the orthotic condition. It is possible that the clinical benefit of a foot orthotic in patients with PFP is related to their effect on the timing of the PFJS.

The increase in the peak PFJS does not support the use of an orthotic in the treatment or prevention of PFP as subjects with PFP demonstrate greater peak PFJS in comparison to healthy control subjects during fast walking and running. Also, this elevated PFJS is thought to be a main etiological factor in the development of PFP and reducing this stress is often a primary objective of interventions designed to treat PFP. As a result, it does not appear that the beneficial effects of a foot orthotic are due to their influence on the peak PFJS. Other studies have incorporated a similar modeling approach with running in a sample of female recreational athletes and reported peak PFJS values which are very similar to the results reported in this study.

The effects of a prefabricated foot orthotic on the magnitude and the timing of the peak PFJS in a group of healthy female recreational athletes were investigated. The hypothesis was that the peak PFJS would be significantly reduced and would occur later in the stance phase with the application of the foot orthotic. The results did not support the hypothesis in regards to the magnitude of the PFJS as the subjects in this study demonstrated a statistically significant increase in the orthotic condition. However, the results did support the hypothesis that there would be a statistically significant shift in the timing of the peak PFJS to later in the stance phase in the orthotic condition. It is possible that the clinical benefit of a foot orthotic in patients with PFP is related to their effect on the timing of the PFJS.

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Kernozek et al\textsuperscript{34} recently reported a peak PFJS of 9.81 MPa in a group of healthy female recreational athletes running at a similar speed (3.52 – 3.89 m/s) to the subjects included in the current study when they implemented a similar PFJS modeling approach. The peak PFJS reported in this study is only slightly higher (within 6\%) than the peak PFJS reported by Kernozek et al.\textsuperscript{34} Although the model used in the current study cannot be validated, it has been used extensively in relation to running injuries and the results are comparable to previous reports.

The effects of the orthotic on the peak PFJRF and the PFJCA were analyzed in order to understand which variable had the greatest influence on the increase in PFJS. The orthotic did not significantly influence the PFJCA; in fact there was a trend towards increased contact area in the orthotic condition, which would effectively reduce the PFJS. However, it is important to note that this effect was not statistically significant. This was consistent with the finding that the orthotic had no effect on the peak knee flexion angle, as the PFJCA is a function of the knee flexion angle. Previous studies have also reported that a foot orthotic with a similar degree of wedging does not have a significant effect on the peak knee flexion angle.\textsuperscript{26,27} The subjects in this study did demonstrate a statistically significant increase in the PFJRF, which was consistent with the finding that the orthotic significantly increased the peak knee extension moment. Similar effects on the peak knee extension moment have also been previously reported with the application of an orthotic during running trials.\textsuperscript{26} Since the increase in the sagittal plane moment and PFJRF occurred without a significant effect on the knee flexion angle, it would seem the orthotic affected the orientation of the GRF. It is possible that the effect of the orthotic is less dependent on the 5° of medial wedging and more dependent on the heel lift it provides (approximately 1 cm).
This small degree of elevation of the heel may result in the change in the orientation of the GRF which results in the increase in the knee extension moment. While this idea is novel, it needs further analysis.

The orthotic did influence the timing of the peak PFJS as this peak occurred later in the stance phase in the orthotic condition. While the magnitude of this effect was not overly large (ES = 0.47), it was fairly consistent as 12 of the 18 subjects demonstrated a shift towards later in the stance phase, while only one subject demonstrated a shift towards earlier in stance with the application of the orthotic. To the authors' knowledge, this is the only study which has reported the effect of a foot orthotic on the timing of the peak PFJS. While it cannot be determined whether or not this effect on the timing of the PFJS is the reason why patients with PFP benefit from a foot orthotic, it is possible as the rate of loading is thought to be an important variable to consider in regards to running-related injuries such as PFP.\(^\text{22,23,28}\) However, since the delay in the timing of the peak PFJS occurred in combination with an increase in the peak PFJS it would seem that the effect of these two factors would off-set each other in regards to the rate of loading to the tissue, making this an unlikely mechanism of action.

It is important to note that the results of this study do not imply that the mechanics of the hip and the knee in the frontal and transverse planes do not play a prominent role in the etiology of PFP. They simply highlight the fact that since it is unclear how the effects of a foot orthotic in the frontal and transverse planes relate to clinical improvements in subjects with PFP\(^\text{22,23,28}\) it is possible that there may be a sagittal plane component to an orthotics’ mechanism of action. Three-dimensional kinematic and kinetic data are typically not available within a physical therapy clinic due the cost, space requirements, and technical expertise required to operate the motion capture equipment. However, there are two-dimensional measures that have been developed for clinical use during dynamic activities\(^\text{8-10}\) which attempt to analyze a subject's mechanics in frontal and transverse planes of motion. These measures may be used in clinical practice in order to make intervention choices. For example, Wouters et al\(^\text{45}\) used a two-dimensional measure related to the medial position of the knee (the frontal plane projection angle) to identify female subjects who may specifically benefit from a lower extremity neuromuscular training program. From a clinical perspective, the results of the current study suggest that even if mechanics in the frontal and transverse planes appear to be within normal limits when comparing between limbs or to some reference data, it does not mean that the patient would not benefit from an orthotic intervention, as their mechanism may be related to their effects in the sagittal plane. This is an important point to consider, as foot orthotics are often prescribed based on the theory that they correct some type of lower extremity biomechanical dysfunction, often in the frontal and transverse planes.\(^\text{12,13}\) In order to determine the mechanism which may promote clinical improvement in patients with PFP, future research may benefit from analyzing the effects of an orthotic in those who have had a positive response to an orthotic intervention. The results of the current study indicate that future studies of this nature should not focus exclusively on the frontal and transverse planes as an orthotic also has a significant effect on the magnitude and the timing of the joint loading in the sagittal plane of the knee.

Although the results of this study provide new insight into the mechanical effects of a foot orthotic, it is important to highlight some key limitations. One major limitation is the relatively simplistic modeling approach utilized. The main limitation of this model is that it only incorporates joint angles and moments from the sagittal plane. As previously mentioned, the mechanics in the frontal and transverse planes can also have a prominent effect on the contact area between the patella and the femur\(^\text{8-10}\) and subjects with PFP have been reported to demonstrate mechanics in both of these planes which differ from those without PFP.\(^\text{15,18}\) Another limitation associated with the modeling approach is the inverse dynamics based methodology used to estimate the quadriceps muscle forces. Kernozek et al\(^\text{14}\) recently reported that this approach may significantly underestimate the quadriceps muscle force estimates in comparison to more sophisticated modeling approaches which can account for co-contraction of the muscles which surround the knee joint. This is a valid point which means that the absolute values provided in this report may actually underestimate PFJS. However, since the same model has been employed previously and the model was consistent between the conditions, the patterns reflected in the
data should still be valid. Another limitation of this study is related to the subject group. Although healthy subjects served as a model, it cannot be determined whether or not similar effects would be observed in a group with PFP. This may be considered a preliminary analysis into another possible mechanism of action of an orthotic. It is also important to point out that the results of this study only reflect the immediate effects of the orthotic as all data were collected during a single session. There may be long-term adaptations that occur with the application of an orthotic. However, this has not been shown in a previous study which investigated a six-week orthotic intervention.

**CONCLUSION**

In conclusion, a prefabricated foot orthotic had a significant effect on the magnitude and the timing of the PFJS in a group of female recreational athletes. While the orthotic resulted in an increase in the peak PFJS, which does not support their use in runners with PFP, it also shifted the timing of this peak to later in the stance phase. This delay in the timing of this peak may be associated with the beneficial effects previously reported with the application of a foot orthotic in a group with PFP, although this suggestion requires further analysis. Clinicians involved in the management of PFP should understand that an orthotics' effects are not limited to the frontal and transverse planes and that the dynamics of the knee joint in the sagittal plane are also affected. As a result, patients may benefit from an orthotic intervention even if they do not demonstrate mechanics in the frontal and transverse planes which are thought to be associated with PFP.

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ABSTRACT

Background: An inadequate level of flexibility of the adductor muscles is one of the most critical risk factors for chronic groin pain and strains. However, measurement methods of adductor muscle flexibility are not well defined.

Purpose: To determine the inter-session reliability of the biarticular and monoarticular adductor muscle flexibility measures obtained from passive hip abduction with the knee flexed over the edge of the plinth test (PHA) and the passive hip abduction test at 90° of hip flexion (PHA90º).

Study design: Clinical Measurement Reliability study.

Methods: Fifty healthy recreational athletes participated in this study. All participants performed the PHA and PHA90º, on four different occasions, with a two-week interval between testing sessions. Reliability was examined through the change in the mean between consecutive pairs of testing sessions (ChM), standard error of measurement expressed in absolute values (SEM) and as a percentage of the mean score (%SEM), minimal detectable change at 95% confidence interval (MDC95), and intraclass correlation coefficients (ICC2,k).

Results: The findings showed negligible or trivial ChM values for the two adductor flexibility measures analyzed (<2º). Furthermore, the SEM and MDC95 were 2.1º and 5.9º and 2.2º and 6.2º for the measures obtained from the PHA and PHA90º, respectively, with %SEM scores lower than 5% and ICC scores higher than 0.90.

Conclusion: The findings from this study suggest that the adductor muscle flexibility measures analyzed have good to excellent inter-session reliability in recreational athletes. Thus, clinicians can be 95% confident that an observed change between two measures larger than 5.9º and 6.2º for the flexibility measures obtained from the PHA and PHA90º, respectively, would indicate a real change in muscle flexibility.

Level of evidence: 2

Keywords: Groin injury, muscle strain, physical therapy, range of motion, reproducibility
INTRODUCTION
Clinicians and sports medicine practitioners routinely assess and monitor the flexibility of the primary muscles involved in the hip joint abduction movement (biarticular muscles: gracilis; monoarticular muscles: adductor brevis, adductor longus, adductor magnus, pectineus and obturator externus) because it has been postulated that an inadequate level of flexibility is one of the most important risk factors for chronic groin pain and adductor muscle strains, particularly in athletes.1,2 Specifically, it has been suggested that having insufficient flexibility of the hip adductor muscles (mainly the biarticular muscles) might result in greater stress across the superior pubic ramus and pubic symphysis during powerful weight-bearing sporting actions, increasing the likelihood of sustaining a chronic groin injury.2 It has also been suggested that participants in sports involving high numbers of repetitive, high intensity bouncing, sprinting, or sudden turning and jumping movements (e.g., soccer, ice hockey, rugby) who have insufficient flexibility in the hip adductor muscles (both biarticular and monoarticular muscles) are more prone to suffer a muscle strain3 because the demands in energy absorption generated during the above-mention tasks may rapidly exceed the capacity of the adductor muscles.4

The passive hip abduction with knee flexed over the edge of the plinth test (PHA; Figure 1) and the passive hip abduction test at 90º of hip flexion (PHA90º; Figure 2) are the measurement methods described in the most prominent sports medicine textbooks5-7 to assess the flexibility of the biarticular and monoarticular hip adductor muscles, respectively. However, before these two measurement methods can be used to identify athletes at an increased risk of injury and establish progress from training and/or rehabilitation programs, the validity and reliability of their outcomes must be determined.8 Although the PHA and PHA90º are indirect measures of the biarticular and monoarticular adductor muscle flexibility, these two tests have been considered appropriate by the most important American medical organizations.9,10 Regarding the reliability of these tests, only three studies (to the authors’ knowledge) have addressed the examination of the inter-session reliability (defined as the day-to-day variability in measurements) of the measure obtained from the PHA, showing moderate to high scores.11-13 However, two of the three above-mentioned studies11,13 analyzed the inter-session reliability of the measure obtained from the PHA using video captures and computer-based 3D analysis. This measurement instrument (3D video analysis)
increases the time required to conduct the test and, hence, reduces the external validity of the measure because is not possible to assess a patient or athlete in mere seconds or minutes. In addition, the video analysis software might slightly deform the electronic images, prejudicing, and consequently, increasing the difficulty of identifying anatomic landmarks. Only one study used a standard goniometer to determine the inter-session reliability of the measure obtained from the PHA. The use of a goniometer as the key instrument of measure may allow practitioners to assess hip adductor muscle flexibility with just one trial and produce results directly in degrees, reducing both the time demands of the test and its difficulty. Surprisingly, no studies have examined the reliability of the PHA. The determination of the inter-session reliability of the measures obtained from the PHA and PHA, is important for clinicians, coaches, physicians and scientists, as if determined reliable, they can be used to estimate the magnitude of individual differences in the response to treatment and monitor the performance or health of their patients and athletes. Therefore, the purpose of this study was to estimate the inter-session reliability of the biarticular and monoarticular adductor muscle flexibility measures obtained from PHA and PHA, tests in recreational athletes.

METHODS
A convenience sample of 25 male (age: 22.2 ± 2.5 years; stature: 175.8 ± 5.6 cm; body mass: 74.1 ± 6.1 kg) and 25 female (age: 20.9 ± 0.9 years; stature: 166.5 ± 7.2 cm; body mass: 61.8 ± 7.7 kg) university students who were recreationally active (engaging in 1.5 h of moderate physical activity 3–4 days per week) completed this study. Although all participants reported engaging in recreational sports (i.e., football, basketball, running), none were involved in a systematic and specific strength and flexibility training program. Participants were instructed to maintain their regular training regimens throughout the experimental period and not to take part in any vigorous physical activity 48 h preceding each testing day.

The exclusion criteria were: (1) episodes of groin and/or adductor injury over the previous six months, (2) missing a testing session, and (3) the presence of self-reported delayed onset muscle soreness at any testing session. The participants were verbally informed about the study's procedures before testing, and they provided written informed consent. The study was approved by the University Office for Research Ethics (DPS.FAR.01.2014), and conformed to the Declaration of Helsinki.

The test-retest reliability of the biarticular and monoarticular hip adductor muscle measures obtained from the PHA and PHA, respectively, was analyzed using a repeated measures design. Thus, each participant underwent the testing procedure twice on four different occasions with a two-week interval.
between testing sessions. The rationale for using 50 participants and four testing sessions to determine the reliability in our study (instead of the two testing sessions that have been typically used in previous reliability studies) was based on the simulations run by Hopkins,8 who stated that, in order to achieve an accurate reliability assessment, a minimum of three testing sessions and 50 participants were needed.

Two physical therapists with greater than 10 years' experience (one conducted the tests and the other ensured the maintenance of proper testing position of the participants throughout the assessment maneuver) conducted each of the four testing sessions at the same time of the day under the same environmental conditions. The physical therapists were blinded to the purpose of the study and test results from previous testing sessions.

A pre-test warm-up routine was not performed in an attempt to reflect real sports and clinic conditions. Participants were instructed to perform two maximal trials of the PHA and PHA90º for each limb in a randomized order, and the mean score for each test was used in the subsequent analysis. The mean of the two trials of the PHA and PHA90º performed at each testing session was used for subsequent statistical analyses instead of the highest score because the magnitude of the error component decreased when the scores were averaged.16 Patients who did not tolerate the sensation of stretching or with low experience with it might set the endpoint of a trial of the test before achieving his/her peak hip abduction range of motion peak score due to a feeling of apprehension. To avoid the possible influence of this source of error on the stability of the measure, when a variation >5% was found in the range of motion values between the two trials, an extra trial was performed, and the two most closely related trials were used for the subsequent statistical analyses. Participants were examined wearing sports clothes and without shoes. The participants were allowed to rest for 30 s between trials, limbs, and tests.

An ISOMED inclinometer (Portland, Oregon) with a telescopic arm was used as the key measure for the PHE90º test, while a flexible adjustable long arm goniometer was employed for the PHA test. The inclinometer was consistently leveled to a vertical reference before each measurement. A low-back protection support (Lumbosant, Murcia, Spain) placed beneath the low back of each participant was used to standardize the lordotic curve (15°) during the both tests. Variations in pelvic position and stability may affect the final score of several measurements of hip movement range of motion.17 Thus, to accurately measure hip joint range of motion, the assessment procedure in this study provided reproducible stabilization of the pelvis using an assistant clinician during all tests.

The endpoint for each test was determined by one or more of these three criteria: (a) the examiner's perception of firm resistance, (b) the palpable onset of pelvic rotation, and (c) the participant feeling a strong but tolerable stretch, slightly before the occurrence of pain.

For a better understanding of the assessment methods (i.e., instrumental, clinician positioning, final point), additional descriptions of the PHA and PHA90º tests are displayed in Figures 1 and 2, respectively.

Prior to the statistical analysis, the distributions of raw data sets were checked using the Kolmogorov-Smirnov test, which demonstrated that all data had a normal distribution (p > 0.05). Men and women were not analyzed separately based on the fact that previous studies have reported that, in both sexes, the baseline joint ROM responds in the same way whether or not specific and systematic flexibility training is performed.18,19 Descriptive statistics were calculated for the hip adductor muscle flexibility measurements. Paired t-tests were used to test for differences between the scores of the dominant and non-dominant limbs.

The test-retest reliability of the hip adductor muscle flexibility measures was determined through the change in the mean (ChM), standard error of measurement (SEM), the minimal detectable change at a 95% confidence interval (MDC95) and intraclass correlations (ICC2k).20 The test-retest reliability for the hip adductor muscle flexibility measures was calculated separately for the consecutive pairs of trials (2-1, 3-2, 4-3) to be consistent with the interval time between testing sessions (two weeks).8

The ChM was estimated using a spreadsheet designed by Hopkins21 via the unequal-variances t-statistic computed for changes in scores between
paired sessions. To make inferences about the true value of the effect, the uncertainty in the effect was expressed as 90% confidence intervals and as likelihoods that the true value of the effect represented substantial change (negative or positive). The probability that the true value of the effect was positive or negative was inferred as follows: <0.5%, most unlikely; 1–5%, very unlikely; 6–25%, unlikely; 26–75%, possibly; 76–95%, likely; 96–99%, very likely; >99%, most likely. The SEM was calculated using the raw data via the following formula: \( \sqrt{\text{MSE}} \), where MSE is the error mean square from the repeated measures analysis of variance. The MDC95 was calculated as SEM \( x \sqrt{2} x 1.96 \). The ICC \( 2,k \) were calculated using the following formula:

\[
\frac{\text{MS}_S - \text{MS}_E}{\text{MS}_S + \frac{k(\text{MS}_T - \text{MS}_E)}{n}}
\]

where MS\(_S\) is the subject’s mean square, MS\(_E\) is the error mean square, MS\(_T\) is the trials mean square, n is the sample size and k is the number of trials. Magnitudes of correlations were assessed using the following scale of thresholds: <0.80 low, 0.80–0.90 moderate, and >0.90 high.

**RESULTS**

Descriptive statistics (mean ± standard deviation for testing session 1) for each variable are displayed in Table 1. The paired t-test analysis reported no significant differences between the dominant and non-dominant legs for both the biarticular (PHA: mean difference less than 0.7º; p > 0.05; degrees of freedom 49; t-statistic ranged from -1.01 to 0.01) and monoarticular (PHA\(_{90º}\): mean difference less than 1.3º; p > 0.05; degrees of freedom, 49; t-statistic ranged from -0.9 to 1.6) hip adductor muscle flexibility measures analyzed in each testing session; therefore, the average of the two legs was used for subsequent reliability analyses.

Reliability statistics (ChM, SEM, %SEM, MDC\(_{95}\) and ICC) for the PHA and PHA\(_{90º}\) values are also presented in Table 1 separately for the three consecutive pairs of testing sessions. The reliability scores obtained for each of the consecutive paired testing sessions (2-1, 3-2 and 4-3) were almost identical, and the mean of the two paired testing sessions for each flexibility measure might be used as a reliability criterion of reference.

The ChMs between consecutive pairs of testing sessions (2-1, 3-2, 4-3) were “most likely trivial” (p > 0.05; trivial effect with a probability of >95%, mean difference ranged from -0.6 to 1.8º) for both biarticular and monoarticular hip adductor muscle flexibility measures. The SEM and MDC\(_{95}\) for both biarticular and monoarticular flexibility measures ranged from 1.5º to 2.9º and from 4.2º to 8.1º, respectively, with %SEM scores lower than 5% and ICC scores higher than 0.91.

**DISCUSSION**

The purpose of this study was to determine the inter-session reliability of the biarticular and monoarticular adductor muscle flexibility measures obtained from PHA and PHA\(_{90º}\) tests in recreational athletes. In this regard, the results of the current study showed that the biarticular and monoarticular adductor muscle flexibility measures analyzed had excellent inter-session reliability scores.

The ChM between consecutive testing sessions was negligible or trivial for both the biarticular (ranged
from -1.2º to 0.4º) and the monoarticular (ranged from -0.4º to 2.2º) adductor muscle flexibility measures. Similar ChM scores were reported by Cejudo et al.12 and Fourcher et al.13 for the biarticular adductor flexibility measure obtained from the PHA test in adolescent athletes, futsal and handball players. Thus, the findings of the current study, in conjunction with findings from previously conducted research, may support the idea that both testing procedures are simple to administer and the instructions are easy to follow for the patients/athletes because no systematic error associated with learning effects or insufficient recovery time was found. In addition, this finding also indicates that, in the absence of a systematic flexibility training program, the hip adductor muscle flexibility tendency over time may be considered stable and linear in uninjured athletes.

Another aspect of reliability that was assessed was the precision of measurements, which was determined using the SEM.20 Admittedly, the clinical decision regarding the cut-off precision values of a measure is challenging, especially since there are no clear guidelines for reference value establishment, and there is the potential need to evaluate multiple factors (training status, sex, age) to reach a knowledgeable decision. However, it appears to be accepted that variability of a measure lower than 10% could be considered appropriate for clinical and research purposes.16,23 Based on this criterion, the biarticular and monoarticular adductor muscle flexibility measures analyzed in this study showed very good precision, since their percentage of variability (%SEM) ranged from 2.9 to 5.5% and from 2.9 to 4.2% for PHA and PHA90º, respectively.

In terms of practical applications, it has been suggested that the MDC95 can be used to indicate the limit for the smallest change that indicates a real improvement in a single person.20 Therefore, clinicians can be 95% confident that an observed change between two measures larger than 5.9º and 6.2º for the flexibility measures obtained from the PHA and PHA90º, respectively, would likely indicate a real change in hip adductor muscle flexibility.

The need of placing the tested hip and knee in approximately 90º of flexion during the hip abduction movement for the PHA90º test may have been a priori considered a source of error, as it makes the testing procedure more difficult than the PHA. However, the precision of measure scores in the current study were very good and similar to those found for the PHA. Perhaps the use of an inclinometer instead of a goniometer may have contributed to the good reliability scores reported for the PHA90º. In this sense, the elongation of the inclinometer’s telescopic arm makes it become a goniometer with only one arm, with the advantage of having a gravity level that provides an accurate measure. In addition, the inclinometer allows the physical therapist who conducts the tests to easily identify the same initial position (the parallel imaginary bisector line of the tested limb) during successive trials without estimating the joint movement center.24

Lower precision in measurement results has been reported by Fourcher et al.11 for the PHA. Specifically, Fourcher et al.13 reported precision of measurement expressed through a coefficient of variation (its magnitude is similar to %SEM) of approximately 7.2%.

One possible reason Fourcher et al.13 showed lower measurement precision scores for the PHA may be attributed to the different testing procedure and instrument of measurement used. In contrast with our study and also with previous ones,11,12 Fourcher et al.13 did not use a low-back protection support to fix the pelvis in an attempt to minimize any movement that may bias the final score. In addition, Fourcher et al.13 used digital motion analysis software to obtain the peak hip abduction angle measure instead of a goniometer. The video analysis software might have slightly deformed the electronic images, prejudicing the identification of anatomic landmark procedures and, consequently, reducing the precision of the measure. A comparison of the precision of the results for the PHA90º obtained in the current research with other studies is not possible; because to the authors’ knowledge, this study is the first that has addressed this issue.

Finally, the results of the current study reported high relative reliability scores for the PHA (ICC > 0.90). Similar ICC scores have been reported by Cejudo et al.12 and, slightly lower scores by Fourcher et al.13 (ICC scores of 0.93 and 0.85, respectively).
While the results of this study have provided information regarding the intra-tester reliability of these common musculoskeletal screening tests, limitations to the study must be acknowledged. The age distribution of participants was relatively narrow, and the generalizability to the broader population could not be ascertained. Similarly, whether the tests would be as reliable in a population of injured participants must be considered, although pre-season screening is generally performed in healthy, uninjured populations. Finally, the use of two clinicians to carry out the tests appears to limit the practical application of these measurement methods in the sports and clinic contexts, especially for the PHA90º. As these measurement methods are simple to administer, the role of the assistant clinician (who provides suitable stabilization of the pelvis during all the tests) could be carried out by any postgraduate student or athletic trainer who performed one or two 10-minute training sessions (statement based on the authors' experience).

CONCLUSION
The findings from this study suggest that the adductor muscle flexibility measures analyzed have good inter-session reliability in healthy recreational athletes. Thus, clinicians can be 95% confident that an observed change between two measures larger than 5.9º and 6.2º for the flexibility measures obtained from the PHA and PHA90º, respectively, would likely indicate a real change in muscle flexibility.

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ABSTRACT

Background: Kinesiology tape has been advocated as a means of improving muscle flexibility, a potential modifiable risk factor for injury, over time. The epidemiology and etiology of hamstring injuries in sport have been well documented.

Purpose: To compare the temporal pattern of efficacy of kinesiology tape and traditional stretching techniques on hamstring extensibility over a five day period.

Study Design: Controlled laboratory study.

Methods: Thirty recreationally active male participants (Mean ± SD: age 20.0 ± 1.55 years; height 179.3 ± 4.94 cm; mass 76.9 ± 7.57 kg) completed an active knee extension assessment (of the dominant leg) as a measure of hamstring extensibility. Three experimental interventions were applied in randomized order: Kinesiology tape (KT), static stretch (SS), proprioceptive neuromuscular facilitation (PNF). Measures were taken at baseline, +1min, +30mins, +3days and +5days days after each intervention. The temporal pattern of change in active knee extension was modelled as a range of regression polynomials for each intervention, quantified as the regression coefficient.

Results: Hamstring ROM with KT application at +3days was significantly greater than baseline (129.18 ± 15.46%, p = 0.01), SS (106.99 ± 9.84%, p = 0.03) and PNF (107.42 ± 136.13%, p = 0.03) interventions. The temporal pattern of changes in ROM for SS and PNF were best modelled by a negative linear function, although the strength of the correlation was weak in each case. In contrast, the KT data was optimised using a quadratic polynomial function ($r^2 = 0.60$), which yielded an optimum time of 2.76 days, eliciting a predicted ROM of 129.6% relative to baseline.

Conclusion: Each intervention displayed a unique temporal pattern of changes in active knee extension. SS was best suited to immediate improvements, and PNF to +30 minutes in hamstring extensibility, whereas kinesiology tape offered advantages over a longer duration, peaking at 2.76 days. These findings have implications for the choice of intervention, timing and duration to assist clinicians in both a sporting and clinical context.

Level of evidence: 2c

Keywords: Flexibility, hamstring, kinesiology tape, stretching

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INTRODUCTION
Recent investigations have examined the temporal efficacy of kinesiology taping (KT), finding that KT offered greater tissue response than PNF and static stretching over an acute time frame (30 minutes), peaking at 24.2 minutes.1 These findings may assist clinicians in determining the optimum application time for kinesiology tape to implement a positive tissue response prior to performance. Changes in tissue extensibility might be due to cutaneous receptor response, tissue deformation, and/or activation of the adhesive properties of the tape. Although manufacturers indicate KT can be worn for a three to five day period in order to have the optimum tissue response, there is currently minimal supporting empirical evidence.2,3 Several authors have considered the response to KT application (for up to 7 days) in pain, range of movement (ROM) and function in those with musculoskeletal pathologies with varying outcomes.4-9

The complex physiological mechanisms underpinning the benefits of KT continue to be debated with both mechanical and sensory theories discussed.10 Suggested mechanical benefits include enhanced muscle extensibility, neuromuscular reflex stimulation (autogenic or reciprocal inhibition), stress-strain relaxation, and tissue and plastic deformation.5,10-13 However sensory tolerance and pain gate control theory may also influence the extensibility of the tissue.10,14

Muscle extensibility is one of many physical components that potentially influences injury, resulting in variations in muscle flexibility intervention strategies.15-17 However direct comparison of interventions between studies is limited with methodological discrepancies in application, procedures, anatomical regions, recruitment criteria and sample size apparent.13,16-21 Restricted hamstring flexibility is discussed as a potential precursor to injury, as a “modifiable” intrinsic risk factor, particularly in maximal speed activities due to the eccentric overload of the tissue.16,22-28 Previously, static stretching (SS) was the common approach used to address flexibility in traditional musculoskeletal protocols15,16,27,28 however evidence that demonstrates potential detrimental effects on strength and power associated with SS has resulted in a greater shift towards dynamic stretching and proprioceptive neuromuscular facilitation (PNF). 28-33

The temporal efficacy of kinesiology taping on muscle extensibility over a three to five day period has been afforded little consideration, despite the common clinical suggestion for use over this time frame. Furthermore, the implications for sporting performance and musculoskeletal pathologies remain under researched. Immediate change in muscle extensibility post-intervention using KT is likely to be through neuromuscular reflex stimulation, stress-strain relaxation or stretch tolerance.17 Thus static stretching and PNF would have an acute effect on hamstring extensibility, with PNF expected to show greater initial gains during and post stretch due to the potential for the contraction to impart an influence on the neuromuscular reflex response.38 However, over a prolonged period it could be hypothesised that KT could show an effect as the properties of the tape are activated over time, influencing cutaneous mechanoreceptor stimulation. Since KT application for muscle stretch is from the origin to insertion while in the lengthened position it could be hypothesised that through prolonged stress-strain relaxation and viscoelastic deformation, applying a constant force over a period of time will assist tissue extensibility over a five-day period. To be able to reduce a potential risk factor for injury, the efficacy of any technique for hamstring extensibility must be studied over longer periods of time in order to determine whether the extensibility is maintained through training and performance. The aim of the present study was to compare the immediate, 30 minute, three- and five-day post-intervention efficacy of KT to traditional stretching techniques on hamstring extensibility. This may assist practitioners in their choice of intervention to maintain muscle extensibility over a key time period. It was hypothesized that the temporal pattern of changes in hamstring extensibility will be unique to each intervention, given their discrete mechanistic influence.

METHODS
An a priori power analysis was performed for sample size estimation based on data and effect size was derived from a previous study.1 Using an alpha = 0.05 and power = 0.80, the projected sample size was nine for each experimental group. Given the
potential for attrition over a five-day testing period, a total of 30 male participants completed the study. Inclusion criteria required each participant to be male, over 18 years, participating in recreational sport four times a week, and asymptomatic from injury and with no history of previous hamstring injury. Exclusion criteria included history of lumbar or neurological symptoms, history of musculoskeletal disorders or injuries within the prior 12 months, medical conditions that may alter muscle flexibility and skin allergies or conditions. All participants were further screened and excluded if their straight leg raise was < 70 degrees, potentially indicative of joint or tissue restriction or pathology. The 30 participants were randomly and evenly selected into three groups by intervention. Detailed information regarding the nature and purpose of the study was provided, and all participants provided written informed consent in accordance with the departmental and university ethical procedures and following the principles outlined in the Declaration of Helsinki. Ethical approval for the study was granted by the departmental research ethics committee.

Data Collection & Analysis
Consistent with a recent study, all participants completed a standardized five-minute warm up on the cycle ergometer. Five centimetre (cm) seat belts were placed across ASIS and the non-dominant leg at 20cm above tibial tuberosity in order to stabilize participants during the standardized Active Knee Extension (AKE) position. The hip was placed at 90° and fixed using a seat belt, proximal to the popliteal crease (Figure 1a). All belts were marked for re-measurement, and the dominant leg was measured for all participants. Dominant leg was identified as the preferred kicking leg.

The measurement of AKE was taken once the participant extended the knee to their point of hamstring stretch tolerance (no pain and initial resistance) and at that point the calcaneus was supported to allow a baseline measurement to be recorded, via a standard goniometer (Myrin, Patterson Medical, North Ryde, Australia) at the tibiofemoral joint. The participant was then placed prone on the plinth with a pillow under the ankles to assist in relaxation of hamstrings.

Subsequent to this baseline measure, AKE measurements were completed immediately, 30 minutes, three- and five- days post intervention. Participant were instructed to continue normal daily activity through the duration of the study and requested to avoid any specific activity related to hamstring flexibility. For intervention in the SS the group, the barrier of resistance was found in AKE and a 30 sec hamstring stretch applied by the researcher at the initial point of resistance, with a 10 sec rest period between each stretch. This was repeated three times. The PNF group was placed in AKE position and the initial stretch barrier held for 10 secs, prior to 10 secs PNF hamstring contract-relax resistance of 75% of their perceived maximum to assist muscle activation. There was a three second release from barrier prior to stretching to new resistance barrier for 10 secs, and this process was repeated three times. For KT application the distributors
guidelines (RockTape®) were followed, with the area prepared and a Y-cut piece of tape applied at 25% stretch from ischial tuberosity to head of fibula, and to the medial condyle of tibia to hamstring muscle insertion points with knee extension (Figure 1b). The KT application remained in place for the five-day duration of the study. For all participants and for each intervention, the same therapist performed all procedures.

Statistical Analysis
A two factor (intervention x time) repeated measures general linear model was used to determine differences between interventions at the progressive time points. Where appropriate, post-hoc pairwise comparisons using a Bonferroni correction factor were applied. Statistical significance was set at \( p \leq 0.05 \). All measures are reported relative to the pre-exercise score, which assigned 100% baseline for each participant. Data are presented as mean ± standard deviation.

In describing the temporal pattern of changes in ROM, a range of regression polynomials were applied to each intervention to determine the optimal model to describe temporal efficacy\(^1\). The strength of the regression was quantified using the \( r^2 \) value.

RESULTS
The subject demographics for each intervention group are summarised in Table 1.

Table 2 summarises the change in ROM for each intervention over the five day period. The only significant changes observed in ROM occurred with KT application (relative to pre-application baseline scores) at 30mins (\( p = 0.03 \)) and 3 days (\( p = 0.01 \)). At the three-day post intervention measurement the KT trial also significantly outperformed the SS (\( p = 0.03 \)) and PNF (\( p = 0.03 \)) interventions. The SS and PNF interventions produced the greatest improvement in performance immediately post-application but these changes were not statistically significantly different (\( p \sim 0.10 \)). The temporal pattern of changes in hamstring extensibility is shown in Figure 2.

Figure 3 shows the temporal distribution in ROM plotted against a linear timeline, with the regression coefficients summarised in Table 3 for both linear

<p>| Table 1. Subject Demographics (presented as group mean ± standard deviation). |</p>
<table>
<thead>
<tr>
<th>Group</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KT</td>
<td>19.5 ± 0.70</td>
<td>177.6 ± 4.62</td>
<td>74.2 ± 5.84</td>
</tr>
<tr>
<td>SS</td>
<td>20.8 ± 2.15</td>
<td>181.6 ± 4.03</td>
<td>80.0 ± 6.38</td>
</tr>
<tr>
<td>PNF</td>
<td>20.2 ± 1.32</td>
<td>178.7 ± 5.64</td>
<td>76.6 ± 9.55</td>
</tr>
</tbody>
</table>

<p>| Table 2. Temporal changes in hamstring extensibility for each intervention. |
|------------------------|-----------------|-----------------|-----------------|-----------------|
| Group | Hamstring extensibility (% of baseline) | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th>Post</th>
<th>+ 30 mins</th>
<th>+ 3 days</th>
<th>+ 5 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>KT</td>
<td>104.06 ± 10.68</td>
<td>120.59 ± 13.41</td>
<td>129.18 ± 15.46</td>
<td>115.40 ± 18.54</td>
</tr>
<tr>
<td>SS</td>
<td>114.04 ± 3.86</td>
<td>112.67 ± 12.72</td>
<td>106.99 ± 9.83</td>
<td>103.32 ± 12.49</td>
</tr>
<tr>
<td>PNF</td>
<td>115.72 ± 7.18</td>
<td>116.36 ± 12.23</td>
<td>107.42 ± 16.13</td>
<td>105.81 ± 12.09</td>
</tr>
</tbody>
</table>

Figure 2. The time history of changes in active knee extension with each intervention. *denotes significantly greater than baseline (\( p \leq 0.05 \)).

Figure 3. The optimum correlational function to model the time history of changes in active knee extension for each intervention.
and polynomial (quadratic) functions. The SS and PNF interventions were best modelled by a negative linear function, although the strength of the correlation was weak in each case. In contrast, the KT data produced a positive linear regression, but was optimized using a quadratic polynomial function ($R^2 = 0.60$). The quadratic equation to describe the temporal pattern of change in ROM with KT application yields an optimum time of 2.76 days, eliciting a 129.6% ROM.

**DISCUSSION**

The current study investigated the efficacy of KT on hamstring extensibility over a five-day period in comparison with traditional stretching methods. There are a few studies (with notable methodological variance) whose authors have reported significant differences between KT and other treatment interventions, although research into the temporal benefits are limited.

While KT demonstrated a positive linear correlation with time post intervention, both SS and PNF presented a negative linear correlation. The findings have implications for the practitioner, since the choice of intervention might depend on the potential for immediate or longer-term utilization for hamstring extensibility. Similar to previous literature, the findings indicate that if immediate and short term improvements are required PNF application is preferable. However if improvement in hamstring extensibility is required over a longer time period then KT offers potential benefits. KT application was best modelled as a quadratic function, predicting optimum yield at 2.76 days.

To date the majority of KT studies have considered the immediate effects after application, while few studies have reviewed over the effects over a prolonged application. Those that have considered immediate or short term effects are associated with a variety of musculoskeletal pathologies including shoulder impingement, whiplash, planter fasciitis, PFPS, achilles tendonosis and chronic lower back pain. Results from these studies should be viewed with caution as all have variance in both clinical and statistical outcomes. Importantly, those studies whose authors’ demonstrated improvements suffered from poor methodological quality.

Any immediate KT benefits reported have not been maintained through the respective follow up periods which does not allow for advocating KT in preference over other interventions, rather, only that KT can be used as an alternative or adjunct intervention.

The proposed physiological mechanisms for the beneficial effects of KT are numerous and complex, however the majority of authors suggesting three main mechanical theories; neuromuscular reflex stimulation (autogenic or reciprocal inhibition), stress-strain relaxation, and tissue and plastic deformation. The current findings suggest the proposed mechanical theories are more likely to influence the immediate change in muscle extensibility. The tissue response to KT application may influence plastic deformation and stress-strain relaxation over a longer duration. The greatest initial gains attributed to PNF may be due to the co-contraction theory through the neuromuscular reflex stimulation and subsequent latency to induce tissue relaxation and allow for a new end range to be established. Previous researchers determined that post PNF intervention, muscle extensibility returned to 50% of baseline within one second and 90% in 10 seconds.

The current findings suggest that KT was the preferential treatment over the five day duration, suggesting that the effects may be due to stress-strain relaxation and viscoelastic deformation. The consistently applied stretch force at the end of range induced by the KT may reduce the viscoelastic energy and promote stress relaxation, so the muscles can experience strain relaxation (creep) resulting in a decline in passive resistance over time. Furthermore within the current study the larger muscle mass associated with hamstrings may induce

<table>
<thead>
<tr>
<th>Linear and quadratic correlation coefficients to predict ROM from time post-intervention.</th>
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<tbody>
<tr>
<td><strong>Linear regression</strong></td>
</tr>
<tr>
<td><strong>KT</strong></td>
</tr>
<tr>
<td>$R^2 = 0.24$</td>
</tr>
<tr>
<td><strong>SS</strong></td>
</tr>
<tr>
<td>$R^2 = 0.15$</td>
</tr>
<tr>
<td><strong>PNF</strong></td>
</tr>
<tr>
<td>$R^2 = 0.11$</td>
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greater improvements as passive elastic stiffness has positive correlation to the strength of muscles in comparison to other studies that utilized other muscles.53,54

The findings indicate the optimum post-intervention time was 2.76 days, suggesting a combination of initial cutaneous mechanoreceptor stimulation, viscoelastic change and stress-strain relaxation may assist in deformation over an approximate three day time period. However the results showed no statistically significant differences in ROM at day five, and a return to resting state by day six based on the regression equation, supporting the suggestion that viscoelastic deformation is transient and it’s magnitude and duration are influenced by duration, intervention and load.10,55,56

It is important to note that additional mechanisms that influence muscle extensibility should be considered, including pain perception from the central and peripheral nervous systems,10 physiological changes in sarcomeres, the stimulation of the rearrangement of collagen,58 or psychological influences.47,57 Minimal literature exists to support alternative theories of plastic deformation and other mechanical mechanisms that consider the adaptive change within connective tissue.10,31 Thus, future research could examine the tissue response to KT application reapplied at day three, recovery days prior to reapplication or methods to achieve greater longer term effects.

Similar to the recent study reviewing the efficacy of KT over 30 minutes to assist hamstring flexibility, KT can be potentially be utilized for technique improvement and performance facilitation.59 However, it is important to consider that an increase in muscle extensibility may be detrimental to power and performance, and may actually increase injury risk.27,51 Thus, findings of the current study cannot be generalized to a wider population that differs in age, gender and health of the subjects.

Understanding the possible mechanisms of influence of KT needs further consideration through other methods such as electromyography, ultrasound, and thermal imaging. The benefits of KT are likely to be influenced by a wide range of extrinsic factors such as therapist experience, the environment, the nature of injury, population, sporting demands, and physiological, psychological and biomechanical characteristics. Efficacy may also be directly related to the execution of the therapist experience, tape application and tape techniques chosen.30 Future studies should consider longitudinal and post application follow up studies, additional muscle groups, functional task assessment, and alternative tape application methods.

CONCLUSION

Each intervention displayed a unique temporal pattern of changes in active knee extension. For an immediate improvement in hamstring muscle flexibility PNF and SS both out-performed KT, however for improvements over a longer duration kinesiology tape is advantageous. The optimum timing of kinesiology tape application was 2.76 days, eliciting a 30% improvement in hamstring ROM relative to baseline. These findings suggest that the choice of stretching intervention be informed by the clinical context.

REFERENCES


ABSTRACT

Background/Purpose: Low back pain (LBP) is a common source of disability in adults and highly prevalent in patients with painful hip pathology. Persistent LBP after hip arthroplasty is associated with lower self-reported function, however, the effect of pre-operative LBP in patients undergoing hip arthroscopy for FAI has not been evaluated. The purpose of this study was to determine whether improvements in self-reported hip function following arthroscopic surgery for femoroacetabular impingement (FAI) differed between those with and without reports of pre-operative low back pain.

Study Design: Cohort

Methods: Three hundred eighteen subjects undergoing primary hip arthroscopy for clinically and radiographically-confirmed FAI were recruited and consented. One hundred fifty-six of these subjects completed the International Hip Outcomes Tool (iHOT-33) and the Hip Outcome Score Activities of Daily Living Subscale (HOS-ADL) before, and six and 12 months after surgery. Subjects were grouped based on the self-reported presence or absence of LBP prior to arthroscopy. A repeated measures analysis of variance was used to determine the effects of time and low back pain on iHOT-33 and HOS-ADL scores.

Results: Seventy-five of 156 subjects (48.1%) reported LBP prior to surgery. A main effect of time was found for both outcome measures (p<0.001), demonstrating improvement in self-reported outcomes over the testing period. There was a main effect of group for the iHOT-33 (LBP: 52.0 [47.9,56.0]; no LBP 57.9 [53.9,61.8]; p = 0.043) but not for the HOS-ADL (LBP: 75.2 [72.2,78.2]; no LBP 78.8 [75.9,81.7]; p = 0.088) indicating that subjects with pre-operative LBP had poorer self-reported function per the iHOT-33 compared to those without LBP.

Conclusion: Self-reported hip function scores improved regardless of the presence of pre-operative LBP; however subjects with LBP reported poorer self-reported function per the iHOT-33 as compared to those without LBP up to 12 months post-operatively.

Level of Evidence: 3c

Key Words: Femoroacetabular impingement, low back pain, outcomes

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INTRODUCTION

Low back pain (LBP) is a common source of disability in adults and is present in up to fifty percent of patients with painful hip pathology. LBP is strongly associated with the presence of radiographic hip osteoarthritis (OA) in patients who report hip pain, and is a significant predictor of higher osteoarthritic pain and disability scores within five years of baseline measures. Hip arthroplasty appears to have a positive effect on LBP and self-reported function post-operatively, however, persistent LBP following total hip arthroplasty is associated with lower self-reported hip function and quality of life.

Femoroacetabular impingement (FAI) is an abnormality in femoral and/or acetabular morphology which can cause hip pain in young and active adults and may be a precursor to joint osteoarthritis. While groin pain is the main symptomatic complaint of these patients, many have pain in adjacent regions. One in four patients presenting with hip FAI report concomitant LBP and have often been diagnosed and treated for lower back pain prior to obtaining a diagnosis of FAI. The presence of LBP in those individuals with FAI may negatively affect post-operative disability and resolution of prior level of function, thereby potentially necessitating targeted low back rehabilitation pre-operatively and/or post-operatively in addition to the management of FAI. The purpose of this study was to determine whether improvements in self-reported hip function following arthroscopic surgery for FAI differs between those with and without complaints of pre-operative LBP. The primary hypothesis tested was that patients with pre-operative LBP would report lower self-reported function both before and up to one year after hip arthroscopy.

METHODS

Three hundred eighteen subjects undergoing hip arthroscopy for FAI were recruited from the Hip Preservation Division at The Ohio State University Wexner Medical Center. Those subjects requiring revision surgery or bilateral hip arthroscopies were excluded. Subjects had to be at least 15 years of age, and surgical eligibility was determined by the presence of all clinical and radiographic guidelines listed in Table 1. Subjects were excluded from the study if they did not provide informed consent or required other hip surgeries, including labral repair without osteoplasty/acetabuloplasty, periacetabular osteotomy, labral reconstruction, or gluteus medius repair. The study was approved by the Ohio State University Institutional Review Board, and all subjects provided written and informed consent.

Table 1. Eligibility criteria for FAI arthroscopy

<table>
<thead>
<tr>
<th>Surgical eligibility for FAI arthroscopy was determined by the criteria listed above</th>
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<tbody>
<tr>
<td>1. Clinical presentation consistent with FAI which adversely affected patient function</td>
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<tr>
<td>2. Alpha angle &gt;50 degrees for CAM impingement; presence of acetabular retroversion and/or coxa profunda for pincer impingement</td>
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<tr>
<td>3. Failed conservative therapy, minimum of ~4 weeks</td>
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<td>4. Hip pain relieved after injection with a local anesthetic</td>
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<tr>
<td>5. Minimal degenerative hip changes (Tonnis grade ≤ 1)</td>
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<tr>
<td><strong>Subjects meeting all listed criteria were considered eligible for FAI arthroscopy</strong></td>
</tr>
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</table>

Figure 1. Subject Recruitment Process

Subjects were recruited from the Hip Preservation Division at The Ohio State University Wexner Medical Center. Subjects who completed outcome measures at all time points were included in the data set and grouped by presence or absence of self-reported pre-operative LBP.
One hundred fifty-six of the enrolled 318 subjects (Age 31.2 years ± 15.4, BMI 24.8 ± 3.8, 39 Males/117 Females) had complete data sets at the time of the data analyses. The International Hip Outcomes Tool (iHOT-33) and the Hip Outcome Score Activities of Daily Living Subscale (HOS-ADL) were completed before surgery, and at 6 and 12 months after surgery to assess self-reported hip function. The iHOT-33 is a 33-item patient self-report outcome measure with questions regarding symptoms and functional limitations; sports and recreational activities; job-related concerns; and social, emotional, and lifestyle concerns. The iHOT-33 is scored from 0-100 with 100 representing the best quality of life and has a minimal clinically important difference (MCID) of 6.1 points and a test/re-test reliability interclass correlation coefficient (ICC) of 0.78. The HOS-ADL contains 19 items pertaining to basic daily activities and is scored as a percentage with 100% representing the highest level of physical function. The HOS-ADL has a MCID of 9 points and a test/retest reliability of 0.98. Subjects also completed a body chart where they were asked to indicate the area(s) in which they were currently experiencing pain. The subjects were then grouped based on the self-reported presence or absence of LBP prior to arthroscopy.

A multivariate repeated measures analysis of variance was used to determine the effects of time and LBP on iHOT-33 and HOS-ADL scores. (SPSS, Inc. Version 22, Chicago, IL) Where significant interactions were identified, post-hoc t-tests were used to determine where group or time differences existed (p ≤0.05). Main effects of time and group were also evaluated and data are reported as means and 95% confidence intervals.

RESULTS
Seventy-five of 156 subjects (48.1%) reported LBP prior to surgery. Groups did not differ based on age, BMI, or sex distribution (p≥0.24). No significant group x time interaction was identified for either the iHOT-33 (p ≥ 0.41) or the HOS-ADL (p≥0.37). A main effect of time was found for both outcome measures (p<0.001) demonstrating improvement in self-reported outcomes over the testing period regardless of group. There was a main effect of group indicating those with pre-operative LBP had poorer self-reported outcomes than those without LBP; there was no statistically significant main effect of LBP on the HOS-ADL scores.

To further explore whether changes were clinically important, the percentage of subjects achieving the minimal clinically important difference (MCID) was calculated. The MCIDs for the HOS-ADL and iHOT-33 are 9 and 6.1, respectively. At six months post-operatively, 39.7% of those subjects with LBP achieved MCID per the HOS-ADL compared to 34.6% of those without LBP. At the six month

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Table 2. Mean scores (with 95% confidence intervals) for the International Hip Outcome Tool (iHOT-33) and the Hip Outcome Score Activities of Daily Living (HOS-ADL)

<table>
<thead>
<tr>
<th></th>
<th>iHOT-33</th>
<th>p-value</th>
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<tbody>
<tr>
<td>LBP</td>
<td>52.0 (47.9, 56.0)</td>
<td>0.043*</td>
</tr>
<tr>
<td>No LBP</td>
<td>57.9 (53.9, 61.8)</td>
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<tr>
<td>HOS-ADL</td>
<td></td>
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<tr>
<td>LBP</td>
<td>75.2 (72.2, 78.2)</td>
<td>0.088</td>
</tr>
<tr>
<td>No LBP</td>
<td>78.8 (75.9, 81.7)</td>
<td></td>
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</table>

LBP= low back pain
* p <0.05
post-operative assessment, 44.2% of subjects with LBP achieved MCID per the iHOT-33 compared to 41.0% of those without LBP. At one year post-operatively, 39.1% of subjects with LBP achieved MCID compared to pre-operative scores per the HOS-ADL and 41% of those without LBP achieved MCID. Per the iHOT-33, 42.9% of subjects with LBP achieved MCID at one year compared to 43.6% without LBP.
DISCUSSION

The purpose of this study was to determine whether the self-reported recovery of function following arthroscopic surgery for FAI differs between those with and without complaints of pre-operative LBP. All subjects who underwent hip arthroscopy for symptomatic FAI demonstrated significant improvement in self-reported hip function, regardless of the presence of pre-operative LBP. However, those subjects with pre-operative LBP reported poorer self-reported function per the iHOT-33 as compared to those without LBP both before and up to 12 months after hip arthroscopy.

The function of the lumbar spine, pelvis, and hips are inextricably linked by their common anatomy, which likely explains the high prevalence of LBP in patients seeking medical care for hip pain.\(^2\)\(^,\)\(^4\) Data from the current study indicate that while both patients with and without LBP have improved self-reported function after arthroscopic surgery for FAI, scores for those with pre-operative LBP are lower at 12 months post-op. Corrective surgery appears to have a positive effect on pre-operative low back pain in patients undergoing THA. Ben-Galim et al.\(^5\) reported improved spinal pain and function at three months post-THA and improved hip function correlated with improved spinal function up to two years after surgery. Parvizi et al.\(^2\) reported that of the 170 patients with LBP prior to THA, 66% had complete resolution of LBP symptoms post-operatively. Additionally, Parvizi found that patients who did not have LBP after THA had higher mean Harris hip and SF-36 scores than patients who experienced LBP after THA.\(^2\) While many patients with hip pain experience relief of LBP following THA, the best course of treatment to address residual LBP and disability following hip arthroscopy is still unknown.

In this study, self-reported hip function was significantly lower in the subjects with LBP, but this relationship was only noted for the iHOT-33 scores. While both the iHOT-33 and HOS-ADL are commonly used to assess self-reported function in those with hip disorders, the HOS-ADL exclusively measures the patient’s perception of physical function during common daily tasks. In contrast, the iHOT-33 also contains questions regarding the patient’s emotional, social, and lifestyle dimensions and was developed for physically active individuals.\(^12\) The HOS-ADL has also been shown to have a ceiling effect, especially at 12 months post arthroscopy.\(^14\) The iHOT-33 seemed to better capture self-reported disability in the present subject population than the HOS-ADL, and may be considered for mid- and long-term outcome studies in patients with FAI.

Although subjects with LBP reported poorer hip function than those without LBP, it is interesting to note that the majority of subjects in either group did not achieve MCID improvements at six or 12 months post-operatively. These data indicate that while patients may report improved hip function after surgery, they do not achieve full, unrestricted function within the first year. Future research to determine which patients would most benefit from surgical intervention as well as identifying additional complicating factors may help to improve outcomes in this population.

This study has several limitations. The study included only the self-reported presence or absence of LBP prior to surgery. Severity and location of LBP and/or back-related disability were not recorded either pre- or post-operatively in this study. The use of a low back-specific outcome tool such as the Modified Oswestry Low Back Questionnaire\(^15\) or a Visual Analog Scale at each time point may have provided additional insight into the relationship between hip function and LBP. Additionally, only subjects with full data sets up to one year post-arthroscopy were included in the analysis. Excluding subjects who dropped out of the study, or did not yet reach the six month or one-year post-operative time point does limit the generalizability of the current findings. Those with poorer outcomes may have been more likely to continue follow-up, thus explaining the high percentage of those with LBP in this study (48.1%) compared to 23% in a previous study by Clohisy et al.\(^3\) This potentially skewed population may also explain why neither group achieved MCID on outcomes measures at either post-operative time point. Another limitation of this study is the lack of clinical objective measures to correlate with self-reported outcome measures. For example, hip range of motion measured pre- and post-operatively may determine whether range of motion had an effect on self-reported function in this population. A hallmark of FAI is the loss of internal rotation range of motion.
of the symptomatic hip, and deficits and/or asymmetry in hip internal rotation have shown to be associated with LBP. Those subjects with LBP may have had more severe loss of internal rotation mobility thus negatively affecting their function compared to those without LBP. Inclusion of objective physical measurements as well as patient-reported outcome tools would improve understanding of how hip and LBP and disability are related in this population.

**CONCLUSION**

Subjects who underwent hip arthroscopy for symptomatic FAI demonstrated improved self-reported hip function, regardless of the presence of pre-operative LBP. Those subjects with pre-operative LBP reported poorer self-reported function on the IHOT-33 as compared to those without LBP up to 12 months post-operatively. Future analyses may support the use of the iHOT-33 in identifying how low back pain influences functional outcomes following hip arthroscopy.

**REFERENCES**


ABSTRACT

Background: Recent evidence suggests performing a warm-up prior to golf can improve performance and reduce injuries. While some characteristics of effective golf warm-ups have been determined, no studies have explored the immediate effects of a rotational-specific warm-up with elements of motor control on the biomechanical aspects of the full X-Factor and X-Factor Stretch during the golf swing.

Methods: Thirty-six amateur golfers (mean ± SD age: 64 ± 8 years old; 75% male) were randomized into a Dynamic Rotation-Specific Warm-up group (n=20), or a Sham Warm-up group (n=16). X-Factor and X-Factor Stretch were measured at baseline and immediately following the warm-up. Mixed model ANCOVAs were used to determine if a Group*Time interaction existed for each variable with group as the between-subjects variable and time as the within-subjects variable.

Results: The mixed model ANCOVAs did not reveal a statistically significant group*time interaction for X-Factor or X-Factor Stretch. There was not a significant main effect for time for X-Factor but there was for X-Factor Stretch. These results indicate that neither group had a significant effect on improving X-Factor, however performing either warm-up increased X-Factor Stretch without significant difference between the two.

Conclusions: The results of this study suggest that performing the Dynamic Rotation-Specific Warm-up did not increase X-Factor or X-Factor Stretch when controlled for age compared to the Sham Warm-up. Further study is needed to determine the long-term effects of the Dynamic Rotation-Specific Warm-up on performance factors of the golf swing while examining across all ages.

Level of Evidence: 2b

Key Words: Golf, motor control, warm-up, X-factor, X-factor stretch

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2 Carolina Ballet, Raleigh, NC, USA
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INTRODUCTION
There are 55 million golfers world-wide with 26 million in the United States alone.\(^1\) Approximately 25% of these are seniors playing at a time in their life span when they are more prone to physical injury than golfers under the age of 65.\(^2\) Golf-related injury rates among amateurs have ranged from 16-36.5%.\(^3,4\) Unlike professional touring golfers, amateur golfers typically do not perform a warm-up prior to play.\(^5,9\) In fact, most amateur golfers lack knowledge regarding what constitutes an effective warm-up. Additionally, they may have negative attitudes regarding performing a warm-up or what it can accomplish.\(^6,7\) If performed at all, most amateur warm-up activity tends to occur at the driving range with a series of air swings or progressive distance hitting, and is not long enough to be effective.\(^5,6,9\)

Adequate warm-up is essential for the amateur golfer, as researchers have indicated that it reduces the risk of injury and improves performance.\(^7,10,11\) Several characteristics of effective golf warm-ups have been identified including that a pre-golf warm-up need only be a minimum of 7–10 minutes long.\(^8,12\) In addition, dynamic warm-ups improve performance whereas passive stretching as a warm-up decreases performance.\(^5,12\) Sport-specific flexibility training is considered an important part of the warm-up process for sports that utilize extremes of movement.\(^9,13\) This is the case with the full golf swing, which is primarily a rotational motion. Resistance warm-ups in functional patterns focusing on rotational and stabilizing muscle groups along with motor patterning have been found to improve maximum driving distance, consistency of ball strike, and smash factor.\(^14\) Tilley and Mcfarlane\(^14\) define smash factor as “the ratio between the ball speed and the club speed, it tells us about the centeredness of impact and the solidity of the shot, an important factor relating to performance.” Due to the equipment needed, it would be difficult to perform a resisted warm-up range-side prior to play, an important factor for compliance in the amateur. Other warm-ups that have been studied include general dynamic movements at the spine, hips and shoulders, but none have focused predominantly on the components of spinal rotation and motor control that could prove helpful in improving golf-specific performance outcomes.\(^9,10,12,15\)

In examining the components of the golf swing, the term X-Factor (XF) is used to describe the amount of transverse plane rotation differential between the shoulders and the pelvis at the top of the backswing and is a measurement of angular motion.\(^16\) Another term, X-Factor Stretch (XFS), is used to describe the additional rotation that occurs following the backswing in the early downswing.\(^17\) Before the transition from the backswing to the downswing, it has been observed that the pelvis has already reversed its direction to rotate towards the target at a time when the upper torso is still moving away from the target. This increases the amount of rotation and separation between the upper and lower segments.\(^17\)

Both the XF and XFS are positively correlated with increased distance in long drives.\(^17-21\) There are differing opinions as to which is more important, XF or XFS.\(^17,21\) When comparing professional golfers to amateur golfers, the amateurs typically over rotate from the pelvis and below while under rotating through the spine, thus not utilizing optimum XF.\(^17\) Given that golf is a popular sport for retirees, age related spinal stiffness makes it understandable that most aging amateur golfers obtain greater rotation through the legs and pelvis rather than through sufficient use of the XF and XFS. Additionally, amateur golfers may lack sufficient muscular stabilization through the legs and pelvis to control large amounts of spinal rotation needed for the full golf swing. In an effort to combine the two problems of inadequate warm-up and an inefficient use of the XF and XFS in amateur golfers, research efforts related to motor control strategies and golf performance may prove to be helpful.\(^22\) Using motor control strategies to improve vertical forces in the lead foot has been shown to allow more effective rotational sequencing through the kinetic chain.\(^23,24\) Professional golfers have been found to place greater vertical force into the lead foot (ground reaction forces [GRF]) during the downswing compared to amateur golfers.\(^23,25\) Better use of these forces allows more time for effective rotational sequencing between the pelvis and spine, thus improving the power imparted into the ball. Use of motor control strategies addressing this issue have not typically been incorporated into golf warm-ups. It is theorized that dynamic motor control drills designed to optimize the acceptance of
vertical forces into the lead foot would assist amateur golfers in attaining the spinal rotation necessary for adequate XF and XFS.

The purpose of this study was to examine the effect of a Dynamic Rotation-Specific Warm-Up (DRSWU) on XF and XFS in the amateur golfer. To date no studies have been conducted on the effects of a rotational specific warm-up on specific biomechanical parameters of the full golf swing. The results of this study could be helpful in guiding and encouraging amateur golfers to perform a DRSWU. It was hypothesized that performing a DRSWU would increase XF and XFS compared to performing a sham warm-up (SWU).

METHODS

Subjects
Forty adult (18 years old and over), amateur golfers volunteered from area golf clubs. To qualify, golfers needed to report golfing at a minimum frequency of once weekly for most of the golf season. There were no restrictions on gender or handicap for inclusion. Subjects were excluded if they were, or ever had been a golf teaching or touring professional. They were also excluded if they reported pain while swinging their club or following play.

Instrumentation
The K-Vest system (K-Vest, K Motion Interactive, Inc., Milford, NH), utilizing TPI software (Titleist Performance Institute, Oceanside, CA), was used to measure angular velocity by time. This system captures 3-dimensional biomechanical data during the golf swing using inertial sensors. These sensors (InterSense Inc., Billerica, MA) measure motion in three degrees of freedom, in 360 degrees at all axes, at a range of 0-1200 degrees per second with an accuracy of one degree in yaw, and 0.5 degrees in pitch and roll at 25 degrees Celsius. The sensors are attached at the upper back between the shoulder blades using a specially designed vest, at the sacrum using a belt, and at the gloved hand (Figure 1).

The K-Vest TPI software captures the kinematic sequence and produces a graph (Figure 2). An additional graph tracks the degrees of thoracic spine rotation.
rotation relative to the pelvis (Figure 3). These graphs of time (seconds) by angular velocity (degrees per second) yield the angle in degrees of rotation between the pelvis and thorax (XF). Using these graphs, calculation of the XFS is accomplished using Cheetum’s27 protocol: degrees of rotation of the pelvis at transition (XF) are subtracted from degrees of rotation at the equal velocity line to determine the XFS, a value representing degrees of angular motion. Values for XFS are considerably smaller than those for XF as they represent the additional rotational stretch achieved following transition.

Procedures
This study was a prospective, randomized within and between (mixed model) subjects design. Subjects were assigned to a group using an online randomization program for two groups of 20 subjects. Subjects were required to wear golf shoes, a golf glove and use their own, non-hybrid 5 or 6 iron. As a condition of testing, subjects had to avoid all golf play or exercise of any type the day of the testing session. The subject donned the K-Vest system and was allowed to perform five practice swings hitting a golf ball into a net prior to obtaining three baseline swing captures, also hitting a golf ball into a net. The 5 practice swings allowed subjects to get used to swinging the club while wearing the K-Vest system as well as to mimic typical golf behavior of performing practice swings prior to hitting. A movement screen consisting of lumbar, cervical, and shoulder active range of motion was performed to further rule out pain or injury and was performed following the first round of swing captures so as not to function as a warm-up, therefore meeting the criteria of no prior exercise. Subjects were eliminated if they reported pain during the screen. Four subjects from the SWU group were excluded: three due to pain during the screening and one for inability to follow the warm-up instructions. Subjects who successfully passed this screen progressed to the warm-up of their respective group: 20 subjects in the DRSWU group and 16 subjects in the SWU group.

The DRSWU is a previously unpublished golf warm-up developed for the purpose of this study in order to investigate the ability to improve full-golf swing performance (Table 1). It was developed in consultation with several golf fitness professionals and several golf instructors, all with background in golf biomechanics. It is a 10 minute warm-up performed at the driving range, which requires no equipment other than the golf club. Compliance factors as well as elements of known, effective warm-ups have been built into this warm-up.5,7,8,9,10,11,12,13 The DRSWU used in this study not only has components of dynamic rotational mobility, but also includes drills to address GRFs, and motor control training of XFS considered important in the ability to incorporate the gains in spinal mobility into the actual swing to increase XF and XFS.14 The intent of the parameters of the DRSWU is to facilitate incorporation of a warm-up into the golfer’s pre-play routine while effectively improving performance. Although not currently examined in this study, the DRSWU may have the potential to have a positive effect in reducing injury however, the prospect of improving driving distance may provide greater motivation for the amateur golfer.6 The SWU was intended to mimic the duration of the DRSWU yet differed due to the emphasis on sagittal plane movements. (Table 2) Subjects were shown an instructional video of their respective group warm-up in order to facilitate their understanding of the movements required during the warm-up. Subjects were then led through their warm-up and allowed five additional practice swings. The final three swing captures were then obtained. Since K-Vest with TPI software allows for real-time analysis, any swings with artifact were eliminated and golfers repeated
swings until there were three adequate swing captures for each pre-test, post-test scenario.

**Statistical Methods**

Descriptive analyses of continuous variables included mean, standard deviation, and 95% confidence intervals. Correlations were examined for relationships between age or handicap and pre-test XF or XFS. Independent t-tests were used to determine differences between groups for variables of age and handicap. The average of the values obtained from each of the three swings for XFS and XF were used to examine differences following the two warm-up protocols. SPSS software (version 22.0; IBM Corp., Armonk, NY) was used to administer a 2x2 mixed-model ANCOVA with age as a covariate and with an alpha level of $p \leq 0.05$. As spinal range of motion tends to reduce with age, it was used as a covariate to eliminate differences due to age in order to focus on the response to warm-up. Warm-up group (DRSWU versus SWU) served

<table>
<thead>
<tr>
<th>Table 1. <em>Dynamic Rotation-specific Warm-up</em></th>
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<tbody>
<tr>
<td>Crossed-arm torso twist without neck rotation</td>
</tr>
</tbody>
</table>
  - Stand in golf address position  
  - Cross hands to opposite shoulders  
  - Rotate torso to the right and then left  
  - Keep chin over breast bone  
  - 20 reps each direction  |
| Thoracic combined motions |  
  - Stand in golf address position with club behind shoulders  
  - Side bend your torso to the Right, then twist to the Left, then repeat the other way  
  - 20 each direction  |
| Neck only rotations/ lateral flexion with hands wrung |  
  - Stand in golf address position  
  - Place hands in “wrung” position: twist forearms into pronation bringing palms together, fingers interlocked  
  - Without moving your shoulders rotate your head side to side for 10 reps  
  - Without moving your shoulders laterally flex your head side to side for 10 reps  |
| Ground Reaction Force (GRF) of the legs in opposition to rotation |  
  - Stand in golf address with club in hands  
  - As you move slowly into your backswing (BS), press the trail foot forward and the lead foot backwards  
  - From the BS proceed into your downswing with focus on shifting most of your weight on the lead leg  
  - Perform 20 reps  |
| Crossed-arm torso twist with neck rotation |  
  - Stand in golf address position  
  - Cross hands to opposite shoulders  
  - Rotate torso to the right and then left  
  - Keep eye on ball so as not to allow any head movement. Shoulders rotating will allow for neck rotation 20 reps each direction  |
| Backswing with focus on internal rotation of the loaded hip |  
  - Stand in address position with club in hands  
  - Place your lead leg behind you and rest your toe on the ground  
  - With near total weight on the trail leg perform a backswing  
  - Perform 10 reps  |
| Pelvic lead into downswing |  
  - Start in golf address with club in hands  
  - Twist to backswing with the club held vertical  
  - Initiate downswing at the pelvis, moving and rotating it first and allowing the shoulders to follow  
  - Perform 20 reps  |
| Swing for remaining time |  
  - Hitting a golf ball into a net for remaining time until 10 minutes total of warm-up |
as the between-subjects variable and time (pre-test, post-test) served as the within-subjects variable.

RESULTS

Subjects
Table 3 contains demographics of the subject population including age, gender and golf handicap. Ages of subjects volunteering for this study were predominantly in the older adult (60-80 years old) age group (78%, n= 28) with the remainder in the middle-aged adult (40-60 years old) group (22%, n= 8). There were no subjects representing the young adult age group (20-40 years old). Subjects reported the following pre-golf warm-up habits; 88.9% typically (n=32) performed some kind of warm-up and 11.1% (n=4) reported no warm-up. Of those performing a warm-up, 96.9% hit range balls (n=31), 62.5% (n=20) performed static stretching, 12.5% (n=4) performed dynamic stretching, and 3.1% (n=1) walked for 20 minutes. Subjects were allowed to report more than one warm-up strategy. A lower handicap was related to a higher pre-test XF, but not XFS. Age was negatively correlated to XF, but there was not a relationship between age and pre-test XFS. Independent t-tests revealed no significant difference between groups for handicap, however there were significant age differences between groups.

Table 2. Sham Warm-up

<table>
<thead>
<tr>
<th>Warm-up</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heel walk</td>
<td>For 40 steps</td>
</tr>
<tr>
<td>Toe walk</td>
<td>For 40 steps</td>
</tr>
<tr>
<td>March in place</td>
<td>For 40 steps, Lifting knees high</td>
</tr>
<tr>
<td>Lunge walk</td>
<td>Step forward with one leg and perform a lunge bending both knees, Repeat with the other leg, 20 steps</td>
</tr>
<tr>
<td>Walking with alternating Quad stretch</td>
<td>Take a step onto one leg and reach behind you with the opposite hand and grab the free ankle and stretch up and back toward the buttock, Release without holding, Take next step performing a quad stretch on the other leg, 20 steps</td>
</tr>
<tr>
<td>Leg swings from hip in flexion/extension</td>
<td>Stand on one leg using your club for balance, Swing your free leg forward and back, Perform 20 on each leg</td>
</tr>
<tr>
<td>Shoulder flexion/extension</td>
<td>Leading with your thumb, raise the arm up overhead and as far back as you can, Reverse and lower the arm bringing it behind you as far as you can, Perform 20 reps on each arm</td>
</tr>
<tr>
<td>Neck flexion/extension</td>
<td>Lower your chin down towards the chest, Gently lift the chin up towards the ceiling, Perform 20 reps of the full motion</td>
</tr>
<tr>
<td>Swing for remaining time</td>
<td>Hitting a golf ball into a net for remaining time until 10 minutes total of warm-up</td>
</tr>
</tbody>
</table>
For this reason age was used as a covariate in the mixed model analysis.

Main results
Pre-test and post-test means for XF and XFS are listed in Table 4. The mixed model ANCOVAs did not reveal a statistically significant group*time interaction for XF (F = 2.479; p = .125) or XFS (F = 0.631; p = .433). There was not a significant main effect for time for XF (F = 0.398; p = .533), but there was for XFS (F = 13.293; p = .001). These results indicate that neither warm-up had a significant effect on improving XF, however performing either warm-up equally increased XFS with no significant difference between the two when adjusted for age.

Discussion
The purpose of this study was to examine the immediate effects of two warm-ups on XF and XFS. The authors hypothesized that the DRSWU would significantly increase both biomechanical measures. Findings from this study did not support this hypothesis. As there has been no prior research into interventions to produce an immediate change in XF and XFS, it is difficult to draw comparisons to other studies. A study by Tilley and Macfarlane\textsuperscript{14} compared a resisted rotational golf warm-up to a linear resisted warm-up. They found the rotational warm-up improved some measures (immediate maximal driving distance, smash factor and consistent ball strike), but not others (drive accuracy or maximum club head speed). The Tilley and Mcfarlane\textsuperscript{14} study did not measure XF or XFS and was performed on a much younger, elite, all-male golfer population making it difficult to draw comparisons with the current study.

The long-term effects of the DRSWU on golf performance are unknown and warrant further investigation based on prior findings that indicate that long-term effects of consistent use of a warm up exceed those seen as initial or immediate effects.\textsuperscript{10} Myers et al.\textsuperscript{22} posed the question of how to increase torso-pelvis separation in the golfer and stressed the importance of investigating strategies to do so. Based on the results of this study, the utility of long-term exercise or motor control programs need to be examined. Further, there may be limited possibilities to improve spinal mobility and thus improve XF or XFS with the older golfer since 33 out of 36 golfers studied were over the age of 50.

Reports by subjects concerning their warm-up habits were similar to prior studies indicating that amateur golfers often do not perform the kinds of

### Table 3. Participant Characteristics

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (Years)</th>
<th>Handicap</th>
<th>Gender</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRSWU (n=20)</td>
<td>61.0 ± 9.1</td>
<td>13.9 ± 6.4</td>
<td>M = 15 (75%) F = 5 (25%)</td>
</tr>
<tr>
<td>SWU (n=16)</td>
<td>66.9 ± 3.8</td>
<td>16.9 ± 6.9</td>
<td>M = 12(75%) F = 4 (25%)</td>
</tr>
<tr>
<td>TOTAL (n=36)</td>
<td>63.6 ± 7.7</td>
<td>15.2 ± 6.7</td>
<td>M = 27 (75%) F = 9 (25%)</td>
</tr>
</tbody>
</table>

Abbreviations: DRSWU: Dynamic rotation-specific warm-up. SWU: Sham warm-up. M: male. F: female. *All values except gender are mean ± standard deviation. Gender values are subject numbers.

### Table 4. Outcomes for X-Factor and X-Factor Stretch

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>Post-test*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>XF</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRSWU</td>
<td>31.0±9.2</td>
<td>34.1±9.0</td>
</tr>
<tr>
<td>SWU</td>
<td>30.3±10.4</td>
<td>32.1±9.3</td>
</tr>
<tr>
<td><strong>XFS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRSWU</td>
<td>1.4±1.4</td>
<td>2.2±2.5</td>
</tr>
<tr>
<td>SWU</td>
<td>2.8±2.7</td>
<td>2.8±2.4</td>
</tr>
</tbody>
</table>

Values represent pre-test/post-test means of X-Factor and X-Factor Stretch in degrees of rotation ± 1 standard deviation. DRSWU= Dynamic Rotation-Specific Warm-up, SWU= Sham Warm Up. *Post-test values were measured following a pain and injury screen and the warm-up intervention approximately 30 minutes later.
warm-ups that have been demonstrated effective in improving performance. A prior study by Fradkin et al.\textsuperscript{5} found less than 3\% of amateur golfers performed an adequate warm-up consisting of all three of the following components: some form of low-level aerobic activity, dynamic stretching, and sport-specific movements. Based on these criteria, the percent of subjects in this study reporting an adequate warm-up is 0\%. Furthermore, the four subjects who reported a dynamic stretching warm-up also reported performing static stretching, and the theoretical possibility exists that these two types of warm-up could negate each other. While the current study results indicate that 11\% of subjects performed no warm-up, this is an encouraging finding compared to the 47\% who did not warm-up in the study by Fradkin et al.\textsuperscript{5}.

This study had several limitations. While both groups made significant increases in XFS from pre-test to post-test, it is difficult to determine if that difference was a result of performing one of the warm-ups or due to the passage of time because there was not a control group. However, it would not be expected that spinal range of motion would increase in a matter of 30 minutes between the two swing captures without any type of activity. The randomization of subjects prior to the pain screen resulted in an imbalance of group numbers with the DRSWU group having 20 subjects and the SWU group having 16. This would not have been an issue if the randomization occurred following the pain screen. By chance the four subjects who were eliminated by the screening procedures were all from the same group. High variance seen in the XFS results in the DRSWU was due to a grouping of four very high XFS outliers scoring 6-8 degrees of rotation, while there were a significant number of subjects scoring less than 1 degree of XFS.

There were also age imbalances between the groups with the SWU group having a statistically older mean age than the DRSWU, thus using age as a covariate was necessary to control for differences. Some studies have reported golfers over the age of 65 represent 25\% of all golfers, suggesting subject age ranges for this study did not accurately reflect those of the entire amateur golfer population.\textsuperscript{2} This may have biased the main effect for time for both groups in a less responsive direction. Equal representation of subjects from young, middle, and older adult age groups would have allowed for examination of age-related spinal stiffness as a potential factor diminishing the effect of the warm-up. Future studies should examine the effects of warm-ups on a more representative age distribution of amateur golfers.\textsuperscript{2}

There was also an imbalance of gender with 75\% of subjects being male across both groups. Horan et al.\textsuperscript{28} recommend not generalizing any data concerning the torso and pelvis from males to females due to differences that exist in swing kinematics. Thus, there may be limited generalizability of the current results to female golfers.

Another limitation of the study could have been the selection of the exercises for the DRSWU and the SWU. It could be argued that the inclusion of some practice swings into the SWU could have been responsible for some improvement in spinal rotation, thus making less of a difference between groups. Regularly performing practice swings at each drive is typical practice by amateurs. Since prior research has illuminated that practice hitting alone is not an adequate warm-up, the goal of the study was to examine what could be done as a warm-up in addition to the typical practice swings.\textsuperscript{5,6,8} Thus, adding a limited amount of practice swings more accurately mimics a baseline of what amateurs are already doing.

Lastly, this study was conducted in an indoor simulation environment with no direct measures of club head speed, driving distance, or driving accuracy, thus there may be limited generalizability to an outdoor golf environment or more direct performance measures. Future studies should continue to examine sport-specific types of warm-ups for improving golf performance by investigating outcomes over a longer time period, using varied direct and indirect measures of golf performance, and studying a varied age range.

**CONCLUSIONS**

In conclusion, performing a warm-up prior to golf improves performance and reduces injury. Warm-ups linked to improving performance will likely provide greater motivation for the amateur golfer. Higher XF and XFS are linked to improved golf performance. The results of this study suggest that performing the DRSWU did not increase XF or XFS compared to the SWU. Neither warm-up had a significant effect on
improving XF, however performing either warm-up equally increased XFS with no significant difference between the two. Further study is needed to determine the long-term effects of the DRSWU on performance factors of the golf swing while examining across all ages.

REFERENCES

Original Research
Cross-Cultural Adaptation and Validation of the Korean Version of the Cumberland Ankle Instability Tool

Jupil Ko, MS, ATC1
Adam B. Rosen, ATC, PhD2
Cathleen N. Brown, ATC, PhD1

Abstract

Background: The Cumberland Ankle Instability Tool (CAIT) is a valid and reliable patient reported outcome used to assess the presence and severity of chronic ankle instability (CAI). The CAIT has been cross-culturally adapted into other languages for use in non-English speaking populations. However, there are no valid questionnaires to assess CAI in individuals who speak Korean.

Purpose: The purpose of this study was to translate, cross-culturally adapt, and validate the CAIT, for use in a Korean-speaking population with CAI.

Study Design: Cross-cultural validity study.

Methods: The CAIT was cross-culturally adapted into Korean according to accepted guidelines and renamed the Cumberland Ankle Instability Tool-Korean (CAIT-K). Twenty-three participants (12 males, 11 females) who were bilingual in English and Korean were recruited and completed the original and adapted versions to assess agreement between versions. An additional 168 national level Korean athletes (106 male, 62 females; age = 20.3 ± 1.1 yrs), who participated in ≥ 90 minutes of physical activity per week, completed the final version of the CAIT-K twice within 14 days. Their completed questionnaires were assessed for internal consistency, test-retest reliability, criterion validity, and construct validity.

Results: For bilingual participants, intra-class correlation coefficients (ICC2,1) between the CAIT and the CAIT-K for test-retest reliability were 0.95 (SEM = 1.83) and 0.96 (SEM = 1.50) in right and left limbs, respectively. The Cronbach’s alpha coefficients were 0.92 and 0.90 for the CAIT-K in right and left limbs, respectively. For native Korean speakers, the CAIT-K had high internal consistency (Cronbach’s α = 0.89) and intra-class correlation coefficient (ICC2,1 = 0.94, SEM = 1.72), correlation with the physical component score (rho = 0.70, p = 0.001) of the Short-Form Health Survey (SF-36), and the Kaiser-Meyer-Olkin score was 0.87.

Conclusions: The original CAIT was translated, cross-culturally adapted, and validated from English to Korean. The CAIT-K appears to be valid and reliable and could be useful in assessing the Korean speaking population with CAI.

Keywords: Ankle sprain, Patient Reported Outcome, Ankle Injury

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All authors indicate that no benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

Part of data from this study had been presented as an abstract format in the South East chapter of American College of Sport Medicine Annual Meeting on February 13-15, 2014.

No authors have any conflicts of interest.

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INTRODUCTION
The ankle is the most common site for a joint sprain to occur, during all types of sporting activities. According to the National Collegiate Athletic Association (NCAA), approximately 15% of athletes have experienced an ankle sprain. Significant health issues caused by traumatic lateral ankle sprains include the initial symptoms of acute pain, swelling, and loss of function and a high rate of recurrence. An estimated 75% of athletes report recurrent ankle sprains with over half of them experiencing significant disability and persistent symptoms which may result in Chronic Ankle Instability (CAI). CAI is characterized by the sensation of “giving way” and a history of recurrent sprain is the main predisposing factor for CAI.

Currently, patient reported outcome (PRO) questionnaires are primarily used to determine the presence of CAI in clinical assessment and research. Gribble et al advocated the use of validated ankle instability PRO questionnaires with specific cutoff scores in order to determine the presence of self-reported ankle instability. Professional organizations, such as the National Athletic Trainers' Association (NATA), recommend the use of PRO questionnaires as one criterion used to identify patients' perception of ankle instability for return-to-play decision making in the management of ankle sprains.

The Cumberland Ankle Instability Tool (CAIT), developed by Hiller et al, is recommended and widely used to identify patients with CAI. The CAIT was originally developed in English. Previous authors have translated and cross-culturally adapted the CAIT into Spanish and Brazilian-Portuguese to provide non-English speaking populations valid and reliable versions of the tool. The previous cross-cultural adaptation and validation studies showed high internal consistency (Cronbach’s α Spanish = 0.77; Brazilian-Portuguese = 0.86) and reliability (intra correlation coefficient Spanish = 0.98; Brazilian-Portuguese = 0.95), correlation with the original English CAIT (rho = 0.24, p = 0.012) in the Spanish version, and good responsiveness, respectively. Currently, there is no valid self-report CAI questionnaire for use in Korean speaking populations.

Therefore, the purpose of this study was to translate, cross-culturally adapt, and validate the Cumberland Ankle Instability Tool-Korean (CAIT-K) for use in a Korean-speaking population with CAI. All validation was performed according to the guidelines for cross-cultural adaptation of self-report measures.

METHODS
The Cumberland Ankle Instability Tool (CAIT)
The original CAIT consisted of nine items to describe the severity of CAI. The items evaluate the degree of difficulty experienced when performing various activities of daily living and other physical activities. The maximum score is 30 with a lower score indicating decreased ankle function. Severity of ankle disability is thought to increase as the score decreases. The original study established a cutoff score of ≤ 27 to identify those with CAI. Subsequent studies have used a range of cutoff scores from 24 to 27, including a recently advocated optimal cutoff score of ≤ 25. The original CAIT showed excellent test-retest reliability with the intra-class correlation coefficient (ICC2,1 = 0.96) and construct validity and internal consistency (α = 0.83).

Cross-cultural adaptation procedure
The English version of the CAIT was adapted for Korean use (CAIT-K) according to the six-step guidelines established for cross-cultural adaptation of self-report measures. In addition the accuracy of wording and item understanding were tested among participants bilingual in English and Korean. Korean is a relatively homogeneous language, with little regional dialect differences, thus one standard was applied.

Step I: One independent native-speaking Korean (the co-investigator and certified athletic trainer) translated the CAIT into Korean.

Step II: Four expert panelists who were native-speaking Koreans (two certified athletic trainers, one sport biomechanist, and one physical educator) reviewed and proofread the first translation of the CAIT-K. These expert panelists and investigators synthesized the first translated version to a preliminary CAIT-K version through a consensus review.
Step III: Two additional people who were native English speakers and raised in Korean speaking homes translated the preliminary CAIT-K back into English. These people were blinded to the concept and had no medical background.

Step IV: Investigators and expert panelists reviewed all the translations, semantic, idiomatic, and experiential equivalencies to resolve all discrepancies. The pre-final version of CAIT-K was amalgamated through this process.

Step V: The original English and CAIT-K were administered to 23 people who were bilingual in English and Korean who were enrolled in, or working at, a large university as a student or faculty member. The accuracy of wording and item understanding for both the CAIT and CAIT-K were tested. Feedback from participants was incorporated into a final version of CAIT-K after review and agreement among the developers (investigators and expert panel).

Step VI: The reliability and validity (construct and criterion) of the final CAIT-K were tested using 168 participants with and without chronic ankle instability at large university in Seoul, Republic of Korea.

Participants
Informed consent was obtained from each participant as approved by the Institutional Review Board (IRB) at the University of Georgia in English for US participants and in Korean for Korean participants.

Bilingual speakers
Twenty three participants between 18 and 65 years of age who were bilingual in English and Korean were recruited. They must have had completed or been enrolled at the time of the study in a bachelor's or higher degree program at an accredited college or university in the United States. Participants were not required to have a history of ankle sprain or residual complaints of instability. For reliability testing, two test sessions were scheduled to complete the pre-final version of CAIT-K in English and in Korean in randomized order. The second test was completed one week after the first administration.

Native Korean speakers
National level athletes in multiple Olympic sports (168 total; 21 boxing, 19 fencing, 13 wrestling, 19 judo, 23 filed hockey, 18 taekwondo, 26 weightlifting, 10 track, 19 swimming) were recruited for reliability testing of the final CAIT-K (Figure 1). Participants had to be 18 to 35 years of age, speak Korean as a first language, and participating in ≥ 90 minutes of physical activity per week. The average number of hours participating in sports was 36.95 ± 13.45 hours per week. Exclusion criteria included: 1) bilateral ankle instability 2) lower leg disorders caused by surgery and/or fracture 3) any type of other lower extremity injury in the previous three months and 4) diagnosis of vestibular disorder, Charcot-Marie-Tooth disorder, Ehlers-Danlos, or other hereditary nerve, balance or connective tissue disorder. Participants were initially classified as “healthy” or “unstable ankle” based upon the results of an ankle injury history questionnaire that incorporated the inclusion/exclusion criteria. The unstable ankle group had a CAIT ≤25 indicating decreased function, self-reported ≥1 moderate-severe sprain that resulted in partial or non-weight bearing for ≥3 days, reported “giving way” of the ankle with activity, and had ≥2 sprains or episodes of giving way in the last year. All participants were screened based on the inclusion and exclusion criteria before they completed the final CAIT-K and classified into groups of healthy (n=107) and unstable ankles (n=61). Two test sessions were scheduled with each participant. Participants completed the CAIT-K in the first session and within one week after the first meeting participants completed the CAIT-K again. When the CAIT-K was administered, 100 participants were in-season, 45 participants were in pre-season phase, and 23 participants were in post-season (off-season) phase. For testing construct validity, all participants in the study (n = 168) completed the CAIT-K as well as the 36-item short-form health survey (SF-36) questionnaire in Korean (Figure 1). One researcher completed all data collection procedures independently. The researcher was blinded to the scores of the CAIT-K, CAIT, and SF-36 until the end of data collection. All procedures from recruitment to survey completion were done between July 2013 and January 2014.

Statistical analysis
Bilingual speakers
For bilingual participants, Intra-class Correlation Coefficients (ICC2,1) between the English and Korean
version of the CAIT were utilized to determine the test-retest reliability.\(^1^7\) Cronbach’s alpha coefficients were used to determine internal consistency within the Korean version of CAIT in right and left limbs, respectively.\(^1^8\)

**Native Korean speakers**

For the 168 native Korean speaking participants, descriptive statistics were calculated for mean, standard deviation, and 95% confidence interval (CI). Internal consistency of the CAIT-K was assessed with Cronbach’s alpha (\(\alpha\)) coefficient.\(^1^6\) ICC\(^{2,1}\) was calculated to determine test-retest reliability between the first and second CAIT-K measures.\(^1^7\) Criterion validity was also calculated by Spearman’s rank correlation coefficient between CAIT-K and SF-36.\(^7\) Construct validity was examined using exploratory factorial analysis with the score of the first CAIT-K.\(^7\) Demographics and CAIT-K scores were compared between groups using independent samples t-tests (\(\alpha<0.05\)). All statistical analyses were performed through the Statistical Package for the Social Sciences\(^{22}\) (SPSS, Inc., Chicago, IL, USA).

**RESULTS**

Of the original 289 enrolled participants, 5.2% (15/289) of participants met exclusion criteria and were not included in the study. Approximately nineteen percent (52/274) of participants were lost to follow up or injured during the timeframe of data collection after the first administration of the CAIT-K. Additionally, 24.3% (54/222) of participants were lost due to incomplete questionnaires. Therefore, a total of 168 (58.1%) of 289 participants successfully completed all procedures during the study period. A total of 61 (36.3%) participants were classified into the unstable ankle group and 107 (63.7%) were classified into the control group (Figure 1). There were no significant differences in age and gender between control and CAI participants (Table 1) (\(p<0.05\)). The

![Figure 1. Flow chart of eligible native Korean participants. Abbreviations: CAI, Chronic Ankle Instability; CAIT-K, Cumberland Ankle Instability Tool-Korean version; SF-36, Short-Form 36](image-url)
CAI individuals presented with significantly lower mean CAIT-K scores compared to the control group during both test sessions \((p=0.001)\) (Table 1). No participants experienced adverse events during the time of the study.

Reliability
For bilingual participants, intra-class correlation coefficients \((ICC_{2,1})\) between the English and Korean version of the CAIT for test-retest reliability were 0.95 (standard error of measurement \([SEM]=1.83\)) and 0.96 \((SEM=1.50)\) in right and left limbs, respectively. The Cronbach's alpha coefficients were 0.92 and 0.90 for the CAIT-K in right and left limbs, respectively.

For native Korean speaking participants, the intra-class correlation coefficient \((ICC_{2,1})\) between the first CAIT-K and second CAIT-K was 0.94 \((SEM=1.72)\). The Cronbach's alpha for the score of the CAIT-K in the first measurement was 0.89. There was no statistically significant improvement in Cronbach's alpha when a particular item was deleted from the scale during the data analysis. However, a slight increase in the alpha value was observed when the item numbers 4, 5, and 9 were omitted (Table 2).

Criterion and Construct Validity
The CAIT-K showed statistically significant Spearman correlation \((\rho=0.70, p=0.001)\) with the physical health component of the SF-36, but no statistical relationship \((\rho=-0.06, p=0.48)\) with the mental health component.

The Kaiser-Meyer-Olkin score that measures sampling adequacy was 0.87. The Bartlett test of specificity \((p<0.0001)\) indicated the suitability of the sample for exploratory factor analysis. The total variance explained was 74.4% (Table 2). Two factors were identified as a component matrix. Six items were classified into the first factor while item 4, 5 and 9 were classed as the second factor (Table 3).

DISCUSSION
The CAIT-K was successfully cross-culturally adapted and the results indicate that the adaptation is reliable, valid, and appropriate for use in a Korean speaking population.

The translation adequately corresponded with the original version. No modifications were included, the meaning of the items were preserved, and there was a slight increase in the alpha value when item 4, 5, and 9 were omitted (Table 2).

### Table 1. Subject Demographics Mean and Standard Deviation of the Korean Version of the Cumberland Ankle Instability Tool

<table>
<thead>
<tr>
<th>Number of Subjects (%)</th>
<th>Age</th>
<th>Gender</th>
<th>Involved Limb</th>
<th>CAIT-K 1st Administration*</th>
<th>CAIT-K 2nd Administration*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean SD</td>
<td>Male</td>
<td>Female</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>CAI</td>
<td></td>
<td>20.3±1.0</td>
<td>39(63.9%)</td>
<td>22(36.1%)</td>
<td>27(44.3%)</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>20.3±1.1</td>
<td>67(62.6%)</td>
<td>40(37.4%)</td>
<td>26(24.3%)</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>20.3±1.1</td>
<td>106(63.1%)</td>
<td>62(36.9%)</td>
<td>53(31.5%)</td>
</tr>
</tbody>
</table>

CAI= Chronic Ankle Instability  
CAIT-K= The Korean version of Cumberland Ankle Instability Tool  
*\(P\leq0.05\)

### Table 2. Internal consistency and total variance explained through exploratory factor analysis of the CAIT-K

<table>
<thead>
<tr>
<th>Component</th>
<th>Corrected item: Total correlation if item was deleted</th>
<th>Cronbach's (\alpha)</th>
<th>Total</th>
<th>Initial Eigenvalues</th>
<th>Cumulative %</th>
<th>Extraction Sums of Squared Loadings</th>
<th>Total</th>
<th>% of Variance</th>
<th>Cumulative %</th>
<th>% of Variance</th>
<th>Cumulative %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 1</td>
<td>0.80</td>
<td>0.86</td>
<td>4.93</td>
<td>54.76</td>
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<td>0.85</td>
<td>0.86</td>
<td>1.77</td>
<td>19.69</td>
<td>74.45</td>
<td>1.77</td>
<td>19.69</td>
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<td>Item 3</td>
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<td>0.71</td>
<td>7.92</td>
<td>82.37</td>
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<td>Item 4</td>
<td>0.39</td>
<td>0.90</td>
<td>0.53</td>
<td>5.91</td>
<td>88.28</td>
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<td>Item 5</td>
<td>0.40</td>
<td>0.90</td>
<td>0.41</td>
<td>4.54</td>
<td>92.82</td>
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<tr>
<td>Item 6</td>
<td>0.70</td>
<td>0.87</td>
<td>0.25</td>
<td>2.81</td>
<td>95.64</td>
<td></td>
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<tr>
<td>Item 7</td>
<td>0.85</td>
<td>0.86</td>
<td>0.15</td>
<td>1.66</td>
<td>97.29</td>
<td></td>
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<td>Item 8</td>
<td>0.60</td>
<td>0.88</td>
<td>0.14</td>
<td>1.54</td>
<td>98.83</td>
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<td>Item 9</td>
<td>0.32</td>
<td>0.90</td>
<td>0.11</td>
<td>1.17</td>
<td>100.00</td>
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</tbody>
</table>

CAIT-K = The Korean version of Cumberland Ankle Instability  
SD = Standard Deviation
complete consensus about the final version among the expert panelists. In the native Korean speakers, the Cronbach’s $\alpha$ of the questionnaire ranged from 0.85 to 0.90, which demonstrated a high internal consistency. In the original version of the CAIT, the Cronbach’s $\alpha$ was 0.83, similar to that obtained in the present study. Additionally, the current Cronbach’s is similar to, or higher than, other cross-cultural adaptation studies of the CAIT in Spanish (Cronbach’s $\alpha=0.77$) and Brazilian-Portuguese (Cronbach’s $\alpha=0.86$ for right ankles and 0.88 for left ankles). For native Korean speakers, Intra-class Correlation Coefficients (ICC$_{2,1}$) of the CAIT-K were 0.94 with $p=0.001$ (standard error of measurement [SEM] = 1.72), very similar to the value (0.95) of the original version of CAIT. The CAIT-K retained a similar test-retest reliability and internal consistency compared to previous adaptations of the CAIT in Spanish (ICC$_{2,1}=0.98$) and in Brazilian-Portuguese (ICC$_{2,1}=0.95$). The test-retest reliability and internal consistency of the CAIT-K are considered excellent and presented a high level of reliability. These data confirm that the CAIT-K may be considered as a reliable and stable instrument for the assessment of CAI in Korean speakers.

Criterion validity was assessed using the Spearman correlation coefficient between the SF-36 summary components and the CAIT-K. The results in the present study showed a stronger correlation with the physical components than with mental component of the SF-36. This supports other studies, which suggests that physical function and pain dimensions of SF-36 seem to be most pertinent in patients with musculoskeletal conditions. In the Spanish version of the CAIT, the Spearman correlation coefficient with the physical component summary was a lower ($\rho=0.24$, $p=0.012$) than the present study ($\rho=0.70$, $p=0.001$), albeit statistically significant. However, the Brazilian-Portuguese version did not attempt to assess criterion validity.

To evaluate the construct validity, an exploratory factor analysis was utilized and two components were extracted that explained 74.5% of the total variance. From nine total items, six loaded in one factor, and items 4, 5, and 9 loaded in the other factor (Table 3). The Cronbach’s $\alpha$ discussed above was slightly increased when items 4, 5, and 9 were deleted. No factorial analysis was performed in the original version of the CAIT, however, a previous cross-cultural adaptation study also assessed construct validity using exploratory factorial analysis and three components were identified that accounted for 66.4% of the total variance. The authors reported three factors: usual/daily activities, single leg stance (item 5) and lateral hopping (item 6). The exploratory factor analysis in the current study demonstrated slightly different results for items 4, 5, 6, and 9. In the current sample, unstable feelings with single leg stance (item 5) was classified into a separate factor from the usual and daily activities factor, similar to the previous study. Unstable ankle feelings with hopping (item 6) could be perceived differently depending on the physical ability of participants. Sport training in national-level athletic participants could require agility drills with hopping performance as a part of daily warm-up and practice. Thus, hopping is a daily activity for them and loaded differently than less highly trained participants in other studies. Also, the average score of item 9 in the CAI group

<table>
<thead>
<tr>
<th>Table 3. Component Matrix: Factor Loadings</th>
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<tbody>
<tr>
<td>Item 3 Sharp Cuts</td>
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<tr>
<td>Item 7 Surface</td>
</tr>
<tr>
<td>Item 2 Activity</td>
</tr>
<tr>
<td>Item 1 Pain</td>
</tr>
<tr>
<td>Item 6 Hopping</td>
</tr>
<tr>
<td>Item 8 Rolling</td>
</tr>
<tr>
<td>Item 4 Down Stairs</td>
</tr>
<tr>
<td>Item 5 Single leg stand</td>
</tr>
<tr>
<td>Item 9 Response to rolling</td>
</tr>
</tbody>
</table>

Note: Values are listed in decreasing order of magnitude for each component, as they are presented in previous literature (Spanish CAIT). These factor loadings indicate correlation between the variable and the factor, and so could range from -1 to +1.
in the current study was 2.0±1.3, which indicated they returned to normal within one day after injuring their ankle. This rapid response and altered perception may be attributable to better medical care or higher pain tolerance than other studies' participants. Elite athletes may have different perceptions and expectations of ankle function and pain. The authors believe that item 4 (perception of ankle instability while going down the stairs) may not be taxing to the current participants because it is more likely to fall into usual and daily activity. Most items were in agreement with responses compared to a previous study, however, a few items differed due to the sample populations who performed alternative activities of daily living.

Study Limitations
There was some loss of participants due to exclusion criteria, loss to follow up, and incomplete questionnaires, but the overall sample appears to be adequately powered based on the results. The majority of participants were highly trained athletes who usually competed at the national level, and thus the findings may not apply to a more general population. Additional participants from a variety of backgrounds and activity levels are necessary in future research to test the CAIT-K for reliability and validity beyond this population. The CAIT-K was designed using a Seoul-dialect which has been the national standard for centuries and is still broadly intelligible for the entire Korean-speaking population. The Korean language is relatively homogeneous and the dialects from different geographical regions can be mutually intelligible. Thus, we believe dialects and regional differences do not affect the generalizability of the CAIT-K, but these results should be validated with geographically distinct Korean groups.

CONCLUSIONS
Overall, the CAIT-K demonstrated good psychometric properties and is comparable to the English original version and other adaptations in other languages. The CAIT-K could be a useful tool in international CAI research and treatment. The authors recommend the CAIT-K for use by Korean clinicians and researchers with Korean speaking populations. Future research should examine cutoff scores and minimum detectable change (MDC) values for the CAIT-K based on various physical levels. Developing cutoff scores and MDC values for the CAIT-K will enhance the usefulness of this tool for clinicians and researchers.

REFERENCES
12. Rosen AB, Ko J, Brown CN. Diagnostic accuracy of instrumented and manual talar tilt tests in chronic


ABSTRACT

Background: The Advanced Throwers Ten Exercise Program incorporates sustained isometric contractions in conjunction with dynamic shoulder movements. It has been suggested that incorporating isometric holds may facilitate greater increases in muscular strength and endurance. However, no objective evidence currently exists to support this claim.

Hypothesis/Purpose: The purpose of this research was to compare the effects of a sustained muscle contraction resistive training program (Advanced Throwers Ten Program) to a more traditional exercise training protocol to determine if increases in shoulder muscular strength and endurance occur in an otherwise healthy population. It was hypothesized that utilizing a sustained isometric hold during a shoulder scaption exercise from the Advanced Throwers Ten would produce greater increases in shoulder strength and endurance as compared to a traditional training program incorporating a isotonic scapular plane abduction (scaption) exercise.

Study Design: Randomized Clinical Trial.

Method: Fifty healthy participants were enrolled in this study, of which 25 were randomized into the traditional training group (age: 26 ± 8, height: 172 ± 10 cm, weight: 73 ± 13 kg, Marx Activity Scale: 11 ± 4) and 25 were randomized to the Advanced Throwers Ten group (age: 28 ± 9, height: 169 ± 23 cm, weight: 74 ± 16 kg, Marx Activity Scale: 11 ± 5). No pre-intervention differences existed between the groups (P > 0.05). Arm endurance and strength data were collected pre and post intervention using a portable load cell (BTE Evaluator, Hanover, MD). Both within and between group analyses were done in order to investigate average torque (strength) and angular impulse (endurance) changes.

Results: The traditional and Advanced Throwers Ten groups both significantly improved torque and angular impulse on both the dominant and non-dominant arms by 10–14%. There were no differences in strength or endurance following the interventions between the two training groups (p > 0.75).

Conclusions: Both training approaches increased strength and endurance as the muscle loads were consistent between protocols indicating that either approach will have positive effects.

Level of Evidence: Level 2

Keywords: Angular Impulse, abduction strength, Thrower’s 10 exercise program

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INTRODUCTION

The use of the overload principle as the foundation of progressive resistive training programs is well established.1,2 According to the overload principle, an individual must gradually increase stresses placed upon the body during exercise training in order to enhance muscular performance.2 Evidence supports the use of progressive isotonic exercises utilizing the overload principle for facilitating strength gains in the upper extremity.3 Exercise guidelines have been developed that consider the type of muscle action (i.e. concentric, eccentric, isometric) as well as the volume (sets, repetitions, and load) in order to achieve desired outcomes.4 Most exercise programs incorporate the use of isotonic exercise, with both concentric and eccentric muscle actions. The use of isometric contractions during exercise often plays a secondary/stabilization role and is commonly incorporated into rehabilitation programs in which range of motion is limited and/or contraindicated. However, the duration of a hold or isometric portion of the muscle contraction during exercise is not well described in the strength and endurance training literature.2,5

The Throwers Ten Exercise Program was originally described as a series of exercises specific to the throwing athlete designed to improve strength, power, and endurance of the shoulder complex.6 Wilk et al., recently published an altered version of this program, titled the Advanced Throwers Ten Exercise Program that incorporates varying levels of sustained isometric holds in an effort to combat muscular fatigue associated with upper extremity injuries in overhead athletes.7 For example, one set of exercises are performed with one arm remaining isometrically contracted at the end of the concentric phase while the other arm performs concentric/eccentric movement. The following set incorporates alternating concentric and eccentric movement with both arms while maintaining a sustained contraction on one arm during the lowering phase of the opposite arm. It has been suggested that incorporating sustained isometric holds will enhance muscle activation and facilitate increases in muscular strength and endurance while producing dynamic stabilization.7 However, to date, no research is available to support this premise. There is some supporting evidence that sustained isometric contractions can have a positive impact on muscular hypertrophy.8 Danneels et al randomized patients with chronic low back pain into one of two groups, a standard training group or a dynamic-static group that incorporated a five second isometric contraction during a core exercise program. The cross-sectional area of the multifidus was measured using standardized transaxial computed tomography images pre and post. Patients in the dynamic-static group demonstrated a significant increase in hypertrophy in the multifidus musculature at the end of the 10-week training program.8 Although muscular strength or endurance was not the primary outcome measure, the results of this study provide some evidence that incorporating sustained isometric contractions facilitates muscle hypertrophy in a small static stabilizing muscle group.

The theoretical approach put forth by Wilk and colleagues7 of using a sustained contraction to further train shoulder musculature has reasonable physiological support.8,9 Currently, the authors could not find published literature that investigated whether use of a sustained muscle contraction during exercise can have a meaningful change in strength or endurance over pre-established progressive resistive exercise protocols. Therefore, the purpose of this research was to compare the effects of a sustained muscle contraction resistive training program (Advanced Throwers Ten Program) to a more traditional exercise training protocol to determine if increases in shoulder muscular strength and endurance occur in an otherwise healthy population. Thus, it was hypothesized that the Advanced Throwers Ten Program would produce greater increases in shoulder muscular strength and endurance compared to a traditional isotonic training program.

METHODS

Participants

A total of 96 healthy adult volunteers inquired about the research, contacting the primary investigator by phone or email (Figure 1, Table 1). Potential subjects were excluded from the study if one of the following criteria were met: 1) shoulder or neck pain within the prior 6 months, 2) past history of shoulder or neck fractures, and 3) past history of shoulder or neck surgeries. Eligible subjects read and signed University of Kentucky Institutional Review Board approved consent forms prior to initiating the study. All testing was performed in the Musculoskeletal...
Laboratory at the University of Kentucky and Berea College Athletic Training Room from July 2013–February 2015.

Subjects filled out demographic information and the Marx upper extremity activity survey in order to evaluate the current level of upper extremity activity.\textsuperscript{10} The Marx activity survey is an activity rating scale that gives a numerical sum of scores, on a scale of 0–20, for five activities rated on a five point scale from never performed (0) to daily (4).\textsuperscript{10} This scale has been found to be reliable (ICC = 0.92), and the developers concluded that a score ≤ 6 represents low activity, 7–15 average activity, and ≥ 7 high activity. Results of the Marx activity scale and demographic information was compared using a t-test and demonstrated that the randomization process generated two similar groups (Table 1).

Sample size was determined from pilot data from six subjects (three in each group) undergoing the two training programs for six weeks. A univariate two-group repeated measures analysis of variance was implemented with 80% power in order to detect an interaction between the two groups using average torque as the primary outcome. With significance set at a level 0.05 it was determined that a sample size for each group was 25 subjects. (NQuery + nTerim 2.0, Statistical Solutions, Saugues, MA)

**Design**

This study was a two-group, pre-test/post-test randomized clinical trial. Following initial average torque (strength) and angular impulse (endurance), subjects followed a six-week exercise program performed primarily at home. The arm was measured in abduction of 90° in the scapular plane, 30° anterior to the frontal plane (scaption).

**Isometric Testing**

Prior to testing, intersession reliability was established and intraclass correlation coefficient (ICC),

### Table 1. Participant Demographic Information reported as mean and standard deviations. Significance reported as probability from an Independent T-test

<table>
<thead>
<tr>
<th></th>
<th>Traditional Training Group</th>
<th>Advanced Throwers Ten Group</th>
<th>p-Value</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>26 ± 8.1</td>
<td>28 ± 8.6</td>
<td>0.28</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>172 ± 10.2</td>
<td>170 ± 23.5</td>
<td>0.61</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>73 ± 13</td>
<td>74 ± 16</td>
<td>0.70</td>
</tr>
<tr>
<td>Arm Length Right (cm)</td>
<td>56 ± 4.6</td>
<td>56 ± 3.8</td>
<td>0.97</td>
</tr>
<tr>
<td>Arm Length Left (cm)</td>
<td>56 ± 4.6</td>
<td>56 ± 3.7</td>
<td>0.89</td>
</tr>
<tr>
<td>MARX Upper Extremity Activity Score</td>
<td>11 ± 3.9</td>
<td>12 ± 5</td>
<td>0.51</td>
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</table>
standard error of measure (SEM), and minimal detectable change (MDC) were calculated for average torque (ICC = 0.96, SEM = 3.2Nm, and MDC = 4.5 Nm), and angular impulse (ICC = 0.95, SEM = 90.2 Nm*s, and MDC = 127.7 Nm*s) using a portable load cell (BTE Evaluator, Hanover, MD). Therefore, gains greater than or equal to 5Nm and 128Nm*s in torque and angular impulse, respectively, were considered to be a meaningful change. All subjects warmed up using a series of arm motions (2 sets of 10) and shoulder stretching exercises (2 sets of 30 seconds) for approximately three minutes. The arm motions included bilateral arm scapular plane abduction (scaption) to 90°, shoulder stretches across body for the posterior shoulder, and behind the head for anterior shoulder. The testing procedures were explained, and subjects’ arm length was measured bilaterally from the tip of the acromion process to the radial styloid process. This was done in order to convert the force generated during the isometric strength testing to torque, by multiplying the forces generated in Newtons by the subject's lever arm, which was measured in meters.

Isometric shoulder torque and angular impulse was measured in the position of arm abduction of 90° in the scapular plane, 30° anterior to the frontal plane (scaption) using a portable load cell (BTE Technologies Inc, Hanover, MD) for a duration of 30 seconds on both the dominant and non-dominant arms. The average torque generated over the first five seconds of the two 30-second maximal effort trials for each arm represented shoulder strength as measured using isometric torque. The average angular impulse over the entire 30 seconds of the two 30-second maximal effort trials for each arm represented shoulder endurance. An impulse represents the amount of force multiplied by the time that the force is exerted.11,12 This represents the integral or area under the curve of the force applied, and is referred to as angular impulse. The area under the curve represents the total work done, which is used as a measure of endurance.13,14 The calculation for angular impulse is detailed in the data reduction section.

All participants were tested in an upright standing position with the portable load cell connected to an inelastic plastic chain that was connected to the participant's wrist at the radial styloid process with a black velcro strap. The strap could be adjusted and modified to fit each participant's wrist size (Figure 2). Once connected, subjects were moved into abduction of 90° in the scapular plane, 30° anterior to the frontal plane. All positions were confirmed with a standard goniometer. Each arm was tested twice with a two-minute rest between tests.4 Subjects were instructed to lift up against the resistance as hard as they could for 30 seconds. During testing subjects were given no verbal encouragement or visual feedback, as past literature suggests that the use of either can bias strength testing values.15,16 Researchers only provided feedback relating to correct posture and arm position if necessary. The testing sequence was the same for all subjects during pre- and post-testing.

Randomization and Blinding
All participants were randomly assigned into one of two treatment groups; the traditional training group (group 1) or the Advanced Throwers Ten group (group 2). An independent investigator on the research team utilized Excel (Microsoft, Redwood, WA) to generate random numbers to create group assignment sequence. The random numbers corresponding to the treatment groups were placed in a

Figure 2. Testing position using portable load cell.
sealed opaque envelope until the initial testing session was complete blinding the investigator from group membership during initial pre-test measurements. After the initial testing session the sealed envelope was opened and the subject was placed in one of the two treatment groups. Therefore the investigators were not blinded to treatment groups at post-testing due to logistics of testing.

**Intervention**

The exercise chosen for both groups were shoulder scaption, described as the arm abducted to 90° and in the plane of the scapula, 30° anterior to the frontal plane. This exercise was selected for this study as it is part of the both the advanced and traditional throwers ten program, and electromyographic evidence supports that the deltoid and rotator cuff muscles are activated in this position making it a common exercise prescribed in rehabilitation and prevention programs.17-19

Scaption exercises were performed with the subject in a standing position elevating the arm to 90°. The participants used specific resistance loads based on the peak force generated during the pre-testing session. Participants starting weight was calculated using 15% of their maximum force during the initial testing session. Researchers then progressed each individual linearly by 25% each week during the six-week intervention.20 Participants were provided resistive weights if they did not have equipment available.

Detailed descriptions of each training program can be found in Table 2. Each participant was instructed to complete the exercises four times per week. Participants were asked to refrain from any upper extremity weight-training or workouts over the course of the study and this was reiterated to each participant at all follow-ups. Researchers contacted participants each week by phone to assure the exercises were performed in the correct manner and being progressed appropriately. Participants were given an exercise log and asked to record repetitions, resistive loads, exercise compliance, and their perceived difficulty when they completed the exercises. Both groups had above a 95% compliance rate throughout the duration of the study. The BORG scale was used to gauge perceived exertion. The scale ranges from 0-10, beginning a level of “no feeling of exertion” and continues to level of “near maximum, very, very hard.” A score of zero denotes no perceived exertion and a score of 10 denotes near maximum perceived exertion, with varying levels in between.21 The BORG scale was used in this study to gauge the individuals perceived level of exertion each day they performed the training program, with respect to gradual load increases. It was also used as a tool to monitor if a subjects load progression should be increased or decreased. If participants reported scores of 2–3 and no soreness in the first two days of exercise they were progressed to the next recommended load. If subjects continuously reported scores between 9-10 they remained at that load for another week.

**Data Reduction**

The raw data from the BTE software was exported and placed with subject specific data into an excel document. A template was created that allowed the researchers to calculate average torque and angular impulse for each trial. The average torque for the two trials for each arm were averaged together and recorded and represents strength. Angular Impulse, or area under the curve, indicated the total effort applied for the 30-second effort and represents endurance. Every 1.56 seconds (6 hz) data was gathered from the load cell in the form of pounds. Pounds were converted to Newtons and each participant’s arm length was recorded in meters allowing for the force generated to be converted into torque (Nm). The resultant of the torque value and the duration of the effort (30 second time window) is represented by Nm*s. The total area under the curve was calculated using the trapezoidal method, which calculates individual impulses over the total time duration. The summations of each of the adjacent trapezoids were summed in order to calculate total area under the curve.11 Therefore, an increase in the area under the curve from pre to post test represented gains in muscular endurance.

**Statistical Analysis**

To determine between group differences, torque and angular impulse percent change scores were analyzed using separate Mann-Whitney U tests for both the dominant and non-dominant arms. Percent change was calculated for torque and angu-
lar impulse using the following equation for each participant.

\[
\text{impulse} = \left( \frac{\text{posttest value} - \text{pretest value}}{\text{pretest value}} \right) \times 100.
\]

The Mann-Whitney U test compares the mean rank scores of the two groups to determine differences between the groups. In order to analyze within group changes for raw torque and angular impulse data four separate Wilcoxon Signed Rank Tests for both the dominant and non-dominant arms were utilized. These non-parametric tests were used because the data were not normally distributed as determined by a Shapiro-Wilk Test \((p < 0.001)\). All data were analyzed using Statistical Package SPSS version 21 [IBM Corp. Armonk, NY, USA]. A \(\alpha\) level of \(p \leq 0.05\) was considered significant for all statistical analyses.

**RESULTS**

Torque and angular impulse improved in the majority of all measures across time (Table 3). Torque and angular impulse on both the dominant and non-dominant arms improved in both the traditional
and advanced throwers ten groups between 10–14% suggesting that both approaches can have positive implications (Table 4). There were no significant differences in torque generated by the dominant arm (p = 0.92) or the non-dominant arm (p = 0.85) following the interventions between the training groups. Likewise, there were no significant differences in angular impulse generated by the dominant arm (p = 0.79) or the non-dominant arm (p = 0.75) between the training groups (Table 4).

DISCUSSION
The advanced throwers ten was designed to enhance strength, endurance, and dynamic stability for return to interval sport training. However, it is currently unknown if improvements in strength and endurance occur following the advanced throwers ten program. Therefore, the current study investigated the effect of a six-week exercise program consisting of two different training programs. It was hypothesized that incorporating sustained isometric holds into a commonly prescribed shoulder scaption exercise would have significantly greater gains in muscle strength and endurance compared to a traditional isotonic scaption exercise. There were no between-group differences; however, the traditional group increased strength and endurance by 13% and 12%, respectively. Similarly the advanced throwers ten group improved strength and endurance by 11% and 12%, respectively.

The evidence to support incorporating sustained contractions into basic strength training regimes should not be underestimated. There is evidence

<table>
<thead>
<tr>
<th>Table 3. Median and interquartile range (IQR) for all dependent measures within pre- and post-test data for both group</th>
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<tbody>
<tr>
<td><strong>Group</strong></td>
</tr>
<tr>
<td><strong>Torque Dominant Arm</strong></td>
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<tr>
<td>Traditional</td>
</tr>
<tr>
<td>Advanced Throwers Ten</td>
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<tr>
<td><strong>Torque Non Dominant Arm</strong></td>
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<tr>
<td>Traditional</td>
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<tr>
<td>Advanced Throwers Ten</td>
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<tr>
<td><strong>Angular Impulse Dominant Arm</strong></td>
</tr>
<tr>
<td>Traditional</td>
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<td>Advanced Throwers Ten</td>
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<tr>
<td><strong>Angular Impulse Non Dominant Arm</strong></td>
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<tr>
<td>Traditional</td>
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<tr>
<td>Advanced Throwers Ten</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Table 4. Median % Change and interquartile range (IQR) for all dependent measures between groups</th>
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</thead>
<tbody>
<tr>
<td><strong>Traditional</strong></td>
</tr>
<tr>
<td><strong>Torque Dominant Arm</strong></td>
</tr>
<tr>
<td><strong>Torque Non Dominant Arm</strong></td>
</tr>
<tr>
<td><strong>Angular Impulse Dominant Arm</strong></td>
</tr>
<tr>
<td><strong>Angular Impulse Non Dominant Arm</strong></td>
</tr>
</tbody>
</table>

Note: All values represent an increase in median % change
that in a small stabilizing muscle group that percent changes as high as 7% occur when assessing muscu-
lar hypertrophy in the lumbar multifidus following a 10-week training program incorporating sustained holds.8 Although the researchers did not measure strength directly, hypertrophic changes in both the upper and lower extremity have been shown to cor-
relate with increases in muscle strength.22,23 Strength and hypertrophic changes have also been shown to accompany one another following resistance-training protocols.24,25 Furthermore, sustained isometric holds increase motor unit recruitment43,46 which may also help explain hypertrophic changes in muscle. Therefore incorporating sustained holds during exercise may provide physiological changes to the targeted muscle group(s).

Strength gains of 12% in the current study are similar to one strength training study despite methodologi-
cal differences in strength measures. In trained ath-
letes strength has been shown to improve between 12–15% over a 12-week period.27 Although, this study did not focus on trained athletes, individuals were considered moderately active on the MARX activity scale.10 Traditionally, strength gains are observed in programs focusing on low repetitions and high resist-
ance as initially suggested by the classic work of DeLorme.28 However, the current study investigated strength gains utilizing a high number of repetitions with low resistance, which targets muscle endur-
ance.28 Despite, DeLorme’s suggestions on strength and endurance intensity and volume training param-
eters, documented upper extremity strength gains have been shown to be as large as 25% following dynamic shoulder activity with prescribed exercise parameters consisting of three sets of 15 repetitions (traditionally thought to train muscular endurance).29 Therefore, it is reasonable to suspect that an indi-
vidual can acquire improvements in strength even when implementing a training protocol that is dosed using parameters more traditionally associated with endurance training. The results of this study demon-
strate that while a training program may emphasize an endurance protocol, there are additional benefits of improving muscular strength as well.

Measuring endurance in addition to strength was an important component of the current study. Strength measures a muscle’s ability to perform maximally over a small time period.30 Endurance measures the ability of a muscle to sustain a contraction at maxi-
mal or submaximal effort over time.30 Another way to interpret endurance would be the ability a muscle has to sustain work. Work is the force multiplied by the distance moved. An impulse is similar to work, as it is the force generated by a muscle multiplied by the time the force is applied.11,12 A sustained maxi-
mal contraction of shoulder abduction for 30 seconds would represent a measure of shoulder endurance. For this study, angular impulse was measured by using the torque generated during abduction multiplied by time, 30 seconds. This measure represents the total work performed during the entire 30 sec-
onds of maximal abduction. Angular impulse or total work represents the muscles’ ability to sustain a con-
traction during the entire time that force is being gen-
erated.13,14 This measure would evaluate the ability of an individual to abduct maximally for prolonged time. This measure is likely to be more representa-
tive of a functional demand in which someone would have sustained a contraction for 30–60 seconds such as installing drywall with a drill while building a house. Maximal strength alone only describes the single highest value obtained momentarily.

There is variability seen in percent change scores when investigating muscular total work or endurance across the current body of literature. Glenohumeral rotation total work as assessed using an isokinetic dynamometer has been shown to increase by 40% following a strength-training program.29 This increase was nearly four times greater than those seen in the current study, and is more than likely contributed to differences in training volume during the protocol. The protocols in this study had a total daily training volume ranging between 90-100 repetitions while the volume in Niederbracht’s study was 225 repeti-
tions. However, the current study demonstrated simi-
lar endurance gains to Campos et al, as individuals’ improved muscular endurance by 10% when partici-
pating in a lower extremity-training regime with exer-
cise parameters consisting of 3 sets of 11 repetitions.5

When designing this clinical trial the researchers con-
trolled for the total volume of training by establish-
ing the total time on muscle tension for the anterior and middle deltoid. This was done through a pilot study conducted before the start of this research that
utilized EMG activity during exercises that would be implemented during the intervention. This allowed researchers to ensure that each training program would produce similar total work values to prevent one group from working more than the other and having greater potential for gains in strength and/or endurance. The results of this study support that the total amount of work completed by each training program was similar. Consequently, this may be one reason why the researchers did not discover any between group differences.

Regardless of non-significant group differences, both groups had some participants that achieved improvements beyond measurement error in muscular strength and endurance across a six-week intervention. The authors acknowledge that meaningful improvements were not seen in the overall pre- to post- intervention scores within each of the groups (Table 3); rather, certain individuals exceeded the numerical value that represented a clinically relevant change in muscular strength and endurance while others did not. Fifteen participants demonstrated meaningful changes in either strength or endurance on the dominant and non-dominant arms. Of those 15 participants, nine increased in both strength and endurance, five participants within the traditional throwers group and four within the Advanced Throwers Ten group. These nine participants ranged in sex, age (19–52), weight (52–89 kg), height (66–183 cm), and MARX activity score (1–20), indicating that both these training regimes may be used on a diverse healthy population, which improves the external validity of this study.

This study is not without limitations as the Advanced Throwers Ten was initially proposed as a new approach to rehabilitate overhead throwing athletes, yet all of the participants enrolled were healthy adults with no previous history of shoulder or neck injury; therefore generalization to an injured population should not be attempted. The scaption exercise described by Wilk et al.7 is performed with the patient sitting on a swiss ball, but the exercise used in this study did not incorporate the use of a stability ball as not all participants had access to such equipment. The exercise programs prescribed in this study were home-based. Given that the exercise program was home-based, the authors relied on the participants' honesty regarding exercise compliance and avoidance of additional upper extremity weight-training. However, all participants completed a weekly exercise compliance log and were reminded to avoid upper extremity weight-training at each follow-up appointment. Furthermore, although all participants were instructed to perform the exercises continuously (i.e. no rest between repetitions), it is possible that some participants performed the repetitions slower than others, thus performing a greater volume of work. Future studies should incorporate the use of a metronome during exercise to avoid this possibility. Incorporating a supervised training session under a personal trainer has been shown to elicit greater gains in strength compared to unsupervised training in moderately training men; however, both modes of training have shown to improve strength by more than 20%.31 Lastly, the starting weight of 15% of the peak force generated may not have stimulated enough muscular demands to illicit early changes in strength and endurance. Future studies should consider increasing the starting weight to be equivalent to 20–25% of peak initial force. Because both exercise programs produced strength gains, future research should be conducted to investigate a combination of exercises from the two programs with respect to overhead athletes.

CONCLUSION

The current study is one of the first studies to investigate the use of sustained isometric exercises in comparison with traditional isotonic training exercises in the shoulder. Given the results, either set of exercises can be used to improve shoulder strength and endurance. Both sets of exercises are time efficient in that they only take five minutes to perform. The advanced throwers ten exercise investigated in this study provides variation to a commonly prescribed scaption exercise that may reduce boredom while training. In addition, incorporating sustained isometric holds during exercise may be beneficial for overhead athletes that must maintain elevation over an extended period of time as such exercises may reduce the likelihood of fatigue.

REFERENCES


ABSTRACT

Background: Professional swimmers are often affected by a high number of injuries due to their large amount of training. The occurrence of musculoskeletal pain during an important tournament has not been investigated.

Objective: The objective of the study was to assess the prevalence of musculoskeletal pain and its characteristics in professional swimmers. Secondary objectives included evaluating the swimmers' injury history over the previous 12 months, and examining the association of the presence of pain with personal and training characteristics of the swimmers.

Design: Observational, cross-sectional study

Method: Two-hundred and fifty-seven swimmers who participated in the Brazilian Swimming Championship were included in the study and answered a questionnaire about personal and training characteristics, presence of pain, and injuries in the previous 12 months. The relative risk of presence of pain was calculated for the following variables: gender, BMI, stroke specialty, swimmer's position, strength training, practice of another physical activity, and previous injuries.

Results: The prevalence of musculoskeletal pain was about 20%, with 60% of swimmers reporting at least one injury in the previous 12 months. The shoulder was the most commonly affected region and tendinopathy was the most common type of previous injury. No significant relationships were found between the presence of pain and personal or training characteristics.

Conclusions: The results demonstrated that the prevalence of musculoskeletal pain in professional swimmers participating in the most important Brazilian national tournament was approximately 20%, while the majority of participants reported previous injuries in many areas.

Level of Evidence: 2c

Keywords: Aquatic sports, epidemiologic studies, injuries, swimming
INTRODUCTION
Swimming is broadly practiced around the world and people of all ages participate. The participants in this sport look for wellness and prevention of systemic diseases, principally in the cardiorespiratory system. However, the high exposure to practice of swimming may be a risk for the integrity of musculoskeletal system. The number of musculoskeletal injuries related to swimming may be an important consideration, mainly among professional swimmers, because they are more exposed by their amount of training compared to amateur swimmers. Professional swimmers can swim around 10 to 14 kilometres a day, depending on stroke specialty and whether they are sprinters or distance swimmers. In the United States, it is estimated that in the last 25 years a total of 42000 swimmers competed at the elite level of the National Collegiate Athletic Association (NCAA). In the Federation Internationale de Natation (FINA) World Championship (2009), a total of 2592 athletes from 172 countries participated in the event.

Despite the apparently high injury rates in swimming, few epidemiologic studies are found in the literature. Available studies usually evaluate injuries in specific joints, particularly the shoulder complex, specific stroke specialties, or injuries related to the biomechanics of the sport. Information about injuries in swimmer who participate in elite tournaments is scarce.

Until now, to the authors knowledge, no studies have investigated the presence of musculoskeletal pain in swimmers competing in a large national tournament. Thus, the objective of the present study was to assess the prevalence of musculoskeletal pain and its characteristics in professional swimmers that participated from Brazilian Swimming Championship. Secondary objectives included evaluating the swimmers’ injury history over the previous 12 months, and to examining the association of the presence of pain with personal and training characteristics of the swimmers.

METHODS
This cross-sectional study utilized swimmers who participated in the Brazilian Swimming Championship (39th Troféu José Finkel Edition, 2010) that occurred in a short course pool (25 meters). The participants could only participate of the event if they achieved a qualifying time established by the Brazilian Aquatic Sports Federation. All 430 swimmers participants in the event were invited to participate in the study. If the participants accepted, they signed the consent form in accordance with the study's requirements and were included in the study.

A questionnaire was developed, in which participants were asked about: 1) personal characteristics (age, gender, weight, height and swimming experience); 2) training routine (weekly distance training, stroke specialty, athlete's position, practice of another physical activity, and strength training); 3) presence of current musculoskeletal pain, pain characteristics, pain anatomic region, situation that caused the pain (practice or competition); and 4) injury history over the previous 12 months, with details regarding the respective situation, type, and region of injury. The following operational definition of injury used was: any musculoskeletal disorder related to swimming in previous 12 months, severe enough for the swimmer to seek medical attention or to prevent the swimmer from performing at least one training session or competition.

The swimmer's position was defined as sprinter (if they typically competed in races of 200 metres or less) or distance (if they typically competed in races of greater than 200 metres). The swimmer's stroke specialty was classified according to the races they competed in (freestyle, backstroke, breaststroke, butterfly, and medley) and participants must to choose only one stroke specialty of his preference. Regarding presence of pain, athletes were asked if they were suffering any current pain of musculoskeletal origin, as well as the pain characteristics. To better identify the type and anatomic region of pain and previous injuries, a predefined list used by previous studies was adopted.

This study was approved by the Ethics Committee of the University of the City of São Paulo and also received approval from the Medical Department of the Brazilian Aquatic Sports Federation in accordance with the Helsinki Declaration of 1975 and the guidelines of Harris and Atkinson. All participating athletes signed the consent form in accordance with the study’s requirements.

Statistical Analysis
The description of participants' personal and training characteristics was descriptively analyzed using frequency distribution and percentages for categorical data (gender, body mass index [BMI], stroke specialty,
swimmer's position, strength training, and previous injuries). Swimmers were categorized as freestyle or non-freestyle, and more than half of the participants had freestyle as their stroke specialty. Continuous data (age, height, weight, swimming experience, and weekly distance) were reported in mean and standard deviation, since all data presented in a normal distribution. Normality evaluation of continuous data was done through a curve symmetry analysis.

For categorical data comparison, the Chi-squared Test was utilized. For continuous data comparison, the Students t-test for independent samples was used. The relative risk of presence of pain was also calculated for the following variables: gender, BMI, stroke specialty, swimmer's position, strength training, practice of another physical activity (another modality besides the swimming), and previous injuries. For all analyses, a 95% significance level was regarded as statistically significant and the analyses were performed using SPSS 17.0.

RESULTS

Two hundred and fifty-seven (59.8%) swimmers accepted the invitation to participate in the study and completed the questionnaire. The description of swimmers’ personal and training characteristics are presented in Table 1.

Table 1. Characteristics of swimmers included in the study

<table>
<thead>
<tr>
<th></th>
<th>Total (n= 257)</th>
<th>Male (n = 140)</th>
<th>Female (n = 117)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>20.1 (3.8)</td>
<td>20.6 (3.7)</td>
<td>19.4 (3.9)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>176.2 (14.4)</td>
<td>181.5 (16.8)</td>
<td>169.9 (6.9)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>70.4 (12)</td>
<td>77.7 (9.9)</td>
<td>61.6 (7.7)</td>
</tr>
<tr>
<td>BMI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 25</td>
<td>92.6% (238)</td>
<td>88.5% (123)</td>
<td>98.3% (115)</td>
</tr>
<tr>
<td>&gt; 25</td>
<td>7.4% (19)</td>
<td>11.5% (16)</td>
<td>1.7% (2)</td>
</tr>
<tr>
<td>Swimming experience (years)</td>
<td>13.2 (4.7)</td>
<td>13.6 (4.7)</td>
<td>12.6 (4.8)</td>
</tr>
<tr>
<td>Stroke specialty</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freestyle</td>
<td>41.6% (107)</td>
<td>40% (56)</td>
<td>43.6% (51)</td>
</tr>
<tr>
<td>Backstroke</td>
<td>18.3% (47)</td>
<td>16.4% (23)</td>
<td>20.5% (24)</td>
</tr>
<tr>
<td>Breaststroke</td>
<td>15.6% (40)</td>
<td>18.6% (26)</td>
<td>12% (14)</td>
</tr>
<tr>
<td>Butterfly</td>
<td>13.2% (34)</td>
<td>13.6% (19)</td>
<td>12.8% (15)</td>
</tr>
<tr>
<td>Medley</td>
<td>11.3% (29)</td>
<td>11.4% (16)</td>
<td>11.1% (13)</td>
</tr>
<tr>
<td>Position</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance</td>
<td>32.7% (84)</td>
<td>33.6% (47)</td>
<td>31.6% (37)</td>
</tr>
<tr>
<td>Sprinter</td>
<td>67.3% (173)</td>
<td>66.4% (93)</td>
<td>68.4% (80)</td>
</tr>
<tr>
<td>Week distance (km)</td>
<td>57.1 (29.9)</td>
<td>59.7 (32.5)</td>
<td>53.9 (26.4)</td>
</tr>
<tr>
<td>Strength training</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>93.4% (239)</td>
<td>94.3% (132)</td>
<td>91.5% (107)</td>
</tr>
<tr>
<td>No</td>
<td>6.6% (18)</td>
<td>5.7% (8)</td>
<td>8.5% (10)</td>
</tr>
<tr>
<td>Another physical activity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>16.3% (42)</td>
<td>16.4% (23)</td>
<td>16.2% (19)</td>
</tr>
<tr>
<td>No</td>
<td>83.7% (215)</td>
<td>83.6% (117)</td>
<td>83.8% (98)</td>
</tr>
</tbody>
</table>

Continuous data are expressed in mean and standard deviation, and categorical data are expressed in percentage and number of participants.
The prevalence of musculoskeletal pain among 257 swimmer participants was 21% (n=54). The pain was most frequent during swimming practice but without performance limitation or after swimming. Around 70% of athletes reported that the pain was derived from training sessions. The anatomic region most commonly affected by pain was the shoulder, followed by the low back. Additional information about pain characteristics reported by the swimmers is provided in Table 2.

A total of 144 swimmers (56%) reported previous musculoskeletal injuries in the previous 12 months. Table 3 shows a description of previous injuries' characteristics. Around 60% of previous injuries affected the upper extremities, and the shoulder was the anatomic region most commonly affected in both genders (males, 41.4%; females, 48%). The second region most affected by previous injuries was the knee and tendinopathy was the most common type of knee injury most reported by swimmers.

<table>
<thead>
<tr>
<th>Table 2. Prevalence and description of current pain reported by the swimmers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Presence of pain (n=257)</td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>Pain situation (n=54)</td>
</tr>
<tr>
<td>Training</td>
</tr>
<tr>
<td>Competition</td>
</tr>
<tr>
<td>Pain characteristics (n=54)</td>
</tr>
<tr>
<td>Continuous</td>
</tr>
<tr>
<td>With performance limitation*</td>
</tr>
<tr>
<td>Without performance limitation#</td>
</tr>
<tr>
<td>After competition/training</td>
</tr>
<tr>
<td>Only during warm-up</td>
</tr>
<tr>
<td>Not reported</td>
</tr>
<tr>
<td>Pain region (n=54)</td>
</tr>
<tr>
<td>Neck/Cervical</td>
</tr>
<tr>
<td>Shoulder</td>
</tr>
<tr>
<td>Elbow/wrist/hand/finger</td>
</tr>
<tr>
<td>Hip/Thigh</td>
</tr>
<tr>
<td>Knee</td>
</tr>
<tr>
<td>Ankle/Foot</td>
</tr>
<tr>
<td>Low back</td>
</tr>
<tr>
<td>Others</td>
</tr>
</tbody>
</table>

*Pain during competition/practice, with performance limitation.
#Pain during competition/practice, without performance limitation.
The comparison of continuous variables between swimmers with pain and without pain is shown in Table 4. It should be noted that there were no statistically significant differences for any of the variables between swimmers with and without pain.

With regard to relative risk for musculoskeletal pain, note that the relative risk values were not statistically different among groups for any of the variables (Table 5).

**DISCUSSION**

The results of the present cross-sectional study demonstrated that approximately 20% of swimmers reported musculoskeletal pain during the Brazilian Swimming Championship (39th Troféu José Finkel Edition, 2010). Around 60% of participants reported previous injuries. Tendinopathy was the most common type of previous injury and the shoulder the most affected anatomic region in both males and females. When analysing the relative risk of pres-
### Table 4. Comparisons of between swimmers with and without pain

<table>
<thead>
<tr>
<th></th>
<th>Without pain</th>
<th>With pain</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>19.9 (3.8)</td>
<td>20.1 (4)</td>
<td>0.09</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>176.8 (9.3)</td>
<td>177.2 (9.6)</td>
<td>0.69</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>70.6 (11.1)</td>
<td>70.9 (11.7)</td>
<td>0.79</td>
</tr>
<tr>
<td>Swimming experience (years)</td>
<td>13 (4.7)</td>
<td>13.8 (4.8)</td>
<td>0.17</td>
</tr>
<tr>
<td>Week distance (km)</td>
<td>57.8 (31.1)</td>
<td>54.2 (25.3)</td>
<td>0.61</td>
</tr>
</tbody>
</table>

Data are expressed in mean and standard deviation. Comparisons were conducted with the Student-t Test for independent samples.

### Table 5. Comparison of categorical data between swimmers with and without pain

<table>
<thead>
<tr>
<th></th>
<th>Without pain</th>
<th>With pain</th>
<th>p-value</th>
<th>RR (CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>79.3 (111)</td>
<td>20.7 (29)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>78.6 (92)</td>
<td>21.4 (25)</td>
<td>1.03 (0.64 – 1.66)</td>
<td></td>
</tr>
<tr>
<td>BMI</td>
<td></td>
<td></td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td>≤ 25</td>
<td>77.7(185)</td>
<td>22.3 (53)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>&gt; 25</td>
<td>94.4 (17)</td>
<td>5.6 (1)</td>
<td>0.25 (0.04 – 1.70)</td>
<td></td>
</tr>
<tr>
<td>Stroke specialty</td>
<td>-</td>
<td>-</td>
<td>0.88</td>
<td></td>
</tr>
<tr>
<td>Freestyle</td>
<td>79.4 (85)</td>
<td>20.6 (22)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Non-Freestyle</td>
<td>78.7 (118)</td>
<td>21.3 (32)</td>
<td>1.11 (0.68 – 1.79)</td>
<td></td>
</tr>
<tr>
<td>Position</td>
<td></td>
<td></td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>Distance</td>
<td>83.3 (70)</td>
<td>16.7 (14)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Sprinter</td>
<td>76.9 (133)</td>
<td>23.1 (40)</td>
<td>1.38 (0.80 – 2.40)</td>
<td></td>
</tr>
<tr>
<td>Strength training</td>
<td></td>
<td></td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>64.7 (11)</td>
<td>35.3 (6)</td>
<td>1.65 (0.82 – 3.44)</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>79.9 (191)</td>
<td>20.1 (48)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Another physical activity</td>
<td></td>
<td></td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>79.7 (169)</td>
<td>20.3 (44)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>76.2 (32)</td>
<td>23.8 (10)</td>
<td>1.17 (0.64 – 2.15)</td>
<td></td>
</tr>
<tr>
<td>Previous injury</td>
<td></td>
<td></td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>82.3 (93)</td>
<td>17.7 (20)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>76.4 (110)</td>
<td>23.6 (34)</td>
<td>1.33 (0.81 – 2.19)</td>
<td></td>
</tr>
</tbody>
</table>

Data are expressed in percentage and number of swimmers. The p-value were obtained using the Chi-squared Test.

RR = relative risk, CI = confidence interval
ence of pain for personal and training characteristics, it should be noted that there were no statistically significant differences for any of the variables between those who had pain and those who did not.

This is first study that has investigated and described a 20% prevalence of musculoskeletal pain in professional swimmer participants in a large Brazilian national tournament. Several previous authors have also evaluated professional swimmers, but with a longitudinal prospective design. Wolf et al reported an injury incidence of four injuries per 1,000 exposures in swimmers from the National Collegiate Athletic Association (NCAA) team followed during five seasons, while Chase et al found an incidence of 5.5 per 1,000 hours exposure in swimmers also from the NCAA. Mountjoy et al evaluated the occurrence of new injuries sustained during the World Swimming Championship, and their incidence was 66 injuries per 1,000 athletes.

The present study also evaluated the rate of injuries in the previous 12 months, and 144 (56%) swimmers reported at least one musculoskeletal injury within the previous 12 months. This injury rate is similar to the results of Aguiar et al, which, despite the use of a different definition of injury, found an injury rate in the previous 12 months of 56.3% in swimmer participants in minor national tournaments. This similar result can be explained by the characteristics that are alike in both studies, such as age, swimming experience, and BMI.

The shoulder was the anatomic region most commonly affected by both musculoskeletal pain at the time of the survey, and by previous injuries (within 12 months) in swimmers from this study. Despite the different ways of monitoring swimmers in their studies, as in a longitudinal prospective way of evaluating new injuries, or only the previous injuries, these previous authors also cited the shoulder as the region most affected by swimming injuries. This finding was expected, as the shoulder is responsible for around 90% of propulsive power in swimmers. When this is associated with the training overloads to which professional athletes are exposed, then this makes the shoulder a region very susceptible to overuse injuries.

The type of previous injuries most reported by swimmers was tendinopathy, similar to the findings in Aguiar et al. Tendinopathy is usually related to excessive loads imposed by sports activities and is characterized as an overuse injury. The tendon, when exposed to repetitive harmful movements, exceeds its physiologic limit, causing the rupture of collagen fibers and tendon degeneration. Overuse injuries were also the most frequent in the studies by Kerr et al, Mountjoy et al and Chase et al, indicating that as in other sports, such as athletics and running, these type of injuries occur most frequently as in swimming. Future studies about preventive measures in swimming should attempt to overuse injuries, specially the tendinopathies, and how the amount of exposure by the athletes could be related to these injuries.

One hypothesis of this study was that variables, such as swimming experience, weekly distance, stroke specialty, swimmer's position, and previous injuries, could be associated with the presence of musculoskeletal pain in the swimmers. However, there were no statistically significant differences found between swimmers with pain and without pain for any of these variables. Previous authors have reported some factors associated with injuries. For instance, Aguiar et al reported that age and swimming experience were associated with previous injuries in swimmers in minor national tournaments. Wolf et al and Chase et al, in prospective studies, noted the association between occurrence of new injuries with backstroke specialty and previous injuries, respectively. These different findings from the present study may be explained by the use of different injury definitions utilized by each study. Another explanation is that sports injuries usually are characterized by a multifactorial causes, maybe the questions included in the current study's questionnaire were not sufficient to detect possible differences between swimmers with pain and without pain.

As a limitation of the present study, one swimming team that had a large number of participants in the tournament refused to participate in the study, explaining why the study had 59.8% of attendance from the swimmers participants in the championship. Another limitation is the use of a questionnaire about previous injuries and swimming distance, since the participants could underreport both information, explaining why the present study did not
find association between presence of pain and previous injuries or swimming distance. Despite limiting the questioning to injuries sustained in the last 12 months, it is not possible to discard the recall bias, since a previous study demonstrated that when a retrospective injury registration is used, participants can forget to record previous injuries and injury rate could be underestimated.

CONCLUSION
The results of the current study demonstrated that the prevalence of musculoskeletal pain in professional swimmer participants in the most important Brazilian national tournament was 20%, while around 60% of participants reported previous injuries. These results indicate that a substantial problem exists involving elite swimmers and further studies should address preventive measures through randomized controlled trials. Because overuse injuries of the shoulder were most common, attention to preventive measures should be given to these types of injuries, especially tendinopathies of the shoulder.

REFERENCES


ABSTRACT

**Background and Purpose:** Patients frequently experience long-term deficits in functional activity following anterior cruciate ligament reconstruction, and commonly present with decreased confidence and poor weight acceptance in the surgical knee. Adaptation of neuromuscular behaviors may be possible through plyometric training. Body weight support decreases intensity of landing sufficiently to allow increased training repetition. The purpose of this case report is to report the outcomes of a subject with a previous history of anterior cruciate ligament (ACL) reconstruction treated with high repetition jump training coupled with body weight support (BWS) as a primary intervention strategy.

**Case Description:** A 23-year old female, who had right ACL reconstruction seven years prior, presented with anterior knee pain and effusion following initiation of a running program. Following visual assessment of poor mechanics in single leg closed chain activities, landing mechanics were assessed using 3-D motion analysis of single leg landing off a 20 cm box. She then participated in an eight-week plyometric training program using a custom-designed body weight support system. The International Knee Documentation Committee Subjective Knee Form (IKDC) and the ACL-Return to Sport Index (ACL-RSI) were administered at the start and end of treatment as well as at follow-up testing.

**Outcomes:** The subject’s IKDC and ACL-RSI scores increased with training from 68% and 43% to 90% and 84%, respectively, and were retained at follow-up testing. Peak knee and hip flexion angles during landing increased from 47° and 53° to 72° and 80° respectively. Vertical ground reaction forces in landing decreased with training from 3.8 N/kg to 3.2 N/kg. All changes were retained two months following completion of training.

**Discussion:** The subject experienced meaningful changes in overall function. Retention of mechanical changes suggests that her new landing strategy had become a habitual pattern. Success with high volume plyometric training is possible when using BWS. Clinical investigation into the efficacy of body weight support as a training mechanism is needed.

**Level of Evidence:** Level 4 – Case Report

**Keywords:** ACL-RSI, biomechanics, IKDC, plyometrics, training volume
BACKGROUND AND PURPOSE

More than 200,000 people injure the anterior cruciate ligament (ACL) of their knee annually in the United States. Of these, approximately 65% undergo surgical ACL reconstruction.1 Initial outcomes following ACL reconstruction are quite good, with resolution of knee laxity and return to independent activities of daily living within three months.2-4 Although current post-operative protocols allow return to normal athletic activity within six months of surgery, a preponderance of recent evidence has shown that many patients have functional outcomes that are poorer than expected in the years following surgery.5-11 Patients who have undergone ACL reconstruction often experience chronic impairment in mechanical performance of the operated limb.12 Specifically, deficits in eccentric knee flexion have been demonstrated during the weight acceptance phase of gait as well as in higher intensity tasks such as stair descent and jump landing.13-16 Decreased knee flexion during weight acceptance may also contribute to a decreased ability to absorb ground reaction forces, leading to higher vertical ground reaction forces (VGRF) when compared to the uninjured side and healthy controls.15,16 Additionally, people who have undergone ACL reconstruction frequently demonstrate high levels of fear of movement, or a lack of confidence in the knee.5,17,18 Ardern et al18 and Chmielewski17 have both demonstrated that psychological impairments such as fear of movement and lack of confidence correlate with poor return to activity outcomes. Recent data19 have demonstrated a negative correlation between psychological impairments and absorption of vertical forces in the surgical knee. Specifically, increased fear of movement correlates with decreased ability to absorb vertical forces. Together, mechanical and psychological impairments have been associated with a 63% rate of return to pre-injury levels of physical activity, a 14% to 25% re-injury rate, and a nearly half of patients who undergo ACL reconstruction develop early-onset osteoarthritis.5,20-23 Despite these shortcomings in long-term outcomes, there has been relatively little research performed exploring interventions designed to address chronic postsurgical psychological and mechanical impairments.

Plyometric or jump training has been recommended to improve mechanical deficits seen in the lower extremity following ACL reconstruction.4,24 However, the evidence supporting this recommendation has been from the literature on primary injury prevention in healthy athletes,25-33 and as such the specifics of exercise dosage may not translate to an injured population. Chmielewski34 reviewed considerations for dosing plyometric exercise following injury, and recommended low repetition due to high ground reaction forces and rapid loading rates. In two recently published clinical commentaries describing optimal post-ACL reconstruction rehabilitation, plyometric training is advised when specific strength and functional criteria are met (generally after 12 weeks), but no specific repetition recommendations are made.4,24 Recommendations for healthy athletes range from 20 contacts per session to 120 contacts per session.26,30,35,36 The inherently high intensity of plyometric activity may cause clinicians to further reduce repetition during training, so as to avoid further injury to an already at-risk knee joint.23,34 Unfortunately, given the complexity and potential chronicity of the mechanical deficits involved postsurgically, low repetition training may not provide sufficient neuromuscular stimulus to allow modification of habitual movement patterns.37 While the literature regarding ways to optimize motor learning can be contradictory, it does seem that higher training volumes in the form of increased task repetition improves retention of that skill.38 High levels of fear and low confidence common after ACL reconstruction may also unduly influence a patient’s ability to complete effective plyometric training. The phenomenon of fear avoidance in chronic pain literature39 bears a marked resemblance to the phenomenon of psychological impairment limiting physical activity following ACL reconstruction. Given this similarity, effective treatment of psychological impairment following surgery may follow the treatment paradigm most successfully associated with fear avoidance.40,41 Kinesiophobia in athletes following ACL reconstruction may therefore be effectively treated through graded exposure to the fear-inducing stimulus. In the case of plyometric training, landing from a jump may be considered a fear-inducing stimulus. However, as Chmielewski34 states, landing on a single leg is inherently high intensity, and there are very few mechanisms by which the intensity of the landing task can be reduced while maintaining specificity of motion.
One method of reducing landing intensity is via body weight support (BWS), which may decrease intensity enough to allow higher repetition plyometric training than normally recommended and to accurately grade exposure to landing tasks. Forms of BWS have been used extensively in rehabilitation of neurologic injury\textsuperscript{42,43} and for orthopedic rehabilitation\textsuperscript{44-46} as well. Unfortunately, aquatic training, plyometric leg press, and treadmill-bound systems do not allow for specificity of movement or sport-specific training. The natural hydraulics of the aquatic environment can result in abnormal shear forces through the joints.\textsuperscript{47} A plyometric leg press requires activation of the hip flexors to maintain the feet in the line of fall, and only allows for sagittal plane movement, without the ability to move freely in three-dimensional space. A treadmill-bound system works by raising the center of mass, disallowing relatively large vertical excursions such as those seen in a jump or hop. To date, BWS systems primarily support walking and running tasks, as the vertical speed of jumping is generally too high for even motorized BWS systems to maintain constant levels of BWS. However, for this study, a novel BWS system was developed to allow specificity of movement during tasks involving vertical excursion, as well as sport specific training including cutting and pivoting motions. Appropriate utilization of this novel BWS system during plyometric training may improve mechanical and psychological, and thereby functional, outcomes following ACL reconstruction.

The purpose of this case report is to report the outcomes of a subject with a previous history of ACL reconstruction treated with high repetition jump training coupled with BWS as a primary intervention strategy. The changes in landing mechanics, psychological readiness for activity, and functional outcomes are detailed.

**CASE DESCRIPTION**

**Subject History and Systems Review**

The subject was a 23 year-old female (BMI: 22.5) who presented with right anterior knee pain of gradual onset following initiation of a running program for fitness eight months previously. At the time of her initial evaluation (Figure 1), the subject was unable to run >1 mile due to pain rated at 5/10 on a visual analog scale. Additionally, she had discontinued playing intramural basketball due to pain. She was able to participate in all activities of daily living without pain with the exception of ascending and descending stairs, and had a Lower Extremity Function Scale (LEFS) score of 71/80. The subject had an unremarkable past medical history with the exception of a right ACL reconstruction with hamstring autograft seven years previously (Figure 1). Her history was otherwise negative for other lower extremity injuries or conditions. A systems review was unremarkable, and the subject otherwise healthy. The subject reported that magnetic resonance imaging two months prior to evaluation demonstrated a “bone bruise” to the tibial plateau, but further detail was unavailable. Her goals were to progress to running at least three miles without pain, and to play intramural basketball without concern for her knee. The subject was initially examined and treated by a licensed physical therapist who is a Fellow of the American Academy of Orthopaedic Manual Physical Therapists.

**Examination**

Passive range of motion (PROM) was limited to 137 degrees of flexion and 0 degrees of hyperextension, compared to 147 degrees of flexion and 5 degrees of hyperextension on the left. She also reported deep joint pain at end range in both directions. Tibiofemoral joint mobility testing revealed normal end-feel and mobility with anterior/posterior glides and distraction, but decreased pain with distraction. Her knee flexion strength was rated at a 4+ /5 as compared to 5/5 on the left; knee extension strength in manual muscle testing was symmetrical side to side for a grade of 5/5.\textsuperscript{48} However, she was unable to perform a single leg squat on the right without femoral adduction and internal rotation, and the
depth of her single leg squat was limited compared to the left side. Single leg stance on the right was notable for excessive use of a hip strategy to maintain balance compared to the left. Excessive lumbar extension and poor control of hip adduction were observed during walking and running gait, resulting in excessive pelvic drop during the stance phase of both gaits.

The subject was diagnosed with internal derangement of the knee with effusion, decreased PROM, and decreased functional capacity. She also displayed dysfunctional biomechanics in closed kinetic chain activities. Due to her work and school schedule, she underwent six sessions of physical therapy over a 10-week period (Figure 1). Treatment consisted of manual therapy for joint and soft tissue mobility to increase PROM and decrease effusion, single leg squats on a Total Gym® (Total Gym Global Corp., San Diego, CA) with cueing for knee, hip, and lumbar control, and running gait training on a treadmill to reduce pelvic drop during stance and lessen frontal plane valgus knee alignment.

**Clinical Impression 1**

After 10 weeks of physical therapy as described above, the subject's PROM and gross strength deficits by manual muscle testing were equal to the contralateral side. She was progressing in a walk/jog program without pain, with a LEFS score of 77/80 at the end of the 10-week period. However, her dysfunctional movement patterns in closed kinetic chain activities persisted. Her continued inability to single leg squat on the surgical side led her physical therapist to refer the subject for biomechanical testing in the University of Montana Movement Science Laboratory (Figure 1). Due to academic scheduling constraints, the subject was unable to complete laboratory testing for another three months (Figure 1). At the time of laboratory testing (Figure 1) as described below, she reported she had been unable to progress in running without pain, and continued to experience effusion after running greater than one mile. Her history, inclusive of the initial evaluation and treatment described above and considering her history of a non-contact ACL injury, indicated a persistent problem in movement coordination in closed-chain tasks, particularly those involving a single leg and/or impact. The subject was informed that data concerning her evaluation and treatment would be submitted for a case report, and she consented to submission.

**Examination**

The full laboratory examination consisted of, in order, administration of the International Knee Documentation Committee Subjective Knee Form (IKDC) and the ACL-Return to Sport Index (ACL-RSI); height and body mass measurement with a standard physician's scale; a five-minute treadmill walking warm-up; PROM measurement and effusion grading; knee flexion and extension strength testing with force dynamometry; application of retroreflective markers; and biomechanical analysis of a single leg landing from a 20 cm box as previously described. Testing and further intervention described below were performed by a licensed physical therapist with board certification as an orthopedic specialist and certification for plyometric training for ACL prevention through SportsMetrics™.

**Outcome Measures and Clinical Tests**

The IKDC was administered as a validated measure of patient-reported function for athletes, which avoids ceiling effects seen in other functional outcome measures, including the LEFS. The ACL-RSI, a validated tool which measures confidence on a 0-100 scale, was administered to provide a measure of psychological readiness for return to activity. Effusion was tested using the stroke test. Passive ROM was measured with a standard long arm goniometer as previously described.

**Isometric Strength Testing**

Knee flexor and extensor isometric strength was tested in sitting using a Kin-Com 125AP dynamometer (Chattanooga Group, Inc., Chattanooga, TN) utilizing previously published methods. The more precise measure of strength afforded by dynamometry was considered important given the relatively poor sensitivity of manual muscle testing to side-to-side differences. The knee was strapped into 60 degrees of flexion for flexor testing and 90 degrees of flexion for extensor testing. The uninvolved limb was tested first to provide the subject with a target force as well as to develop task familiarity. Visual and verbal encouragement were provided during trials.
At least 1 minute of rest was allowed between trials. When force production decreased or failed to increase more than 5% from the previous trial, the testing was complete and the trial with the highest force production was utilized for analysis. Force data were electromyographically sampled at 200 Hz utilizing a BIOPAC MP 150 (BIOPAC Systems, Inc., Santa Barbara, CA) data acquisition workstation with Acqknowledge v.3.7 software and processed with a 6 Hz low pass filter prior to determining maximal force production.

**Biomechanical Analysis of Single Leg Landing**

A single leg landing from a 20 cm box as previously described\(^49,57\) was chosen for testing, as the primary mechanism of continued pain for the subject was running, which consists of multiple single leg landings. Her difficulty with maintaining desired dynamic postures during closed kinetic chain single leg squat activities also played into this decision. Further, her history of non-contact ACL injury suggested potential neuromuscular faults,\(^27,59\) and the most frequent mechanism of non-contact ACL injury is a single leg landing.\(^50\) The subject stood approximately 10 cm from the edge of a 20 cm high box, hands on hips, and was instructed to gain her balance on a single leg before hopping off the box onto a force plate with her eyes looking forward. She performed five successful test trials of the single-leg landing task after five practice trials on each leg. A trial was deemed successful if she maintained a single leg stance for at least 2 seconds upon landing, and regained dual leg stance in a controlled manner.

Kinematic data were obtained during the single-leg landing task using an eight-camera VICON Nexus system at 200 Hz (Oxford Metrics, Ltd., London, UK). Retro-reflective markers (14 mm diameter) were placed per previously published methods\(^49,57\) to allow tracking of the three-dimensional position of bilateral feet, shanks, thighs, pelvis, and trunk. A standing calibration was performed prior to completing the landing trial to identify joint centers with respect to each segment’s coordinate system.

A 400 x 600 mm force plate (AMTI, Watertown, MA) interfaced with the VICON Nexus system captured ground reaction forces during landing. Force plate data were sampled at 1200 Hz. Marker trajectories and force plate data were filtered at 12 and 50 Hz respectively with fourth-order phase-corrected Butterworth filters. The peak vertical ground reaction forces (VGRF) and joint moments were normalized to the subject’s body mass. Joint kinematics were calculated using Euler angles, and joint kinetics were calculated with inverse dynamics using rigid body analysis through custom applications with Visual 3D software (Visual3D, Version 4.75.29, C-motion Inc., Rockville, MD). Joint angles and moments were time normalized to 100 increments from initial contact on the force plate to peak knee flexion during landing to allow calculation of an ensemble average across trials, as the time between those events varied slightly between trials.

**Clinical Impression 2**

Patient-reported outcome measures obtained during the laboratory testing showed moderate to severe decreases in self-reported function and confidence (Figure 2), with an initial IKDC score of 67.8% and an ACL-RSI score of 42.5%. Anderson et al\(^60\) reported...
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an average IKDC score for people with a history of any right knee surgery (median of five to 10 years prior) of 56.3%. The mean score for 18-24 year old women inclusive of those with and without knee injury was reported as 86%. The subject's IKDC score put her in the 15th percentile of 18-24 year old women with or without injury. Initial validation of the ACL-RSI scale showed a mean ACL-RSI score of 39.1% for athletes who have given up sport following ACL reconstruction. Athletes who had not attempted sport but had planned to return to their sport had scored a mean of 54.9%. Further, an ACL-RSI score at six months after surgery of 52.3% has been found to be a cut-off point using ROC analysis to discern between those athletes that eventually return to sport and those that do not (sensitivity = 0.97 specificity = 0.63).

Her PROM was symmetrical side-to-side, with 145 degrees of knee flexion and 5 degrees of hyperextension. She presented with trace effusion. Her side-to-side strength symmetry, as a ratio of the involved to uninvolved torque production during isometric strength testing, was 76.8% for the quadriceps and 73.2% for the hamstrings (Table 1). These strength values are below suggested side-to-side strength ratios typically advised for return to sport after ACL injury, which recommend 85% to 90% of the non-operated limb. Her kinematic and kinetic measures (Figure 3) illustrated a hard, stiff landing, with a relatively high VGRF and relatively little knee flexion and small internal knee extension moment. Mean VGRF, knee flexion, and knee extension moment during single leg landing in patients who have returned to activity after ACL reconstruction have been reported previously as approximately 3.5 Nm/kg body weight, 56°, and 2.5 Nm/kg body weight, respectively.

The subject was deemed appropriate for a high repetition jump training intervention to target her chronic difficulties in absorbing load through the involved knee and her poor functional state. Augmenting the intervention with BWS allowed training even with the limiting factors of decreased strength and decreased confidence in her knee. All training was undertaken to directly address the subject's goal of returning to running and playing basketball.

**Intervention**

The subject participated in an individualized jump training program twice weekly for eight weeks. Each session took approximately one hour as detailed in Table 2. She did not participate in any other strengthening, training, or other physical therapy intervention during this period, with the exception of occasional intramural basketball games.

The jump training treatment progression is outlined in Table 3. Although the task progression is similar to recently published neuromuscular training protocols, BWS allowed decreased intensity and higher repetition than the 20-120 contacts per session currently recommended for healthy athletes. For the first six weeks, the subject performed her training in a custom BWS system designed to allow freedom of movement within a 1.5 x 3 x 4 m volume with a consistent vertical force (Figures 4 & 5), thereby providing movement and sport specificity. Elastic tubing is stretched around a 75-meter pulley system and connected to a custom harness made of neoprene shorts. The final pulley is directly overhead and slides on a near-frictionless steel track bolted into the ceiling, allowing movement in any direction along a 1.5 x 3 m area on the floor. Taking advantage of the relationship between elastic recoil force and percent strain, the system is able to generate a vertical force at the center of mass that var-

<table>
<thead>
<tr>
<th>Table 1. Side-to-side thigh muscle strength symmetry via force dynamometry*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Quadriceps</td>
</tr>
<tr>
<td>Hamstrings</td>
</tr>
</tbody>
</table>

*Symmetry is expressed as a ratio of the surgical side to the non-surgical side.
†Post-training testing was performed immediately following the 8-week training intervention.
‡Retention testing was performed eight-weeks following post-training testing.
§Recommended values are taken from Adams et al (2012).
Table 2. Intervention protocol performed twice weekly for eight weeks

<table>
<thead>
<tr>
<th>Treatment Component (for previous treatment)</th>
<th>Specific Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint reaction check *</td>
<td>Knee pain rating on 0-10 VAS</td>
</tr>
<tr>
<td></td>
<td>Report of muscle soreness and fatigue</td>
</tr>
<tr>
<td></td>
<td>Stroke test for joint effusion</td>
</tr>
<tr>
<td>Warm-up</td>
<td>5 minute treadmill walking (3-3.5 mph)</td>
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<tr>
<td></td>
<td>High knee running</td>
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<td></td>
<td>Heel-to-gluteal running</td>
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<tr>
<td></td>
<td>High kick walking</td>
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<tr>
<td></td>
<td>Hip wrap walking with heel raise</td>
</tr>
<tr>
<td></td>
<td>Lunge walking</td>
</tr>
<tr>
<td>Jump Training</td>
<td>Per progression (Table 3)</td>
</tr>
<tr>
<td>Cool-down</td>
<td>5 minute treadmill walking (3-3.5 mph)</td>
</tr>
<tr>
<td></td>
<td>Quadriceps stretch (30 seconds)</td>
</tr>
<tr>
<td></td>
<td>Hamstrings stretch (30 seconds)</td>
</tr>
<tr>
<td></td>
<td>Calf stretch (30 seconds)</td>
</tr>
<tr>
<td></td>
<td>Hip adductor stretch (30 seconds)</td>
</tr>
<tr>
<td>Joint reaction check † (for current treatment)</td>
<td>Knee pain rating on 0-10 VAS</td>
</tr>
<tr>
<td></td>
<td>Report of muscle soreness and fatigue</td>
</tr>
<tr>
<td></td>
<td>Stroke test for joint effusion</td>
</tr>
</tbody>
</table>

* If knee pain was >2 levels higher than previous treatment, treatment was delayed and the next treatment did not progress in repetition or intensity. If muscle soreness did not relieve during warm-up and visually compromised landing technique, treatment was delayed. If the stroke test graded at or above a 2+ effusion, treatment was delayed and the next treatment did not progress in repetition or intensity.

† If knee pain increased >2 levels during treatment, the next treatment did not progress in repetition or intensity. Muscle soreness and fatigue was noted for comparison to the next pre-treatment check. If the stroke test graded >1 level above the pre-treatment grade, the next treatment did not progress in repetition or intensity.

Figure 3. Kinematic and kinetic measures over training and retention periods.
*VGRF, vertical ground reaction force.
†Mid-training testing occurred at week 4 of training. Post-training testing occurred after full 8 week training period. Retention testing occurred after 8 weeks without training or contact with the investigators.
ies by less than 10% through the 3-D movement of jumping up to 1.5 m.61 As such, the subject was able to perform high volume, sport-specific, jump landing training with decreased impact loads.61

The initial training was begun at a BWS level of 30%, wherein a near-constant vertical force equal to 30% of the subject's body weight was exerted at the center of mass. Previous work determined that between 20% and 30% BWS, VGRF decreased to levels approximately those of distance running without intrinsically changing lower extremity kinematics or relative joint kinetics.61 The level of BWS was decreased every two weeks, from 30% to 20% to 10%, per tolerance to activity. The final two weeks of training were performed without BWS. Training volume was tracked via contacts, defined as the number of times the involved leg hit the ground or generated a directional change as in cutting.

The number of contacts listed is the actual number of contacts performed by the subject during that session.

Table 3. Jump training treatment progression

<table>
<thead>
<tr>
<th>Week</th>
<th>BWS*</th>
<th>Contacts by Session†</th>
<th>Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30%</td>
<td>235 220</td>
<td>Vertical jumps, lateral jumps, broad jumps, spinning jumps, split jumps</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>241 270</td>
<td>Vertical hops, lateral hops, broad hops</td>
</tr>
<tr>
<td>3</td>
<td>20%</td>
<td>290 235</td>
<td>Above + Triple broad hops, box hops, bounding</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>306 310</td>
<td>Above + Combination jumps, Lateral cutting</td>
</tr>
<tr>
<td>5</td>
<td>10%</td>
<td>275 210</td>
<td>Above +</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>266 305</td>
<td>Combination jumps, Lateral cutting</td>
</tr>
<tr>
<td>7</td>
<td>0%</td>
<td>184 180</td>
<td>Above + Lateral box hops, agility drills</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>180 180</td>
<td>Above +</td>
</tr>
</tbody>
</table>

Note: This progression is adapted from multiple current neuromuscular training protocols for injury prevention. Twice-weekly sessions were separated by at least 48 hours. Progression to a lower body weight support level was determined by tolerance as described in Table 2.

*Body weight support, or delivered vertical force expressed as the percentage of body weight.
†Contact is defined as an instance of landing or changing direction on the surgical leg, eg. landing a hop, landing a jump, or cutting/stepping on surgical side. The number of contacts listed is the actual number of contacts performed by the subject during that session.

Figure 4. Illustration of body weight support system with harness.

*A, 15 m elastic tubes stretched over approximately 76 m around pulleys, redirected upward toward final pulleys. B, final elastic element to which appropriate tubes (A) may be attached. C, final conjoined pulleys. D, 2.44 m. tensioned steel rod upon which top pulley of (C) can roll. E, hollow core aluminum yoke. F, free-sliding webbing. G, 3mm neoprene shorts customized to allow movement without sliding.
ing, even with 30% BWS, she required extensive cueing to perform each task correctly. She also required more rest between sets in the first two weeks.

All other training parameters progressed over time as well. Feedback progressed from immediate visual, verbal, and tactile specific knowledge of results, to delayed verbalization of perceived performance. Cueing was geared toward positive reward throughout training, to reinforce desired behaviors (increased knee flexion, soft landing, upright posture)\(^{36,62}\) rather than punishing undesired behaviors (straight knee, stiff landing, bending at the waist). The subject was cued primarily with an external attentional focus (eg, “try to sit down in a chair during landing”), with an internal focus as needed but not preferred (eg, “land with your knees bent”).\(^{63,64}\)

Practice patterning progressed from blocked practice of each skill (vertical, lateral, sagittal, rotational jumping, and vertical, lateral, sagittal hopping) to serial practice and then random practice over time. Sport specific activities were introduced in week five and continued to progress through week eight, emphasizing dual task performance. For example, initially the subject performed jumps while holding a basketball. She progressed to catching and throwing the ball during landing, and then to dribbling during cutting and hopping, as well as performing a layup and landing appropriately.

**Outcome**

The subject underwent re-testing mid-training, post-training, and again after eight weeks without supervised training for retention testing (Figure 1). All parts of the initial examination were performed at re-testing, including administration of the IKDC and ACL-RSI, effusion testing, knee flexor and extensor strength testing, and biomechanical analysis of the single leg landing task.

The subject's subjective functional level as measured by the IKDC improved throughout training to 95% (Figure 2). A change score of more than 20 points has a specificity of 0.84 for perceived improvement.\(^{65}\) Since the change in the subject's IKDC score was 28 points, it is likely that she considered her condition improved. Her confidence in her knee's performance as measured by the ACL-RSI increased.
to 84% (Figure 2). Muller et al. found that people that returned to sport had an average ACL-RSI score of 76.8%. She maintained her increased level of function and improved psychological readiness for sport over the two-month retention period. Six months following the conclusion of BWS training, the subject reported that she had progressed to running over six miles without knee pain. At the end of the training period, she reported that she had been playing basketball without consideration of her knee.

The subject's strength symmetry improved slightly throughout the training period. Further improvements in strength symmetry were made during the two-month retention period; as at the retention testing session, she demonstrated equal strength compared with the nonsurgical side (Table 2). She presented without effusion at all follow-up testing sessions, and her PROM remained symmetrical. Her VGRF in landing decreased by 0.5 BW through the training and retention periods (Figure 3). Her peak knee flexion in landing increased by 31° within the first four weeks, then maintained at the same approximate level of peak flexion. Peak hip flexion also increased through training, and continued to increase over the retention period. Ankle dorsiflexion during landing remained approximately the same with training.

DISCUSSION

In this case report, BWS was used to modify an evidence-based jump training protocol to mitigate the inherently high intensity of jump training, allowing the subject to both increase training volume and target movement deficits in accordance with motor learning principles. Additionally, BWS decreased the perceived threat of injury with landing, thereby decreasing the likelihood of inducing subject apprehension. The current findings demonstrate that successful retraining of athletic tasks is possible in a subject with a history of ACL reconstruction and knee dysfunction. In particular, high volume training with BWS improved subjective outcomes, strength symmetry, and mechanical performance. Retention of these improvements after 8 weeks without training suggests that the new landing strategy had become a habitual pattern.

Chmielewski et al. have documented high fear of movement (or kinesiophobia) in people who have injured their ACL and undergone ACL reconstruction. Recent reviews by Ardern et al. have shown that psychological factors such as fear of movement and lack of confidence in the surgical knee play large roles in whether an athlete returns to their original level of activity after ACL reconstruction. However, no previous studies have demonstrated the ability to decrease post-surgical fear and increase confidence with physical training. This subject's gains in confidence and function with gradually increasing exposure to plyometric activity are consistent with those of graded exposure for psychologically driven activity limitation.

Following ACL reconstruction, many patients are released to sport based solely on the elapsed time since surgery. However, the intensity of the fear stimulus in returning to play may be psychologically traumatic. Repeated exposure to the high intensity stimulus may not be enough to counteract fear behaviors. The current subject had undergone a six-month period of rehabilitation following her ACL reconstruction seven years previously, and had returned to playing recreational basketball. Regardless, she was unable to regain functional mechanics and confidence in her knee. However, by gradually performing sport-specific activities in a safe environment, she was able to increase in confidence and function simultaneously. Her success demonstrates that interventions for motor skill re-training can be effective, regardless of the time since surgery.

As expected, the subject increased peak knee flexion and decreased peak VGRF during landing, and continued to improve in these measures over the entire training period. She demonstrated relative retention of her improvement in mechanics after eight weeks without training or contact with the investigators. Her strength symmetry also improved, which may have contributed to her mechanical improvements. Recent evidence has shown an effect of plyometric training on maximal volitional strength. However, Herman et al. found no significant differences in kinematic and kinetic variables during a stop jump task before and after a nine-week strengthening program. Therefore, rather than strength gains affecting habitual mechanics, the opposite effect is posited. As the subject's mechanics improved, her strength increased. Indeed, her continued increase in...
strength over the retention period without any training intervention further supports the hypothesis that habitual changes in mechanics led to strength gains.

Further contribution to her mechanical improvements may have come from healing of the subject's reported bone bruise, which had been demonstrated by MRI two months prior to her initial examination. The treating therapist was unable to obtain an imaging report to differentiate between subperiosteal hematoma or bone marrow edema. However, the time from the subject reported MRI to her laboratory examination was 7.5 months, during which time either problem would be likely to heal. At the time of laboratory examination, her mechanics in single leg landing remained demonstrably poor. Improvements in her mechanics in the next to months are most likely due to intervention, rather than healing of the bone bruise. The presence of a bone bruise does suggest a chronically insufficient use of the muscular shock absorbers and inappropriate impact force transmission and trauma to bony structures. The subject had previously been unable to modify her movement patterns without direct intervention into her mechanical behaviors, in keeping with evidence demonstrating a high risk for poor long-term outcomes following ACL reconstruction.7-10,12,20 The current case report demonstrates that chronically dysfunctional movement patterns can be changed through direct intervention in the form of task-specific training, even with extensive time since the original injury and rehabilitation.

Prior efforts to mitigate loading during sporting tasks have utilized three basic methods: aquatic therapy, plyometric leg press, and treadmill mounted systems such as the AlterG® (AlterG,Inc, Fremont, CA).44,45,47,70 Indeed, the subject in this case study was initially treated via a plyometric leg press (the Total Gym®) to avoid excessive compression due to her verbal report of a bone bruise. All of these methods suffer from a lack of specificity to task training. The aquatic environment does support the center of mass and provides effective mitigation of load according to the level of body submersion. However, speeds of body and limb movement differ substantially from standard exercise due to hydraulic and drag forces, which can also create abnormal shear torques through joints due to turbulence and pressure gradients.47 Additionally, while jump landing is primarily an eccentric task, the aquatic environment allows nearly exclusive concentric activity.47 Alternatively, a plyometric leg press can allow patients to practice jumping or hopping in place. While this does, again, reduce the amount of compression load through the limb, gravitational forces continue to be felt by the body. During a jump on a plyometric leg press positioned at 45 degrees or parallel to the ground (as with a Pilates Reformer), for example, a person must utilize the hip flexors to maintain the leg in a position for landing. Again, specificity is lost. These applications are also confined to a small, solid landing platform, disallowing any sport specificity. The BWS system utilized in this case allows near total specificity of movement as well as support during cutting, pivoting, and other sport specific tasks.

While this case report focused on a young athlete with chronic deficits in absorption of VGRFs in landing, BWS may be useful at earlier times in the healing process and in the treatment of other functional deficits in other populations. For example, BWS may allow early and intensive retraining of landing mechanics following ACL reconstruction prior to return to sport. Athletes returning to closed-chain activity following cartilage or meniscal repair may also benefit from a more specific training environment. Performance of a full squat or sit to stand involves complex weight shifting and balance along with force production. Performance of a full squat in an aquatic environment changes the amount of support offered by the water, and a leg press machine does not challenge the balance component of the squat task. Stair climbing and descent frequently remain problematic for people with total knee arthroplasty,71 including many older athletes. It is difficult to decrease the intensity of the activity without decreasing the height of the stair and thereby reducing task specificity.

The current case report also provides an example of the relative importance of volume and intensity in retraining complex movement patterns. As when retraining gait patterns following neurological insult,42,43 high training volume may be necessary to attain appropriate neuromuscular adaptation. In rats with spinal cord transection, 1000 steps per training session improved stepping quality more than 100
steps per session. The degree to which the training intensity must be specific to single limb jumping and landing is unknown and should be explored further. The training protocol as developed accounted for specificity of training intensity by gradually weaning the subject from BWS, but it is unknown whether she would have been able to make equivalent changes in her movement patterns through high-intensity training with the requisite lower training volumes.

The outcomes of this case study are not generalizable to other patients due to the nature of the single subject design. Further studies are needed to elucidate the differences in outcomes between high-intensity/low-repetition and high-repetition/low-intensity training paradigms in larger samples. Additionally, the measurement and treatment methods described may not be available in a typical outpatient physical therapy clinic. The eight-camera motion analysis system utilized here is able to capture and visualize kinetic outcomes, allowing improved identification of specific functional impairments. While kinetic analysis is generally unavailable in most clinics, video analysis may provide kinematic information that is useful. Further, though the space requirements and expense of a seated dynamometer may be prohibitive to its clinical use, handheld dynamometry may allow improved testing of strength. Tests and measures adequately sensitive to the specific patient population should be more consistently used in clinic. The BWS system is also not currently available for widespread use due to its custom design. However, the components of the BWS system are inexpensive and could be installed in a gym space given the potential for safe ceiling suspension.

CONCLUSIONS

In sum, a low-intensity, high-volume training intervention using BWS during plyometric training was able to generate positive changes in both mechanical and psychological impairments in a single subject with chronic dysfunction following ACL reconstruction. Further research into the mechanical, neuromuscular, psychological, and functional changes possible with plyometric training is needed, particularly in a population with poorer-than-expected long-term outcomes.

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ABSTRACT

Background and Purpose: This case report describes a physical therapist's use of diagnostic ultrasound imaging in the decision making process used to refer a patient to a physician for a suspected fibular stress fracture. The purpose of this case report is to 1) describe the history, subjective examination, and objective examination findings of a fibular stress fracture, 2) describe the ultrasound findings associated with a fibular stress fracture, and 3) describe the decision making process of a physical therapist in the decision to refer the patient to a medical physician for further work-up.

Case Description: A 52-year-old female recreational runner with a recent increase in running intensity self-referred to a physical therapist with a 19-day history of lateral lower leg pain. Examination revealed relatively normal ankle range of motion, mild weakness of ankle invertors and evvertors, no increase in pain with resisted muscle tests of the ankle, and tenderness to palpation over the fibularis brevis muscle and distal fibula. Diagnostic ultrasound examination of the fibularis muscles revealed cortical irregularity of the distal third of the fibula in the location of tenderness.

Outcomes: The physical therapist used the abnormal ultrasound findings, running history, symptoms, and physical examination for differential diagnosis, and decided to refer the patient to a physician for further examination. Radiographs revealed a fibular stress fracture. Follow-up ultrasound imaging demonstrated a mixed hypoechoic-hyperechoic appearance of the fibular cortex typical of healing fracture and the presence of bony callus.

Discussion: Diagnostic ultrasound imaging is increasingly being used by physical therapists to guide rehabilitation. Ultrasound imaging of musculotendinous structures may display adjacent bone. Physical therapists should be knowledgeable of normal and abnormal bony ultrasound imaging findings. Abnormal ultrasound findings may be one sign indicating the need to refer a patient for consultation by a physician.

Key Words: Differential diagnosis, musculoskeletal ultrasound, running, stress fracture
BACKGROUND AND PURPOSE
Stress fractures are common injuries in runners, athletes, and military recruits due to repeated mechanical loading experienced during activities such as running and marching.1-6 Excessive repetitive sub-maximal loading of normal bone without sufficient rest time results in greater osteoclastic than osteoblastic activity of the loaded bone.9,10 This excessive stress on normal bone leads to the development of microfractures, which is known as a stress reaction.9 If repeated submaximal loading continues without sufficient rest, the bone stress reaction may progress to a stress fracture, a fracture of the bone cortex.9,10 The reported incidence of stress fractures in athletes varies according to sport; however, track and field athletes have been reported to have the highest incidence rates of lower extremity (LE) stress fractures.11 Incidence of LE stress fractures among competitive track and field athletes may be as high as 20%.11,12 Incidence of LE stress fractures among recreational and competitive runners was reported to be 8.3% in males and 13.2% in females.13 The bones with the greatest incidence of stress fractures include the tibia, metatarsal, fibula, tarsal, femur, and pubic bones.2,3,7,10,11,14,15 The incidence of fibular stress fractures in athletes and military recruits is reported to range from 3.5% - 29.6%, depending on the population.2,4,7,10,11,14,16 In a recent literature review, Kahanov and colleagues16 reported the proportion of fibular stress fractures among runners to be 7% - 12% of all stress fractures; however, the proportion may be as high as 33% and 20% of stress fractures in female and male distance runners, respectively.11

Risk factors for stress fractures can be classified as extrinsic or intrinsic.17 Extrinsic risk factors are causes that exist external to the individual affecting his or her risk of developing a condition, e.g., participation in activities or environmental features.17 Intrinsic risk factors are features that exist within the individual that impact his or her likelihood of contracting a condition, e.g., gender or biomechanics.17 Reported extrinsic risk factors for stress fractures include participation in running sports, military recruits’ participation in basic training, increased training intensity (speed or duration/number of training sessions), and participation in recreational running more than 25 miles per week.1,17 Intrinsic risk factors for stress fractures are reported to include female gender, amenorrhea, reduced caloric intake, reduced physical fitness, decreased bone mass, and previous history of stress fracture.1,17-19 In a recent meta-analysis, Wright and colleagues18 reported that the two strongest risk factors for a LE stress fracture in runners are a history of a stress fracture (odds ratio [OR] 4.99; 95% confidence interval [CI] 2.91 to 8.56; p<0.001) and female gender (OR 2.31; 95% CI 1.24 to 4.29; p = 0.008).

Diagnosis of stress fractures requires a careful review of an individual’s activity including current and past exercise regimens.8 The history may reveal a recent change in exercise/training such as increased intensity or alteration in terrain.1,9 There is a high incidence of recurrence of stress fractures,18,20,21 thus, a history of previous musculoskeletal injuries should be explored.1,22 Pain may be constant or intermittent, depending on the severity of the fracture.1 Physical examination may reveal point tenderness on bones which are accessible to palpation.3,9 Active and passive joint movement may be painful if the fracture is close to a joint.3 Resistive muscle tests may be painful if the tested muscle is attached to the portion of bone with the stress fracture or if resistance causes movement of the fracture site.3 Soft tissue swelling and warmth may be present.9,19 However, tenderness to palpation, appreciable swelling, and palpable warmth may not be apparent in bones with extensive overlying soft tissue or for stress fractures that are less severe.3,15 Stress fractures in LE bones cause pain in stressful weight-bearing activities such as running.2,15 More severe LE stress fractures may provoke pain during less stressful weight-bearing, for example during walking.1,15,19 Stress fractures of the fibula are most common in its distal third and cause pain in the lateral distal third of the lower leg.2,15 Additional pathologies that may cause pain in this location include fibularis muscle strain or tendinopathy (particularly fibularis brevis) and lateral ankle ligament sprain.1

Ultrasound imaging (USI) has been used to examine musculoskeletal tissues,23-25 including diagnosis of fractures.26-29 Behrens and colleagues2 suggested that USI could be useful to diagnose stress fractures since it is non-invasive and relatively easy to perform. The sensitivity and specificity of USI for diagnosis of
early metatarsal stress fractures in persons with normal radiographs was reported to be 83% and 76%, respectively.\textsuperscript{30} Physical therapists (PTs) currently use USI to examine muscle, tendon, and other soft tissues to determine optimal rehabilitation strategies.\textsuperscript{24, 25, 31} Since USI may reveal bony changes consistent with fractures, PTs should be knowledgeable in USI findings for stress fractures. If present, these examination results may be signs used by the clinician in the decision to refer a patient to a medical physician. The purpose of this case report is to 1) describe the history, subjective examination, and objective examination findings of a fibular stress fracture, 2) describe the USI findings associated with a fibular stress fracture, and 3) describe the decision making process of a PT in the decision to refer the patient to a medical physician for further work-up.

**CASE DESCRIPTION: HISTORY AND SYSTEMS REVIEW**

The subject was a 52-year-old female who participated in a "couch-to-5K" running training program. She self-referred to a PT with a chief complaint of constant right lateral ankle pain that prevented her from participating in recreational running. The subject reported that she first felt mild pain towards the end of a 20-minute run 19 days prior. The pain did not prevent her from finishing the run, was initially mild in intensity, and abated with completion of the run. But symptoms returned and became severe following her participation in a 5 kilometer (5K) run nine days prior to her physical therapy examination. She reported that the pain was severe and she was not able to tolerate normal weight-bearing on the right LE during running. However, she continued to run and completed the 5K despite the pain. Although the pain had decreased in intensity since the 5K, the subject reported that she was concerned because it was still constant despite cessation of running.

The subject's chief complaint at the time of initial examination was constant right LE pain, localized posterior to the distal third of the fibula. Numeric pain rating was reported to be 2-8 on a verbal scale of 0-10 (10 = worst pain). The pain was worsened by weight-bearing and palpation; pain was relieved by remaining non-weight-bearing. The subject's goals for physical therapy were to be able to return to running for fitness.

The subject's medical history was unremarkable related to LE injury. Prior to participation in the couch-to-5K program, she reported exercising at a fitness center two to three times per week including weight training and cardiopulmonary activities (elliptical or treadmill running). This included treadmill walk-run interval training for 20-30 minutes at approximately 3.0 - 5.0 miles/hour for distances of 1.5 – 2.5 miles. The subject reported that she tried to alternate weeks of treadmill training and elliptical training for 20 – 30 minutes per session. Her weight training included use of exercise machines for LE and lower back strengthening, free weights for upper extremity resistance exercise, and planks and therapeutic exercise ball exercises for abdominal and back exercise. She reported no previous injuries from running or exercising. Medications included only a daily multivitamin.

**CLINICAL IMPRESSION #1**

The subject's primary problem was an inability to run and difficulty with full weight-bearing on the right LE during ambulation due to moderately severe lateral lower leg/ankle pain. Given the location of symptoms and running as the mechanism of injury, the differential diagnosis list included fibularis muscle strain/tendinopathy and fibular stress fracture. The plan for the examination included a focused exam of the right LE including the selective tissue tension tests, palpation, and USI examination of the musculotendinous tissues. The PT was an experienced clinical researcher with five years of experience using USI for examination of degenerative and traumatic conditions of the Achilles tendon, gastroc-soleus muscle group, plantar fascia, and other musculotendinous structures of the LE.

**EXAMINATION**

Physical examination began by observing the subject's gait while ambulating to the examination room. She ambulated without an assistive device with decreased stance time on the right LE, decreased left step length, a reduced heel rise at right terminal stance, and slow gait speed. Observation revealed a mild hallux abductovalgus deformity on the right foot. Non-pitting edema at the right lateral distal lower leg and proximal lateral foot was present along with mild warmth to palpation. Right ankle active
and passive motion did not alter symptoms and were nearly equal to the left ankle (plantarflexion, dorsiflexion, inversion, and eversion). Resisted tests of right ankle inversion and eversion were painless and 4+/5 strength on manual muscle testing, compared to 5/5 for the left LE. Sensation was intact to light touch in both distal LE. There was tenderness to palpation over the right fibularis brevis muscle posterior to the fibula and on the fibula approximately 6 cm proximal to the inferior border of the lateral malleolus. A firm enlargement over the fibula was palpable at the location of tenderness.

The PT performed an examination of the fibularis brevis muscle in the area of tenderness with comparison to the contralateral fibularis brevis muscle in order to determine if changes in muscle architecture were present. Longitudinal USI images of the distal fibulae and surrounding tissues were taken with a LOGIQ™ e USI system with a 7.5 MHz, 38 millimeter linear-array probe (GE Healthcare, Wauwatosa, WI, USA). The USI settings were B mode, 10 MHz, depth 3.5 cm, image width 3.84 cm. Images were captured over the area of tenderness to palpation of the right distal fibula, approximately 4 cm – 8 cm superior to the inferior border of the lateral malleolus. This revealed an alteration of the normal contour of the right distal fibula at the location of tenderness (Figure 1). A 1.90 cm long hypoechoic area was visible overlying the normal hyperechoic surface of the bony cortex.

**CLINICAL IMPRESSION #2**

The initial impression of severe strain of the fibularis brevis muscle was ruled out by the lack of alteration of symptoms by active ankle motion, the strong, painless result from resisted tests of the ankle evertors, and the apparently normal results for USI assessment of the fibularis brevis musculotendinous unit. The findings of point tenderness of the distal fibula, warmth, edema, constant pain, increased pain with weight-bearing, history of recently increased duration and frequency of running activity, and apparent unusual contour of the fibula on USI examination made the PT suspect a possible fibular stress fracture. The PT instructed the subject to contact a medical physician for further work-up. Use of crutches for ambulation non-weight-bearing on the right LE was recommended; however, the subject declined. She reported that she had a straight cane and that she would use that to decrease weight-bearing on the right LE. It was also recommended that she minimize ambulation and refrain from running until she was examined by a medical physician.
The subject’s examination by a physician was delayed due to a previously planned trip. Due to persistent intermittent pain during ambulation, the subject made an appointment with a podiatrist following her return. Radiographs taken four weeks after her physical therapy examination revealed a healing stress fracture of the distal fibula (Figure 2). Since symptoms and ambulation were improving, the podiatrist recommended continued conservative management. This consisted of refraining from running until symptoms were completely abated, and then gradual resumption. The subject contacted the PT to relay the results of her examination by the podiatrist. Repeat USI revealed enlargement of the area of visible cortical irregularity (Figure 3). Eight weeks following the injury, the subject reported being pain-free during ambulation. She was able to return to running on the treadmill and on an indoor cushioned track six months following the initial injury.

**DISCUSSION**

This case report has shown how the results of portable USI were useful in the decision making process to refer a 52-year-old female recreational runner to a physician for a suspected fibular stress fracture. Physical therapists have been reported to use therapeutic ultrasound to screen for the presence of stress fractures. Although it is currently not common...
practice for PTs to use USI to diagnose fractures, the clinical use of USI by PTs to make qualitative assessments of muscle architecture in rehabilitation is growing. Physical therapists have been reported to use USI to assess the trunk muscles in persons with low back pain, the infraspinatus muscle in persons with shoulder impingement syndrome, the scapular muscles in persons with lateral epicondylalgia, and the levator ani muscles in persons with pelvic floor dysfunction. Ultrasound imaging provides visualization of muscle tissue and is able to provide dynamic images of muscle during contraction and activity. Since abnormal findings of bony structures may be visible with USI, PTs should be knowledgeable of normal versus abnormal bony architecture to aid in clinical decision making.

The fibular stress fracture developed by this recreational runner was initially not suspected as the cause of her symptoms due to her relatively small amount of running. Although the subject did recently increase her running mileage and frequency, this was done over a period of nine weeks. Her reported weekly mileage was much less than 25 miles per week, the amount reported to be an extrinsic risk factor for stress fractures. She reported exercising several times per week prior to beginning the “couch-to-5K” running training program. The training program utilized interval training, which was found to be protective of running related injuries in a prospective study of recreational runners. Although a 10% rule for a graded progression of exercise volume is commonly recommended, there is insufficient evidence to the beneficial effects of such a program. But in light of the diagnosis, it is apparent that several risk factors for a stress fracture were present including female gender; altered training regimen for both amount and surface of running terrain, and a possible biomechanical risk factor related to the foot structure of the patient’s right foot. It is possible that additional factors may have contributed to development of the stress fracture including hormonal influences, older age, nutritional deficiencies, reduced physical fitness, reduced bone mass, and being a novice runner. Lower estrogen levels in amenorrheic female athletes was reported to interfere with the ability of bone to adapt to increased mechanical loading due to disruption of the osteoclast/osteoblast activity. It may be that perimenopausal female recreational athletes are at increased risk of stress fractures due to lower estrogen levels, amenorrhea, and reduced caloric intake for weight loss. A recent meta-analysis found that novice runners were at greater risk for running-related injuries versus regular recreational runners.

Although fibular stress fractures have been reported, this is the first case reporting the use of USI findings of a distal fibular stress fracture. A systematic review concluded that USI was accurate for diagnosis of long bone fractures in the emergency department setting. Ultrasound imaging has also been used at the hospital bedside for diagnosis of pediatric long bone fractures. Metatarsal and tibial stress fracture cases diagnosed with USI have been reported. A case series of primarily metatarsal stress fractures included one case of an adolescent male with a proximal fibular stress fracture. Importantly, comparison of USI findings to MRI for detection of early metatarsal stress fractures in persons with negative radiographs demonstrated sensitivity of 83%, specificity of 76%, a positive likelihood ratio of 3.45, and a negative likelihood ratio of 0.22. A recent systematic review of studies examining diagnostic imaging for LE stress fractures reported that USI has higher sensitivity than specificity. The authors recommended that the best use may be to rule out a LE stress fracture when USI findings are negative; magnetic resonance imaging is the current recommended “gold standard” to diagnose a LE stress fracture.

The USI image cortical irregularity overlying the stress fracture in this case is similar to the reported findings of earlier case reports involving the tibia and the metatarsals. This case has a few additional findings of interest, notably visible periosteal elevation demonstrated by the hypoechoic area overlying the hyperechoic area of the bony cortex and hypoechoic areas in the soft tissues, which are fluid from inflammation. Ultrasound imaging signs reported to indicate a stress fracture include periosteal elevation, fluid in the soft tissue surrounding the bone, increased acoustic shadowing posterior to the stress fracture, and increased vascularization due to healing (visible on Doppler color USI). The follow-up USI illustrates posterior acoustic shadowing and the mixed hypoechoic-hyperechoic character of
healing bone callus, visible on the subject’s radiograph taken a few days prior. It may be that the tender, firm enlargement palpated by the PT over the subject’s fibula was a healing bone callus at the site of the stress fracture. Physical therapists using gray-scale USI to assess muscle morphology should be alert for signs of cortical irregularity, increased posterior shadowing, increased vascularization, and hypoechoic areas overlaying normal hyperechoic bone as possible signs of occult stress fractures. If color Doppler USI is used, the PT should be alert for signs of increased vascularization as an early indication of bone healing in a suspected stress fracture.

Ultrasound imaging is being used more frequently for assessment of muscle morphology and motor control in rehabilitation and for clinical diagnosis. Reported benefits to USI as an imaging modality are: it does not expose a patient to radiation, it is inexpensive, it may be portable, it is becoming readily available, and it is easy to perform. Physical therapists are using USI to assess musculoskeletal structures for clinical decision making in designing the rehabilitation program. In response to the growing clinical use of USI by PTs, recommendations regarding its use by PTs have been published.

This case report suggests that USI may be useful to assist clinicians with clinical decision making as a screening tool for the need to refer. Although fibular stress fractures are considered low risk injuries since they are not likely to progress to complete fracture or to develop nonunion or delayed union, they still may result in significant morbidity if not managed properly. Importantly, USI may be useful for examination of other bones in which stress fractures are considered high risk, such as the femur. If PTs have access to this diagnostic imaging device, the images collected may be useful to send with a patient when referring him/her to a medical physician. This is only a case report; however, so firm conclusions cannot be made. Future research is needed to evaluate the sensitivity and specificity of USI for the detection of early stress fractures.

CONCLUSIONS
This case report has shown the use of USI results in the decision making process of a PT to refer a recreational female runner for a suspected fibular stress fracture. The abnormal bony findings of the right fibula, coupled with the patient history, age, gender, constant pain, and physical examination findings indicated that referral to a medical physician was necessary. This case illustrates the importance of a PT being familiar with bone findings on USI since they may be signs of an occult stress fracture. This may be particularly important for those PTs examining patients who are self-referred or for patients who have only been examined with plain radiography.

REFERENCES


ABSTRACT

**Background and Purpose:** Participation in baseball is prevalent across all age groups. Baseball injuries are common and can impact a player's ability to participate. An injury to any region can influence the player's ability to swing the bat. As a part of the athlete's rehabilitation, a sports-specific program should be implemented re-introducing the hitting cycle that addresses proper biomechanics as well as providing a progressive atmosphere to return to hitting. Although there are several return to throwing progression programs in the literature, to the author's knowledge no published hitting progression programs exist. Thus, the purpose of this clinical commentary is to propose a progressive return to hitting program that emphasizes proper mechanics for ballplayers who have sustained an injury.

**Description of Topic:** This return to hitting program describes in detail the phases of the baseball hitting cycle. Proper biomechanical information is provided on each phase that can be used to assist the clinician in injury prevention. This article gives the healthcare professional guidance for assessment for appropriate readiness for return to sport using impairment measures, patient-report measures, and physical performance measures. The purpose of this hitting progression is to provide a safe, gradual increase in hitting intensity by moving from a fixed position to soft toss and finally to increasing pitch velocity.

**Discussion:** This interval hitting program guides the clinician from when the patient is ready to begin hitting through a full return to sport. Use of appropriate hitting mechanics must be ensured during rehabilitation to avoid compensation. Similar to the return to throwing programs that exist, this interval hitting progression program can provide a framework to quantify progression and reduce the chance of re-injury from occurring during the return to sport phase of rehab.

**Keywords:** Baseball, hitting, injury progression

**Level of Evidence:** Level 5

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INTRODUCTION
Baseball has gained popularity over the years and participation continues to increase. Estimates have shown that 4.8 million children between the ages of 4-15 years old participate in some form of competitive or recreational baseball. This popularity does not stop at the youth level of play, rather it continues into higher levels as well. As many as 11.5 million athletes participate in the sport of baseball at the high school and club levels. Compared to other high school sports, baseball and softball were ranked second in popularity during the 2012-2013 school year. An estimated 27,262 athletes are involved in baseball amongst all divisions of collegiate play. At the professional level, 750 athletes participate in Major League Baseball while approximately 2,100 participate in minor league baseball each year.

As with any other sport, playing baseball can lead to injury. To ensure the athlete does not suffer another injury, the athlete should be slowly progressed back into sport. Interval sport programs are created to provide a progressive atmosphere in which the athlete can return to sport-related tasks in a safe manner. Although several return to throwing progression programs exist in the literature, to the author's knowledge no current hitting progression program is available in the published literature. Experts in the past have postulated such a program; however, further commentary and detail needs to be addressed. In addition to a progressive return to hitting program, an introduction of proper biomechanics related to the baseball swing that uses the entire kinetic chain must be addressed to reduce the onset of re-injury.

INJURIES IN BASEBALL
Between the years of 1994 to 2006, an estimated 1,596,000 children under the age of 18 were treated in United States emergency departments for baseball related injuries. Injuries that occur in baseball can involve the upper extremity, lower extremity, back, head/neck and the trunk. For college participants, of the reported injuries 58% were of the upper extremity, 27% involved the lower extremity, 15% involved the trunk or back, and 7% the head or neck. At the professional level, 47%-51% of injuries involved the upper extremity. At the high school level, 1.49 injuries occur per 10,000 athletic exposures, with an estimated 64,229 injuries occurring annually in the United States.

Risk of injury can also be influenced by position participation. Pitchers at the professional level, many of whom do not bat, missed more days of play related to upper extremity injuries, whereas catchers and positional players missed more days for lower extremity injuries. Younger players may find themselves not only pitching, but also playing additional positions. Risk of injury at this young age is rising as participants play on more teams during a single year and throw more during practices and games. The frequency at which medial elbow pain occurs in adolescent baseball players can be found to be between 4-49%. It is not atypical for a youth athlete to be called upon to play a position in the field, possibly pitch, and bat in a regular season of play. Due to the high axial trunk velocity that occurs during the baseball swing, injuries can occur at the lumbar spine and abdominal musculature as well. Ten percent of the injuries among Major League Baseball players occurred in the trunk, and of these, half occurred in the abdominal musculature. Other literature has shown that out of the reported 69 cases of symptomatic lumbar disc herniation, 58% of these injuries at the professional level were related to hitting. Even though throwing causes most injuries in the upper extremity, the high velocity produced by the shoulders during the baseball swing combined with repetition can cause injury. A syndrome known as batter's shoulder occurs due to continual exposure to the baseball swing producing posterior instability of the lead shoulder; but the incidence of this injury is comparatively low. Even though most baseball and softball injuries are not a direct result of hitting, there is not a segment in the body that does not play a significant role in the player's swing. Much of the clinicians thought process is using regional interdependence to restore proper throwing mechanics as well as a controlled return to throwing. What many clinicians forget is that those injured players will have to return to hitting as well.

To return injured athletes back to all aspects of baseball or softball, many will need attention paid to return to hitting. As part of their rehabilitation, an appropriate return to hitting progression must occur.
to ensure the athlete’s safety regarding re-injury and further injury prevention. To gain a full appreciation of this progression, one must first understand the biomechanics that occur during the hitting cycle. Thus, the purpose of this clinical commentary is to propose a progressive return to hitting program that emphasizes proper mechanics for ballplayers who have sustained an injury.

OVERVIEW OF HITTING MECHANICS

The mechanics of hitting have been broken into several phases: the preparatory phase, stance phase, stride phase, drive phase, bat acceleration phase and follow through phase.18 (Table 1) These combined phases produce the baseball swing, which assists in making contact with the baseball. This section will make reference to the baseball swing; however, these thoughts could translate into the swing used by a softball player as well. In order to understand the intricate nature of the hitting cycle, one must be a keen observer of each phase and how their successive order can play an influential role in producing the swing.

PREPARATORY PHASE

Prior to initiating the hitting cycle, the batter must assume a position that is optimal and individualized to meet the needs of their swing. There are many personalized differences in preference for the stance. The closed stance, where the hitter’s front foot is positioned closer to home plate than the back leg, is typically used by hitters who have a tendency to open their hips at an earlier moment. It is also often used for hitters who have difficulty attempting to swing at pitches placed further away from their body.19 Limitations to using this type of stance include the inability of the hitter to produce full rotation of the hips and axial spine, especially when pitches are thrown closer to the body.19 Another stance that is often used by batters is the open stance. This is where the front foot is placed further away from home plate than the back leg, which is often used by hitters who have a tendency to pull the ball or hit toward their field of preference.19 Other authors have argued that the square stance provides the most optimal position, where the feet are shoulder width apart and the toes are pointed toward home plate, because it gives the batter the ability to hit pitches that are placed within any area located around home plate.19 This stance also provides no compensatory movement or extra motion to rotate through the baseball swing making it more efficient.19

After the athlete has assumed this preparatory position, the initiation of the baseball swing can be further discussed in several stages. Each one of these stages is summarized in Table 1. Like any other high velocity movement, the art of hitting is considered a plyometric activity. A plyometric exercise is defined as a “…quick, powerful movement using a pre-stretch, or countermovement, that involves the stretch shortening cycle.” The purpose of plyometric exercise is to increase the power of subsequent movements by using both the natural elastic components of muscle and tendon and the stretch reflex.20 The loading period of the swing causes a countermovement which produces a quick eccen-

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<tr>
<td>Preparatory Phase</td>
<td>Occurs as the hitter assumes the proper position in the batter’s box. The actual swing has not started in this phase</td>
</tr>
<tr>
<td>Stance Phase</td>
<td>From weight shifting onto the back leg to the stride foot lift-off</td>
</tr>
<tr>
<td>Stride Phase</td>
<td>From stride foot lift-off to stride foot contact</td>
</tr>
<tr>
<td>Drive Phase</td>
<td>From stride-foot contact to maximal loading of the bat</td>
</tr>
<tr>
<td>Bat Acceleration Phase</td>
<td>From maximal loading of the bat to ball contact</td>
</tr>
<tr>
<td>Follow-Through Phase</td>
<td>From ball contact to completion of the baseball swing</td>
</tr>
</tbody>
</table>
tric stretch of the agonist muscles that produce the baseball swing. This period of loading must take place in order to aid with eliciting the stretch-shortening cycle.\textsuperscript{22} When considering the baseball swing this period of loading normally occurs from the start of the stance phase and is completed at the drive phase; an eccentric movement must take place to set-up or aid in initiation of the swing. This loading phase is often referred to as the coiling or trigger mechanism by the baseball community.\textsuperscript{23} The stored elastic energy is then released during the concentric contraction of the agonist muscles and transferred through the entire kinetic chain in a sequential order where different segments of the body are rotated.\textsuperscript{23} When a large base segment starts to slow down or decelerate the other segments that are left gain velocity from that base segment assuming its' momentum.\textsuperscript{23} The baseball swing acts in this manner with the lower extremities rotating first, followed by the trunk, then by the upper torso, then by the upper extremities, culminating the effort at ball contact. Further discussion of the hitting cycle will occur in the following sections.

**STANCE PHASE**

The initiation of the hitting cycle is first established at the start of the stance phase. The stance phase consists of the batter picking up their front leg and shifting their weight onto the back leg.\textsuperscript{24} (Figure 1) This phase is completed when the stride foot is lifted off of the ground.\textsuperscript{18} The process known as the loading period is initiated as soon as the stride foot is taken off of the ground. This mechanism is often referred to as the act of coiling because the hitter is moving different segments of the body away from the pitcher, which acts as the hitter's loading period.

**STRIDE PHASE**

The next phase of the hitting cycle is the stride phase. This phase takes place as the front leg advances toward the pitcher, linearly, and ends when the hitter's front leg makes contact with the ground.\textsuperscript{18} A vital role in performance is finding lower extremity balance or a state of equilibrium. The hitter must find a position that is balanced between his base of support and center of gravity. As the player picks up the front leg during the stance phase, the hitter's
base of support goes outside of their center of gravity, the ground reaction force of the back leg is thus increased. At this moment in time, the body will try to find a state of equilibrium by forcing itself in a linear motion forward, initiating the stride phase. Proper stride length can aid with increasing performance during the hitting cycle. The starting position and the stance chosen influence the outcome of the swing. The stride should be long enough to promote linear movement forward and to aid with force production. Timing is crucial when it comes to the baseball swing; a stride that is either too long or too short could potentially produce detrimental effects for the swing. A shorter stride length could cause early initiation of the swing and a longer stride could potentially produce delayed activation of hip rotation, either one potentially reducing outcomes in performance. These subtle compensations could cause injury during the swing by disrupting the sequential timing of other body segments. The average stride length for hitters is normally 3.8 times greater than hip width and the position of the stride foot should be placed 12 degrees closed and facing 67 degrees toward home plate. This closed position can be defined as the direction of the stride occurring toward home plate. This position is not to be confused with the preparatory phase prior to initiating the hitting cycle.

There are age-related differences that are apparent in youth versus adult hitters described by Escamilla et al.(Table 2). Adult hitters were found to have a longer stride phase time versus youth ballplayers, allowing for additional time spent during their loading period, which creates an increase in bat velocity. Youth ballplayers may produce a shorter stride length due to their lack of maturation, decreased muscular strength and shorter stature, when compared to adult players. This could possibly be a potential area that predisposes younger players to injury. An optimal stride length will also allow for the best angular rotation during acceleration. Youth hitters also have a tendency to flex their stride knee less and produce a knee extension force at a decreased velocity when compared to adult hitters; potentially leading to reduced kinetic energy transferred up the body and decreased bat velocity production. This could possibly cause another segment of the body to compensate and attempt to produce more force while approaching bat to ball contact ultimately leading to injury.

**DRIVE PHASE**

The next successive phase is the drive phase, which is considered from the point of foot contact into maximal bat lag or loading. The loading period that started in the initial stance phase continues through
the stride phase until the upper extremities achieve complete bat loading. As the stride foot lifts off the ground in the stance phase the arms will produce an approximate reverse rotation of 60 degrees in the transverse plane away from the pitcher, however when the stride foot makes contact with the ground the arms will continue to rotate in this reverse direction approximately an additional 12 degrees achieving maximal bat loading. If the hitter cannot produce the adequate amount of reverse rotation then this could be a potential area for injury. This could eminently produce an inability to obtain the full stretch-shortening cycle thus causing decreased force production and other segments of the body to work harder to create bat velocity. The hips achieve their maximum loading at stride foot contact. The delay in upper segmental rotation aids in the ability to produce maximal bat acceleration in the successive phases of hitting.

While the hitter assumes proper lower extremity positioning there is also an optimal placement of the upper extremities that must occur. Prior to initiating the baseball swing, the bat should be placed in a position that elicits the greatest mechanical advantage. Although many hitters start in different positions, when the drive phase is completed the bat should end in a position that adheres to a few principles: 1) The back elbow should have increased elbow flexion versus the front elbow, 2) The bat should be placed at a position of approximately 45 degrees in the frontal plane and the bat should bisect the batter’s helmet in half, 3) The back elbow should be down, 4) Both upper extremities should be positioned close to the hitter’s body, and 5) The proximal interphalangeal joints of the hand of both upper extremities should align on the handle of the bat.

**BAT ACCELERATION PHASE**

As the hitter moves into the next phase of the hitting cycle, an interaction must occur between linear movement and angular or rotational velocity. After the lead leg contacts the ground the body is in a closed kinetic chain. At this point the elastic energy gained from the loading period is used to produce segmental rotation in different parts of the body. The hips will turn first, followed by the trunk, gradually gaining angular velocity up the kinetic chain to produce contact between the bat and the baseball. The bat acceleration phase takes place from the point of maximal bat loading until the bat makes contact with the baseball. Once the stride foot/front foot has landed, the center of pressure that is created by the body is then outside of the center of mass (anterior to the body), it is at this moment that the hip segment starts to move toward the pitcher, which is often referred to as an uncoiling effect. (Figure 1) The rotational velocity created at the hips and lower portion of the trunk is axially transferred up the kinetic chain to the upper segment of the body. Near ball contact this upper segment continues to rotate, however rotation at the lower portion of trunk including the hips is minimal at this point. To produce effective bat velocity each segment must rotate in a sequential manner, if a higher segment reaches its peak velocity before its

---

**Table 3. The Loading Period: degrees of motion per body segment. The below data was collected from Welch et al**

<table>
<thead>
<tr>
<th>Body Segment</th>
<th>Stance Phase (degrees)</th>
<th>Maximal Loading during Stride &amp; Drive Phases (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip Rotation</td>
<td>11 - 25</td>
<td>28</td>
</tr>
<tr>
<td>Shoulder Rotation</td>
<td>16-44</td>
<td>52</td>
</tr>
<tr>
<td>Arm Rotation</td>
<td>45 - 75</td>
<td>58 - 86</td>
</tr>
</tbody>
</table>

The body has three segments that contribute to rotation: Hip segment is defined as a vector from the right to the left hip; Shoulder segment is defined as a vector from the right to the left shoulder and the arm segment is defined as a vector from the mid-shoulders to mid-wrists. The orientation of the trunk axis is defined in the transverse plane of motion where reverse rotation occurs in the opposite direction of bat-ball contact. For example: For a right-handed hitter: clockwise rotation.
lower previous segment then the hitter has lost the ability to efficiently transfer kinetic energy up the kinetic chain. 23

At ball contact, the hands should be placed out in front of the body with the elbows extended. Hitting coaches recommend keeping the hands above the barrel to optimize a direct path to the ball when approaching a contact position.19 At contact position, the high amount of rotation occurring in the trunk forces the stride leg to become a blocking mechanism to assist the body to decelerate the linear movement previously accomplished.23 For this blocking mechanism to occur, the stride leg has been found to be in a position of 15 degrees knee flexion and applies a total ground force of equal to 84 % of the hitter's body weight.23 Once the bat has made contact with the ball, the baseball swing continues as the hitter finishes their swing entering into the follow-through phase of the hitting cycle.

**FOLLOW-THROUGH PHASE**

In order to achieve optimal effort, full hip rotation toward the pitcher needs to take place. Fleisig et al18 have found that axial trunk acceleration once again increases as the hitter goes through the follow-through phase aiding in completion of full rotation.18 Many youth players are often times told to overly rotate or “squash the bug” with their back foot, however, this could potentially reduce the hitter's ability to shift their weight forward reducing the amount of hip rotation that needs to occur during the follow-through phase. Pointing the laces of the rear shoe toward the pitcher can aid in achieving this full rotation.19

The proper sequence of each of these phases helps with producing an efficient swing and from a rehabilitative standpoint can aid with observing biomechanical inadequacies. When it is time for the patient to introduce hitting, the rehabilitative specialist should observe these key areas of focus and implement them as needed. Three-dimensional motion analysis has previously been used to observe the hitting cycle and should be considered to look for subtle motion insufficiencies that cannot be observed naturally.18 Even collaboration with a qualified hitting coach may be beneficial. Prior to such considerations, each clinician should determine when it is safe for the patient to return to sports-related functional tasks.

**READINESS TO RETURN TO SPORT**

The purpose of this proposed interval hitting progression program is to gradually introduce the demands from hitting, in order to avoid re-injury. The overall goal of any progression program is to introduce progressive loads that focus on gradually increasing intensity and duration of effort.26 Prior to entering such a program the patient must meet certain criteria. Assessment measures must be used to determine if an athlete's current status is at the level needed to start hitting. Due to the high velocity of movement and the complex sequence of events that take place, hitting can be considered an activity that requires a higher level of function. Assessment of function can be broken down into three areas: impairment measures, patient-report measures, and physical performance measures.27 Each one of these areas contributes to the bigger picture of performance. To begin an interval progression program, such as the one proposed in this commentary, the athlete must be evaluated through all three of these areas.

Examination regarding the patient's concordant injury must show adequate range of motion to meet the demands of the hitting cycle, minimal to no pain, lacking tenderness to palpation, and adequate strength needed for the activity.6, 28, 29 To initiate a sports-related activity, it is recommended that the involved extremity should meet eighty percent of strength performance compared to the uninvolved extremity.30, 31 However, manual muscle testing has been found to be unreliable; thus, the use of handheld dynamometer or electromechanical dynamometers is recommended.32, 33 These impairment measures provide the initial framework or building blocks for progression into performance.

When considering which impairment measures are most beneficial to the baseball swing, the clinician must place emphasis on which muscle groups are most active and how many degrees of motion are required at each body segment during each phase of the hitting cycle. Previous electromyographical studies reveal that there is a certain sequence of muscle
activation that takes place.\textsuperscript{34} As previously mentioned rotation occurs at different areas of the body with the first being from the lower extremities then moving up the entire kinetic chain. For instance the hamstrings and gluteus maximus appear to be most active during the drive and bat acceleration phases.\textsuperscript{34} The quadriceps have also been found to be active in later stages of the hitting cycle signifying their importance as the stride's leg blocking mechanism.\textsuperscript{34} The abdominals, specifically the obliques, and erector spinae musculature play a crucial role activating at the start of foot contact to the end of the hitting cycle.\textsuperscript{34} Not only is adequate strength necessary to aid with reduction of re-injury, but range of motion also plays a significant role. A hitter must have adequate axial trunk rotation throughout their body and possess the proper lower and upper extremity motion to complete the baseball swing.\textsuperscript{18, 23} (Table 4) Proper knee, trunk and elbow motion is necessary as well to obtain optimal performance. (Table 4) Inadequate motion or strength at any of these body regions could cause compensation from another area of the body and could potentially lead to injury. Therefore, it is important to examine the athlete with an eye for these potential deficits in an athlete who would like to return to baseball.

Impairment measures alone cannot determine whether an athlete is ready to return to sport. Therefore, the clinician must also assess physical performance. Physical performance measures are considered tests that challenge a physical action that is necessary to complete a particular task.\textsuperscript{35} These performance measures are assessed in a standardized manner and are repeatable by the tester.\textsuperscript{35} These types of tests are typically used to assess limb symmetry and to determine a patient's current probability for sustaining an injury.\textsuperscript{36} To the author's knowledge there have not been any performance measures established specifically for return to hitting. But, a clinician may select a performance measure based on the injured body part and the objective of the test. Since weight shifting occurs on the stance and stride legs dynamic balance plays a significant role; therefore tests such as the Y-Balance test (YBT) can be useful.\textsuperscript{37} During the acceleration phase there is a significant amount of trunk or torso rotation that uses the entire kinetic chain. Previous research has used simulated medicine ball throwing for hip-torso-arm rotational power which has shown to be a useful measure.\textsuperscript{38, 39} The two tests that showed validity for torso rotational power were the whole body medicine ball throw, or otherwise known as the hitter’s throw, and the seated medicine ball toss.\textsuperscript{38, 39} A 1-kg medicine ball is used for these tests and the maximal distance the athlete can throw the ball using rotational forces is recorded.\textsuperscript{40} This data can be used as a physical performance measure to determine progress during rehabilitation or tolerance of the hitting motion. If a clinician chooses not to perform one or more functional performance tests, at the very least the patient should be able to swing a bat without pain or compensation prior to beginning the return to hitting program.

The final part of the functional assessment relies on the patient's self-perception of functional ability. Patient-reported outcome measures are used to give a subjective report regarding what the patient perceives they are able to do. These can be useful tools to

<table>
<thead>
<tr>
<th>Body Segment</th>
<th>Degrees of motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stance leg knee flexion</td>
<td>19-57</td>
</tr>
<tr>
<td>Stride leg knee flexion</td>
<td>6-55</td>
</tr>
<tr>
<td>Back elbow flexion</td>
<td>48-134</td>
</tr>
<tr>
<td>Front elbow flexion</td>
<td>29-97</td>
</tr>
<tr>
<td>Trunk extension (-)/flexion (+)</td>
<td>(-15) – (+27)</td>
</tr>
<tr>
<td>Trunk lateral flexion (-) away/ (+) towards pitcher</td>
<td>(-10) – (+25)</td>
</tr>
<tr>
<td>Maximal trunk rotation at ball contact</td>
<td>55</td>
</tr>
</tbody>
</table>

Each recorded value is along the X-axis; position from home plate to the pitching rubber; parallel to the batter's box. (+) is toward the pitching rubber and (-) value is toward home plate.
aid with determination if an athlete is mentally prepared to participate or if there is some apprehension to start a progression program. To the author's knowledge, no patient-report measure currently exists for hitting. However, other patient-report measures exist for particular injured body parts or for those experiencing kinesiophobia. Many patient-reported outcome measures can be found in the literature: Fear Avoidance Belief Questionnaire,41 The Tampa Scale of Kinesiophobia-II,42 Foot and Ankle Ability Measure,43 Hip Outcome Score,44 Lower Extremity Functional Scale,45 and Kerlan-Jobe Orthopaedic Clinic Shoulder & Elbow Score.46 The clinician should use valid and reliable measures that appropriately assess the patient's abilities or feelings based on their condition or site of injury. These patient-reported outcome measures can assess patient progress and help determine if the patient feels ready to begin the return to hitting program.

**THE INTERVAL HITTING PROGRESSION PROGRAM**

There is a vast array of individual strategies that can be used with the baseball swing; however, it is pertinent that proper mechanics be introduced to the patient in a rehabilitation setting. An alteration in hitting mechanics can produce an increased potential for injury, a single example would be changing the angle of the shoulders; therefore, appropriate mechanics can aid with the reduction of injury.17 Once proper mechanics are obtained, the clinician can then introduce the outlined interval hitting progression program.

The interval hitting progression program proposed in this commentary uses percentage of effort. (Appendix 1) It is important to keep in mind that estimation of percent effort can be perceived differently from one athlete to the next.47 Therefore, the rehabilitation specialist must understand the cognitive aspect of the athlete when describing effort.

The warm-ups found in Appendix 2 are used to simulate the actual hitting motion through exercise selection. Many baseball players use weighted bats prior to hitting in practice and during games; however, the selection of these devices have not been shown to improve bat velocity.48 The application of such a device should not be used as a warm-up tool. Increasing the resistance of the bat may prove to be provocative to the injury that the athlete is trying to overcome. Therefore, the use of such a device is discouraged. Exercises that focus on total body rotation through movement should be used instead.

The proposed protocol for hitting progression moves from hitting off of a tee, to soft toss, then finally to simulated hitting. The purpose behind this progression is to slowly introduce an environment that begins at a lower intensity by having the baseball first placed in a fixed position then progressing to the baseball in trajectory with soft toss then finally followed by an increase in velocity.

The chosen change in ball location established for Phase 2, soft toss, was used to simulate differences in placement of pitches that may occur while hitting in a game. Higuchi et al.49 proposed that a hitter may be able to visually pick up on the velocity and trajectory of the ball as soon it is released by the pitcher. If the hitter is able to pick up on different target positions, such as the height of the pitch, then there could be an increase in performance.49 Soft toss is considered an effective drill for most hitters and used by many baseball experts.19 This normally consists of the hitter's teammate or coach kneeling approximately thirty to thirty-five feet away from the hitter, facing the hitter at an angle of 45 degrees and tossing the ball in an underhand action. Some coaches prefer to kneel behind the hitter at a safe distance away to provide differences in ball location for outside or inside pitches, while others prefer to have the hitter angled away or toward their teammate/coach to simulate this change in ball location. Either way the hitter, as well as the person performing each toss, should familiarize themselves with their preferred technique prior to implementation.

Timing of sequential body segments plays a substantial role in the outcome of the swing. To elicit the stretch-shortening cycle a hitter must have the proper loading period that is appropriately timed to improve force production. With the randomization of how pitches are delivered during play, a hitter must practice under similar conditions in order to accommodate for an increase or decrease in pitch velocity. This interval hitting progression program captures this concept in Phase 3.
Progression within this program provides a physical stimulus designed to promote adaptation of healing tissue. This stimulus, like any other physical conditioning program, is often referred to as the overload principle. Muscular soreness can be a by-product of this change and it is often described as a muscle feeling stiff, tender and aching to touch or when applying movement. Eccentric-based exercise can produce the associated soreness which has previously been reported to last forty-eight hours. To avoid any additional injury, proper rest guidelines must be initiated. For progression in this program, the patient should follow the established soreness rules. These soreness rules have been adapted from previous literature to fit the needs of this specific progression program. These rules provide the patient the ability to modify progression according to the symptoms that they experience. If muscular or joint stiffness and or tenderness is present then the soreness rules should be observed. It is important to note that the sensation of soreness is different than the sensation of pain. If the patient is complaining of concordant pain experienced at the site of initial injury that lasts longer than the expected time frame for muscular soreness, the clinician should reevaluate the patient's symptoms and alter or postpone the return to hitting program. If no soreness is present then the patient is instructed to move onto the next step in the hitting progression program and this should occur on the next day of training. Each training day should have one day of rest in between steps to ensure proper recovery and adaptation to the stimulus of hitting. All other exercises, such as a home exercise program, should be performed on the same day after the patient has completed hitting. These recommendations have been adapted from other previously established interval sport programs.

**CONCLUSION**

Since hitting is a complex activity requiring coordinated motion of the entire body, any injury may impact a patient's ability to swing a bat. Similar to the return to throwing programs that exist, this interval hitting program guides the clinician from when the patient is ready to begin hitting through a full return to sport. Sports-related exercises should have been implemented in a pain-free environment, (including plyometric exercises) prior to starting this program. The proposed interval hitting progression program should be used as a method to quantify progression and may reduce the chance of injury from occurring. Future research should be conducted that studies the use of this program on injured baseball players as well as other rehabilitation models that are specific to hitting.

**REFERENCES**


**APPENDIX 1**

**Interval Hitting Progression Program**

**Instructions:**

- **Each step should be performed in succession; starting with Step 1 performed on Day 1, Step 2 performed on Day 2, and so forth**

- **Each training day should have one day of rest in between steps to ensure proper recovery and adaptation to the stimulus of hitting.**

- **All other exercises, such as a home exercise program, should be performed on the same day and after the completion of hitting.**

- **Perform Lower & Upper Extremity Warm-ups prior to performing each step. Please refer to Appendix 2 for these warm-ups**

- **Please follow the soreness rules for advancing to each step included in this Appendix**
### Phase 1

#### Basic: Hitting off of Tee

<table>
<thead>
<tr>
<th>Step</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1</strong></td>
<td></td>
</tr>
<tr>
<td>Tee set-up: ball placement middle of plate and at waist height</td>
<td></td>
</tr>
<tr>
<td>Perform 25 swings at 50% of effort</td>
<td></td>
</tr>
<tr>
<td>Concentration should be placed on addressing mechanics of the baseball swing</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Hitting off of Tee:</th>
<th>Direction of Challenge</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 2:</strong></td>
<td><strong>Step 3:</strong></td>
<td><strong>Step 4:</strong></td>
<td><strong>Step 5:</strong></td>
</tr>
<tr>
<td>Tee set-up at waist height</td>
<td>Tee set-up at waist height</td>
<td>75% Effort</td>
<td>Repeat Step 4 90 to 95% Effort</td>
</tr>
<tr>
<td>50% Effort</td>
<td>75% Effort</td>
<td>20 swings middle of plate consisting of:</td>
<td>20 swings middle of plate consisting of:</td>
</tr>
<tr>
<td>15 swings middle of plate</td>
<td>15 swings middle of plate</td>
<td>1. 5 swings letters/chest height 1. 5 swings letters/chest height</td>
<td>1. 5 swings letters/chest height</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. 10 swings waist height 2. 10 swings waist height</td>
<td>2. 10 swings waist height</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. 5 swings just above knees 3. 5 swings just above knees</td>
<td>3. 5 swings just above knees</td>
</tr>
</tbody>
</table>

| 15 swings tee set-up inside corner of plate | 15 swings tee set-up inside corner of plate | 20 swings inside corner of plate consisting of: | 20 swings inside corner of plate consisting of: |
| | | 1. 5 swings letters/chest height 1. 5 swings letters/chest height | 1. 5 swings letters/chest height |
| | | 2. 10 swings waist height 2. 10 swings waist height | 2. 10 swings waist height |
| | | 3. 5 swings just above knees 3. 5 swings just above knees | 3. 5 swings just above knees |

| 15 swings tee set-up outside corner of plate | 15 swings tee set-up outside corner of plate | 20 swings outside corner of plate consisting of: | 20 swings outside corner of plate consisting of: |
| | | 1. 5 swings letters/chest height 1. 5 swings letters/chest height | 1. 5 swings letters/chest height |
| | | 2. 10 swings waist height 2. 10 swings waist height | 2. 10 swings waist height |
| | | 3. 5 swings just above knees 3. 5 swings just above knees | 3. 5 swings just above knees |

**Phase 2**

#### Basic: Soft Toss

<table>
<thead>
<tr>
<th>Step 6</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft toss (underhand toss) 25 swings at 50% effort with partner, set-up at 45 degrees away from hitter. Hitter will be hitting into net or cage</td>
<td></td>
</tr>
<tr>
<td>Placement of ball should be at waist and middle of plate</td>
<td></td>
</tr>
<tr>
<td>Concentration should be placed on addressing mechanics of the baseball swing</td>
<td></td>
</tr>
</tbody>
</table>

*Prior to performing each step in phase 2 perform 10-15 swings off of tee as a warm-up*
### Phase 2

#### Soft Toss:

<table>
<thead>
<tr>
<th>Step 7:</th>
<th>Step 8:</th>
<th>Step 9:</th>
<th>Step 10:</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% Effort</td>
<td>Repeat Step 7</td>
<td>75% Effort</td>
<td>90 to 95% Effort</td>
</tr>
</tbody>
</table>

- 10 swings with ball placed at waist height & middle of plate
- 10 swings with ball placed at waist height & middle of plate
- 10 swings with ball placed for outside corner
- 10 swings with ball placed just above the knee & middle of plate
- 10 swings with ball placed for inside corner
- 15 swings with ball placed for outside corner
- 15 swings with ball placed for inside corner

#### Direction of Challenge

- 30 swings middle of plate consisting of:
  1. 10 swings waist height, middle of plate
  2. 10 swings ball chest/letters height, middle of plate
  3. 10 swing ball just above knees, middle of plate

- 10 swings with ball placed at waist height & middle of plate
- 10 swings with ball placed at letters height & middle of plate
- 10 swings with ball placed just above the knee & middle of plate

NOTE: An “L” screen should be used for protection while performing certain soft-toss positions. Please refer to Appendix 3 for Soft Toss Variation.

### Phase 3

#### Basic: Simulated Hitting

**Step 11**
- This phase should be performed in a batting cage or on the field
- 30 swings of fastballs consisting of: 10 inside, 10 outside, 10 middle of plate
- Height of pitch can be left randomized
- Perform at 50% effort

*Prior to performing each step in phase 3 perform 10-15 swings of soft-toss
*The partner should use an “L” screen for protection

**Step 12:**
- 75% Effort
- In cage/on field

**Step 13:**
- 75% Effort
- In cage/on field

**Step 14:**
- 90-100% Effort

- 25 swings against fastballs; Randomized placement
- 15 swings at change-ups; Randomized placement
- For ages 14 and above add in 15 swings against curveballs

*An “L” screen should be used for protection for the person throwing

### Soreness Rules (Adapted from Axe et al)²⁶

<table>
<thead>
<tr>
<th>Soreness Rules for progression:</th>
<th>Interval Hitting Progression Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>If there is no soreness present</td>
<td>Progress to the next step on the next day of training</td>
</tr>
<tr>
<td>If soreness occurs during the warm-up and then goes away in the first 15 swings</td>
<td>Repeat the previous step</td>
</tr>
<tr>
<td>If soreness occurs during the warm-up and continues during the first 15 swings</td>
<td>Stop, take 2 days off and upon returning drop down 1 step</td>
</tr>
<tr>
<td>If soreness occurs for more than hour after swinging</td>
<td>Take 1 additional day off and repeat the most recent stage</td>
</tr>
</tbody>
</table>
APPENDIX 2

Warm-ups prior to interval hitting progression program

Figure 2. Rotational Arm movements
The athlete starts with both palms pointed toward the ceiling, then the feet are rotated to the right and the left arm will perform internal rotation (keeping arms shoulder level). Rotate to the opposite direction performing the same movement. **Perform 2 sets of 10 repetitions each side.

Figure 3. Side Lumberjack Chops
First pivot and rotate away from the direction you will be actually performing the lumberjack chop. Use a light ball (such as a volleyball); The ball should be above your head with both arms extended and the back foot should be pivoting facing this same direction.
Then take the medicine ball from the top of this motion in a diagonal pattern/across the body and perform a lunge in the opposite direction while pivoting again on both legs (back and head should be straight and be sure that the front knee is behind your front foot.
**Perform 2 sets of 10 repetitions each side

Figure 4. Hitters Throw
Assume a batting position and hold the ball as if you were holding a baseball bat.
Then throw a light ball (such as a volleyball) simulating the baseball swing toward a wall or open field.
**Perform 2 sets of 10 repetitions each side