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Abstract
The use of the RICE (Rest, Ice, Compression, Elevation) protocol has been the preferred method of treatment for acute musculoskeletal injuries for decades. However, the efficacy of using ice as a recovery strategy following injury in humans remains uncertain, and there is a growing trend recommending against icing following injury. Animal models suggest that while ice can help to accelerate the recovery process, extreme muscle cooling might delay repair and increase muscle scarring. Despite the conflicting evidence, ice should not be dismissed as a potential treatment option. When considering what is known about the injury cascade, the optimal application window for ice is in the immediate acute stage following injury to reduce the proliferation of secondary tissue damage that occurs in the hours after the initial injury. Practitioners should tailor the application of ice based on the injury timeline and repair process, consistent with applications in 20-30 minute intervals within the first 12 hours post-injury. Until the evidence unanimously proves otherwise, the culture of icing injuries should remain a staple in sports medicine.

The RICE (Rest, Ice, Compression, Elevation) protocol has been the preferred method of treatment for acute musculoskeletal injuries since Dr. Mirkin coined the term with his coauthor Marshall Hoffman in 1978 in *The Sports Medicine Book*. In reality, the implementation of this protocol to accelerate recovery was unsubstantiated in the publication. Although the recommendations were reaffirmed in subsequent decades, Mirkin recanted his original position on the protocol in 2014. There is a growing trend recommending against icing following injury so as not to blunt the natural healing response and potentially cause further damage to the affected tissue. Subsequently, there has been much debate among clinicians about best practice following injury, with some recommending that ice be removed from the standard management of soft tissue injuries altogether.

The injury cascade involves primary injury resulting in immediate structural changes in the tissues, followed by secondary injury, which encompasses delayed proliferation and exacerbation of the initial structural damage. Based on what is known about the injury cascade, the optimal application window for ice is in the immediate acute stage following the injury. The rationale for administering ice at this stage is to reduce the proliferation of secondary tissue damage that occurs in the hours after the initial injury. Although applying ice on the days following injury will provide pain relief through the slowing of neural conductance velocity, it is of little additional benefit. In practice, administering ice in the immediate stage after injury can be challenging. Most individuals, practitioners, and even animal model studies often fail to apply ice within the first hours after injury. In the acute post-injury phase, we cannot expect a modality, often administered only one time, and often too late, to have any consequential impact on the recovery and healing process.
While controlled trials implementing the use of ice immediately following musculoskeletal injuries in humans do not exist, there is plenty of evidence in the literature from animal models. The scientific basis for administering ice, or any form of cryotherapy for that matter, to reduce metabolism and inflammation following injury comes from animal models. Animal models suggest that by promptly applying ice, the metabolic demand in the affected area might be suppressed, which in turn could limit the magnitude of the pro-inflammatory response, help to accelerate the onset of the anti-inflammatory phase, and reduce the area of secondary muscle injury. On the contrary, animal models caution that if extreme muscle cooling is achieved following injury, it might delay repair and increase muscle scarring. Although these results are inconclusive in determining whether using ice hinders or expedites recovery after injury, recent evidence suggests that ice may have a beneficial effect by reducing the immediate pro-inflammatory response and promoting muscle regeneration. This is especially true in injury models that involve smaller magnitudes of necrotic myofibers, which more closely resemble the conditions in human injuries. Collectively, the evidence from animal models should not deter practitioners and athletes from implementing ice as a recovery strategy following injury.

Summary
The efficacy of using ice as a recovery strategy following injury in humans remains uncertain, highlighting the need for high-quality, randomized controlled trials that focus on the impact of ice on the healing process to inform practitioners. With conflicting evidence, it is important to consider the current best available evidence and avoid selectively choosing evidence to support biased conclusions.

While a clear cause-and-effect relationship between ice and injury recovery in humans has yet to be established, evidence from animal models suggests that ice should not be dismissed as a potential treatment option. In fact, ice can be considered a useful tool in minimizing the proliferation of secondary tissue damage and should remain a mainstay in the field of play and emergency care following injury during training or competition. To promote functional recovery of the athlete after injury, practitioners should tailor the application of ice based on the injury timeline and repair process, consistent with applications in 20-30 minute intervals within the first 12 hours post-injury. Practitioners should reach for a wet ice pack and have the athlete sit on the bench while receiving treatment (only if they have been ruled out from the practice or game). Further, the training staff should educate their injured athletes on the importance of repeat applications during the acute stage of injury.

Overall, until the evidence unanimously proves otherwise, the culture of icing injuries should remain a staple in sports medicine. So, is the ice age coming to an end? Not anytime soon.

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Clinical Viewpoint

The Evolution of Rehabilitation and Return to Sport Following Cartilage Surgery

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Keywords: cartilage rehab, knee, OCA, OATS, MACI

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Rehabilitation after knee cartilage repair or restoration can be a challenging and nuanced process. Historically, conservative rehabilitation protocols have been characterized by limited weightbearing and restricted range of motion (ROM) were created to primarily protect the repaired cartilage but did little for progression into higher level activity. Recent literature has supported accelerated protocols in a variety of cartilage procedures ranging from osteochondral allograft (OCA) Osteochondral autograft surgery (OATS) to matrix-based scaffolding procedures such as Matrix Induced Chondrocyte Implantation (MACI) or Denovo procedures. Advances in technology such as blood flow restriction (BFR) and testing equipment with progressive rehabilitation from the acute phase through the return to sport continuum have made it possible to return to a higher level of activity and performance than first thought of for these procedures. This clinical viewpoint discusses the evolution of knee cartilage rehabilitation characterized by early but progressive weightbearing and early ROM while maintaining early homeostasis in the knee, and then its progression to return to sport and performance in the higher-level athlete.

Level of evidence

V

No matter the location of the country, or the specialty of the clinic, the ever-looming diagnosis of knee osteoarthritis cannot help to rear its ugly head. These ailments start as a minor cartilage delamination but can evolve into a bone on bone arthritis which at times can tri-compartmentalize and lead to knee replacement at some time in the patient’s lifespan. In the past 2-3 decades we have not only seen an aging overall social population, but also degenerative cartilage injuries that have developed via sports injuries and more vigorous exercise programs. With this, the incidence of cartilage injuries has increased tremendously and now in the younger population has necessitated advanced rehabilitation protocols and testing to return a person to their optimal level of sport. One of the first osteoarticular transplants was described as being done as early as 1925,1 and one of the first osteochondral allografts was performed in the early 70’s. Since then, surgical techniques, the use of biologics and the evolution of rehabilitation as a whole has contributed to the growth and success of this surgery. The evolution of rehab after cartilage surgery is multifaceted because surgery has evolved from mainly microfracture surgeries to now advanced osteochondral auto/allografts, and Autologous Chondrocyte Implantation (ACI) surgeries. The nuances of rehabilitation in this field can be very descriptive and extensive, but this viewpoint will discuss the evolution of rehabilitation and how changes have helped the success of this surgery and patient population, specifically range of motion changes, weight bearing progression, usage of bracing, blood flow restriction training, and advanced return to sport testing.

RANGE OF MOTION

In the context of an osteochondral allograft or autograft, traditionally range of motion has not been particularly restricted in this patient population. Some restrictions in the first 2 weeks post operatively were utilized at the onset of cartilage surgery, and some surgeons seem to follow similar restrictions today. The premise of motion restriction
has changed throughout the decades though. At first it may have been believed that forced passive range of motion would hinder overall healing of a fragile donor graft, but as surgical technique and rehabilitation has evolved the restrictions are mostly in place as to not aggressively push flexion in the knee and cause more effusion in an already compromised knee complex. After 2 weeks most guidelines will permit ROM as tolerated, with an effort to achieve >120 degrees of flexion by 6 weeks post-op. A difference would only be seen in a ACI or Matrix-Induced Autologous Chondrocyte Implantation (MACI) procedure in which the consensus is to start at 45 deg flexion and increase 15 degrees each week, achieving 90 degrees by week 4. After that period, progressing ROM as tolerated with the goal of reaching full motion by weeks 7 to 9.

The usage of a continuous passive motion (CPM) machine, in today’s rehab setting has varied usage. In the past it was thought that this was the best way for the newly introduced cartilage graft to gain nutrition since weight bearing was limited. As time evolved, we have seen that this joint nutrition is better achieved through gradual weight bearing, which will be discussed later. Some surgical protocols still involve the use of CPM for the first 6 weeks, but in this authors opinion with proper guided physical therapy in this first 6 weeks motion can easily be maintained and progressed with edema control, gentle progressive PROM and stretching, and when achievable, stationary bike to help promote motion.

WEIGHTBEARING PROGRESSION

The evolution of weight bearing with cartilage procedures has changed most markedly over the last three decades. In the procedure’s infancy, patients were mainly non-weight bearing for several reasons, primarily fearing damage to the new fragile graft despite the lesion’s location. As time has evolved, weightbearing progressions have trended towards more permissive progression but can be highly individualized by a number of factors including lesion location, size, surgical procedure, graft type and surgeon preference. We have seen those lesions along the patella (since it is not a weight bearing surface), can have immediate partial weight bearing and become weight bearing as tolerated in as little as 2 weeks. Some procedures such as an ACI or MACI procedure still follow a graded weight bearing progression for tibial femoral grafts to aid with integration and maturation of the implanted cartilage, as the newly implanted membrane incorporates into the knee. For example, a MACI procedure to the weightbearing surface of the lateral femoral condyle may initially start with toe-touch weightbearing (TITWB) (for approximately 2 weeks) and gradually progress to weightbearing as tolerated (WBAT) by 6 weeks post-operatively. However, for osteochondral allografts and autografts limited weight bearing in the initial stages has been challenged. As the understanding of the biology and biomechanics of cartilage have advanced, so have the notions that non-weightbearing in the initial stages help overall graft healing. As mentioned before the usage of the CPM machine was used so that nutrients of the synovial fluid would be expressed into the newly placed cartilage and promote healing. Now we see that weight bearing promotes the nutrients from the synovial fluid into the cartilage matrix, stimulating an anabolic chondrocyte response.

That said, there is still a lack of consensus on the optimal post-operative weight bearing regimen after an allograft or autograft surgery. Kane et. al in 2017 in a retrospective study described the trends present in weight bearing post-surgery, and most surgeons were still demonstrating restrictive initial weight bearing but progressing to full weight bearing by 6 weeks post op. Recent studies have also shown that a surgeon’s experience in the procedure may influence their permissiveness in post operative guidelines, which includes weight bearing progression. With all of this in mind cautious progression with weight bearing should be utilized throughout the rehab process in order to decrease rates of recurrent pain and/or joint effusion. Being too aggressive has be shown to overtax the healing cartilage and result in proteoglycan loss and a deterioration of mechanical properties. It is imperative that the rehab professional not only follow the surgical guidelines but can understand and recognize the signs of overload that can lead to increased inflammation and delayed overall healing.

BRACING AFTER SURGERY

The age-old question of to brace or not to brace after surgery will continue to be asked throughout generations of rehabilitation. The construct, extent of surgery, and limited knowledge of cartilage healing made the notion of bracing after surgery a non-negotiable factor as to not damage an implanted graft early on. Limiting overall motion by the patient was one of the safeguards used to ensure that the newly implanted cartilage would heal. As time has gone on there are two things that have happened. First, we see that implanted cartilage grafts are much heartier and heal better than first thought. There is a robust mechanical fixation of the graft during surgery, leading to a stable construct after an initial period of bracing to avoid excessive shearing forces and graft damage. Bordes et al., showed in an analysis of 969 patients post ACL reconstruction there was no difference in the frequency or severity of complications between three groups with different bracing protocols including a rigid-knee brace, hinged knee brace, and no brace at all. Furthermore, the group with no brace had lower rates of early post-operative stiffness. After this initial period, brace discharge is allowed if the patient demonstrates adequate quadriceps control. It has been our experience that prolonged brace usage leads to more quadriceps inhibition, in the early stages of rehabilitation. It should be noted that discharge from bracing should be a collaboration between the surgical and rehabilitation team so as to make sure that both parties are satisfied with overall protection and quadriceps activation respectively. A mainstay of cartilage rehab is to engage the quadriceps musculature in order to support the healing knee complex. Chronic degeneration of the knee joint can lead to a progressive strength loss in patients secondary to pain and the inability to gain strength due to it. Excessive bracing can lead to a quad
avoidance gait pattern and in turn weakness in the complex. Ligamentous laxity in this patient population is not the problem, so once proper quad activation is obtained a cessation of brace usage is necessary to progress strength in the quadriceps musculature and avoid further disuse. In this author’s experience for most patients, this is seen as about 2-3 weeks after surgery.9 Again, it is the job of the rehab professional to use a criteria-based progression (minimal effusion, full knee extension, quadriceps control) to make a decision, and not base the decision merely on time.

**BLOOD FLOW RESTRICTION TRAINING**

As mentioned before chronic knee pain and degenerative cartilage can inhibit a person from fully participating in strength training secondary to pain with higher intensity strength training. This effect flows over into post-surgical rehabilitation, because although the cause of the pain and dysfunction (the inherent cartilage lesion) is corrected, the patient still has limited overall weight bearing in the initial phases, joint effusion, and still the inability to push higher loads. The adjunct of blood flow restriction (BFR) in this population has shown tremendous effects by improving overall quadriceps atrophy and strength utilizing low external loads, 20-30% of 1 rep max.10,11 Research in this patient population is not heavily documented, but it is well documented in patients with osteoarthritis, patellofemoral pain and inpatient military personnel.12–16 The usage of BFR in the ACL population has also been better researched and used to date, with evidence indicating the ability to improve overall quadriceps activation and strength along with decreasing joint effusion and pain.17 The overall effect of exercise in populations with musculoskeletal conditions in general, especially knee conditions, can be attenuated in the presence of pain18 due to a detrimental effect on motor control and muscle function19 and can lead to compensations and modified movement patterns. The implementation of BFR in this population can help decrease overall joint inflammation, modulate overall pain, and help with muscle hypertrophy in a joint with limited loading capacity. As the rehabilitation process progresses BFR can continue to be used so as to not overload the joint with progressive training but by continuing to make strength gains. Implementing this technology not only at the beginning, but throughout the rehab process will help progress the strength of the quadriceps and help the patient progressively load the knee joint. Proper load of the joint throughout the rehab process will prevent overloading during the performance stage and prevent joint effusion and pain in the late phases of rehabilitation and return to sport.

**RETURN TO SPORT AND TESTING**

As the 21st century has evolved so has the active population in the world. In decades past it was seen that an aging population decreased their overall exercise regimen and became more sedentary or participated in exercise programs that were easier and less taxing for the most part. In today’s world it is not uncommon to see the aging population still participating in higher level activities. Cartilage surgery in its early stages was a "salvage" surgery, that was meant to decrease a patient’s pain so that normal functional activities could be performed. Fast forward to 2023, and we see that due to the heartiness of the implants and constructs it is possible to progress to high level activities. Balasz et al demonstrated that in a cohort of high-level basketball players, 80 percent returned to their previous level of competition.20 In a systematic review of return to sport after surgical management of cartilage lesions in the knee, Krych et al., demonstrated cartilage restoration surgery had a 76% return to sport at mid-term follow-up. Of the surgical techniques included, osteochondral autograft transplantation (OAT) offered the fastest time to return to sport time (mean = 5.2 ± 1.8 months) with the highest rates of return to sport (93%). Osteochondral allograft transplantation and ACI took longer to return to sport (9.6 ± 3.0 months for OCA and 11.8 ± 3.8 months for ACI) but also resulted in high RTS rates (88% and 82%, respectively). Microfracture took a longer time to return to sport (9 mos on average), but also yielded the lowest overall return to sport rate (58%).21 This may be a factor of why the choice of microfracture for the higher level athletes and activity has evolved into using a more viable and durable osteochondral autograft. This along with the fact that the fibrocartilage clot formed after a microfracture surgery has a limited overall shelf life and viability for higher load levels and athletic activity causing a higher failure rate in this population,22–26 If this patient population is going to return to high level sport and performance it is necessary to make sure that qualitative along with quantitative measures are reached to make sure that they not only return safely but at a high level if needed.27 Serial strength testing throughout the rehabilitation process using handheld or fixed dynamometers or isokinetic testing is needed to make sure that optimal quadriceps and lower extremity strength is attained so that the joint is not overloaded. Isometric strength assessments with force plates and fixed dynamometers can allow the clinician to look beyond peak force and look at force/time derivatives such as rate of force development (RFD) over various time epochs (RFD100, RFD150, etc.) Deficits in RFD have been shown to persist past the resolution of peak isometric strength. In a cohort of 45 male professional soccer players deficits in RFD remained 6 months post ACLR despite full recovery of maximum voluntary isometric contraction (MVIC) on an isometric leg press test.28 Historically, hop testing has been used as a measure of lower extremity power in RTS testing after knee injuries. Recent work by Kotsikaki et al., demonstrated that looking at the propulsive phase of hop testing does a poor job of evaluating knee and quadriceps function.29,30 This is problematic as hop distance is reported as the primary measure for LE power in several studies.31 Performance metrics such as jump height in a single leg vertical jump can be used to better assess vertical lower extremity power output and overall knee function.30,32,33 Reactive strength ability during drop vertical jump tests (DVJ) and single leg drop vertical jump tests (SL DVJ) can be assessed with force plates, contact mats, and cell phone applications.29–37
vancements such as dual force plate technologies can permit even more in-depth analysis of phase specific asymmetries that is beyond the scope of this commentary. Finally looking at movement characteristics is important in this patient population since faulty movement patterns have been engrained in this population to compensate for pain that was present. Individuals will often use a hip/trunk strategy with functional movement patterns to avoid large knee extension moments and mask residual strength and power deficits. Movement screening can be implemented in any clinic situation because it can be as easy as using a simple video capture to a more complex motion capture system. The main point is that if patients can now return to higher-level activity and sport, it is not just the surgeon’s responsibility to make sure that a technically sound surgery is performed and that biological healing as taken place, but the rehab professional’s job to test in a quantitative and qualitative aspect to make sure they are ready to reach such high level demands.

SUMMARY

The evolution of cartilage surgery has made great strides in the past 3 decades with surgical advances that have made it possible to return to an elevated level of activity and sport. Cartilage implants have proved to be sturdier and have shown much more durability than when they were first introduced. However, although documented here, rehabilitation guidelines seem to have evolved a bit slower than the actual surgery. With the aging population becoming more active it is essential that we continue to progress with rehabilitation guidelines in a safe manner, but also keeping in mind that protocols should also be adjusted as techniques have become more refined and implants becoming more robust. With many surgeons there is still a fear factor in trying to progress weight bearing a bit faster or not prescribing a CPM machine after surgery. This may be because they all may not fully trust in the rehabilitation professional in progressing patients properly, and hence still the rigid protocols in place. Progression of weight bearing and ROM, along with inclusion of advanced strengthening techniques can help evolve rehab even further than where it is presently. In the authors opinion the realm or cartilage rehabilitation continues to be an evolving artform which should continue to be advanced in the coming years. Surgical research continues to evolve with cartilage, but further research in the rehabilitation and return to performance realm must be initiated by the rehabilitation community to further progress protocols and rehab for the higher-level population which will be getting these procedures in the future.

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REFERENCES


Is it Time to Normalize Scapular Dyskinesis? The Incidence of Scapular Dyskinesis in Those With and Without Symptoms: a Systematic Review of the Literature

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Keywords: shoulder pain, scapular dyskinesis, overhead sports, scapular translation, symptomatic, asymptomatic

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Background
Up to 67% of adults experience shoulder pain in their lifetime. Numerous factors are related to the etiology of shoulder pain, one of which is thought to be scapular dyskinesis (SD). Given the prevalence of SD among the asymptomatic population a concern is that the condition is being medicalized (clinical findings suggested to require treatment but is ultimately a normal finding). Therefore, the purpose of this systematic review was to investigate the prevalence of SD among both symptomatic and asymptomatic populations.

Methods
A systematic review of the literature up to July of 2021. Relevant studies identified from PubMed, EMBASE, Cochrane and CINAHL were screened utilizing the following inclusion and exclusion criteria; inclusion: (a) individuals being assessed as having SD, including reliability and validity studies (b) subjects aged 18 or older; (c) sport and non-sport participants; (d) no date restriction; (e) symptomatic, asymptomatic, or both populations; (f) all study designs except case reports. Studies were excluded if: (a) they were not published in the English language; (b) they were a case report design; (c) the presence of SD was part of the studies inclusion criteria; (d) data were not present distinguishing the number of subjects with or without SD; (e) they did not define participants as having or not having SD. Methodological quality of the studies was assessed utilizing the Joanna Briggs Institute checklist.

Results
The search resulted in 11,619 after duplicates were removed with 34 studies ultimately retained for analysis after three were removed due to low quality. A total of 2,365 individuals were studied. Within the studies for the symptomatic athletic and general orthopedic population there were 81% and 57% individuals with SD, respectively, and a total of 60% among both symptomatic groups (sport and general orthopedic population). Within the studies for the asymptomatic athletic and general population there were 42% and 59% individuals with SD, respectively, and a total of 48% among both asymptomatic groups (sport and general orthopedic population).

Limitation
A strict inclusion and exclusion criteria was used to identify studies that provided the appropriate data for the purpose of this study. There was a lack of consistency for measuring SD across studies.
Conclusion

A considerable number of individuals with shoulder symptoms do not present with SD. More revealing is the number of asymptomatic individuals who do present with SD, suggesting that SD may be a normal finding among nearly half of the asymptomatic population.

Level of Evidence

2a

INTRODUCTION

Within the adult population, 67% of individuals will experience shoulder pain at some point throughout their lifetime.1 There are numerous factors related to the etiology of shoulder pain and it has been hypothesized that the presence of scapular dyskinesia (SD) is a contributing factor to shoulder pathology.2,3 Scapular dyskinesia has been defined as alterations in scapular positioning at rest as well as during dynamic movement. Common variations in scapular movement4,5 include increased scapular superior translation along with reduced scapular posterior tilt, upward rotation, and internal rotation.6 Give the theorized relationship between SD and certain shoulder pathologies there have been several methods proposed to evaluate these alterations in scapular positions and movements.

McClure et al.7 developed a commonly used method of identifying SD, the scapular dyskinesia test (SDT), to identify the presence of SD and classify individuals into three levels: normal motion, subtle dyskinesia, and obvious dyskinesia. This is one of several methods commonly used during an evaluation related to shoulder pathology presented in Supplement A. Though the SDT has been proven to be a reliable and valid method of identifying SD, not all clinicians are trained to use this tool and current literature describes a wide variation of assessment methodology.6 Along with this lack of homogeneity in assessment of SD, there is a lack of evidence to support the idea that identification and correction of SD may help to prevent or treat shoulder pathology. Even with this lack of evidence, identifying SD is a common screening tool for both symptomatic and asymptomatic individuals. The evaluation is especially common in predicting or preventing injury in overhead athletes, however there is conflicting evidence regarding the link between SD and injury in this population exists.5,9 Clinicians often direct their treatment toward correcting the SD which could be normal movement variability.10,11

Because the identification of SD is a common part of a patient evaluation, it is often used to guide clinical decision making; however, there is considerable debate around linking the presence of SD to certain shoulder pathologies. Some studies have shown no difference in the prevalence of SD between symptomatic and asymptomatic populations.12 This raises the question of utility when screening for SD in patients seeking treatment for shoulder pain as well as for the asymptomatic population.

The purpose of this systematic review of the current literature to investigate the prevalence of SD among both symptomatic and asymptomatic populations. Understanding the relationship between SD and the presence or absence of symptoms may help to direct conversations regarding the clinical utility of SD. The authors hypothesized that SD is a common finding that has been medicalized (clinical findings suggested to require treatment but is ultimately a normal finding).

MATERIALS AND METHODS

GUIDELINES

This systematic review utilized the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines during the search and reporting phase of the research process. The PRISMA statement includes a 27-item checklist designed to improve reporting of systematic reviews and meta-analyses.13

LITERATURE SEARCH

An online literature search was conducted utilizing PubMed, EMBASE, Cochrane and CINAHL from the dates of their origin until July 2021. The search strategy was created and performed by a biomedical librarian. An example of the search strategy used for the PubMed database is provided (Supplement B) and similar strategies were utilized for the remaining databases. The study was registered using the International Prospective Register of Systematic Reviews (PROSPERO) in May of 2020 with a corresponding reference number: CDR42020187045.

STUDY SELECTION

All titles were independently appraised by two authors (TB) and (AW) after the initial online literature search for studies to be retained. The abstracts of these titles were read to determine if the studies met the inclusion criteria. Studies with abstracts that met the inclusion criteria were accessed in their full-text format and then read to determine their eligibility for the review. The same two authors performed the study selection process for this review with a third author (PS) available to handle disagreements. The inclusion criteria for studies to be retained in the present review consisted of: (a) individuals being assessed as having SD, including reliability and validity studies (b) subjects aged 18 or older; (c) sport and non-sport participants; (d) no date restriction; I symptomatic, asymptomatic, or both populations; (f) all study designs except case reports. Studies were excluded if: (a) they were not published in the English language; (b) they were a case report design; (c) the presence of SD was part of the studies inclusion criteria; (d) data were not present distinguishing the number of sub-
jects with or without SD; 1 they did not define participants as having or not having SD.

DATA EXTRACTION

The data and results from the studies that were retained as part of the review were extracted using a format to identify study type, population, methods for evaluating SD, and the prevalence of SD. Data were extracted, reviewed, and analyzed by the primary author (PS) and verified by a research assistant (ZS). Discrepancies in data collection were resolved through discussion.

METHODOLOGICAL QUALITY ASSESSMENT TOOL

The Joanna Briggs Institute (JBI) checklist for prevalence studies was used to evaluate methodological quality within the individual studies.14 There are nine items related to methodological quality included in the checklist which can be answered as yes, no, unclear, or not applicable. Following the scoring of each item, those individuals scoring the study are asked to provide an overall appraisal to include, exclude, or seek further information regarding if the article should be retained. The decision to include or exclude each article is then made by the reviewer(s) based on the completed checklist and consensus. Two authors, (DH) and (AM), performed the methodological quality assessment independently with discrepancies handled by the primary author if necessary. Prior to methodological quality assessment those involved in worked through scoring several unrelated prevalence studies in order to align definitions and interpretations of the various elements present in the JBI tool.

DATA SYNTHESIS AND ANALYSIS

Data were extracted and pooled to include the incidence of scapular dyskinesis, as defined by the authors, among those individuals that were symptomatic and those that were asymptomatic. The results were reported on percentage of incidence differentiating between classification of individuals with SD and shoulders with SD among each identified population. Data on relevant subcategories were identified and individually accounted for with separate analyses. Data from the identified studies did not allow for a quantitative analysis given the heterogeneity of several variables.

RESULTS

SEARCH RESULTS

The initial search resulted in 11,619 after duplicates were removed. Following title and abstract screening 11,505 were removed. Full text articles were retrieved for the remaining 114 studies of which 77 were removed due to not meeting the inclusion criteria. The remaining 37 studies were retained for quality assessment Figure 1.

Following quality assessment 34 articles were ultimately retained for analysis. Study characteristics for each of the 34 studies consisting that examined 2,365 individuals can be seen in Table 1. Retained studies were categorized into either symptomatic or asymptomatic within either an athletic population or a general orthopedic population.

The general orthopedic population among the retained studies included study participants where the upper extremity was of interest, primarily the shoulder. However, there were a small number of individuals that had neck pain where SD was also evaluated, which is more clearly identified in the results section.

METHODOLOGICAL QUALITY

Of the 37 articles assessed three15–17 were excluded and 3412,18–50 were included for synthesis (Table 2).

The excluded articles all had a score ≤ 5 on the JBI tool. The reasoning for exclusion of articles was to remove poor quality studies due to low quality or high risk of bias. Otherwise, there would be little value in scoring quality if high- and low-quality studies are all given the same "voice". Additionally, the JBI tool is specifically designed to give the raters the choice of including or excluding the scored study based on their interpretation of the scoring. Of the included studies, 1812,21–27,32,37–41,44,45,49,50 addressed the target population appropriately with the sample frame and had adequate sample sizes. However, only 13 studies12,19,23,24,26,28,31,32,41,42,47,49,50 reported both the study subjects and setting in detail. Additionally, 11 studies19,20,22–24,26,27,38,45,47,50 measured the condition in a standard reliable way, 15 studies12,19,22,23,26,30,32,34–36,40–42,48,50 used valid methods to identify the condition, and 8 studies21,22,32,37,39,41,48,50 included information on response rate as most studies were one-time measures. The JBI tool, like other quality and risk of bias assessment tools, does not advocate for a summative score as the constructs being scored are not similar. Therefore, in order to be as transparent as possible, we listed each item in the table along with their score, as well as provided a summary of those studies and which were the most common items not reported as you mention above.

PREVALENCY RESULTS

The number of studies with available data for the asymptomatic and symptomatic populations and relevant subgroups are reported. Table 3 reflects studies with available subgroup data for asymptomatic and symptomatic populations. Data for asymptomatic individuals are reported in Table 4. Finally, symptomatic athletic population results are reported in Table 5 while the asymptomatic general population results are reported in Table 6.

Although the inclusion criteria were intentionally broad in respect to diagnoses for the symptomatic population, all but three studies20,35,40 consisted of individuals with some form of shoulder pain including diagnoses such impingement, instability, rotator cuff tear, labral tear, and upper extremity pain, all of which are listed in Table 1. Two of the three studies35,40 consisted of mixed upper extremity diagnoses but the SD data was not parsed out by diagnosis. The authors were able to examine them based on the inclusion criteria. This was an attempt to be transparent
Table 1. Characteristics for each of the retained studies

<table>
<thead>
<tr>
<th>Authors</th>
<th>Setting Type</th>
<th>Population Type</th>
<th>Total Population/Shoulders (n/ n)</th>
<th>With Scapular Dyskinesis (n)</th>
<th>Symptomatic (Y or N)</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Akodu et al 2018</td>
<td>General population (from Department of Physiotherapy, U of Lagos)</td>
<td>77 undergraduates without history of shoulder or neck pathology</td>
<td>77/77 (reported as individuals with SD)</td>
<td>54 (a 1.5 cm asymmetry between R/L scapulae was considered the threshold for SD)</td>
<td>No</td>
<td>SICK scapula, Static Measurements 0 to 20 Point Rating Scale</td>
</tr>
<tr>
<td>Alves de Oliveira et al 2013</td>
<td>Amateur Athletes</td>
<td>30M amateur athletes (15 with SIS and 15 without); SIS mean age 22; control mean age 20.27</td>
<td>30/30 (dominant shoulders only)</td>
<td>SIS (14 (93.3%) present, 1 (6.7%) absent) Control (6 (40%) present, 9 (60%) absent)</td>
<td>15 symptomatic 15 asymptomatic</td>
<td>LSST</td>
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<td>Balci et al 2016</td>
<td>Outpatient clinic at a university</td>
<td>53 subjects (40F/13M); diagnosed as unilateral AC (stage II) and SPN for at least 3 months</td>
<td>53/53 (shoulder in pain)</td>
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<td>LSST</td>
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<td>Bullock et al 2021</td>
<td>Wake Forest pitching lab</td>
<td>33 asymptomatic M high school baseball pitchers; mean age 16.3</td>
<td>33/33</td>
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<td>McClure method (5 reps, etc.)</td>
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<td>Camci et al 2013</td>
<td>General population</td>
<td>64 asymptomatic individuals</td>
<td>64/64 (reported as individuals with SD)</td>
<td>40 yes (24 no)</td>
<td>No</td>
<td>Yes/no method</td>
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<td>Castelein et al 2016</td>
<td>General F population</td>
<td>19F with idiopathic neck pain; mean age 28.3 19F without (serving as control); mean age 29.3</td>
<td>38/38 (dominant shoulders only)</td>
<td>Neck pain group (9 yes, 10 no) Control group (8 yes, 11 no)</td>
<td>19 symptomatic 19 asymptomatic</td>
<td>Yes/no method described by Uhl et al. (visual observation)</td>
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<td>Chen et al 2018</td>
<td>General orthopedic with SPN</td>
<td>186 (115F and 71M) individuals with shoulder conditions; mean age 45.74 SIS: 59, partial cuff tear: 6; FS: 23; bicep tendonitis: 15, GH OA: 13, cuff tendonitis: 10, SLAP tear: 10</td>
<td>186/186 (reported as individual, not shoulder)</td>
<td>Yes: 140 (type I, II, III) No: 46 (type IV)</td>
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<td>Christiansen et al 2017</td>
<td>Rehabilitation units, physical therapy clinics, and hospital setting</td>
<td>40 patients (27M and 13F) with SIS</td>
<td>40/40 (reported as individual with SD)</td>
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<td>Yes (SIS)</td>
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<td>Da Silva et</td>
<td>Elite tennis</td>
<td>73 individuals (53 elite tennis players (31M)</td>
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<td>Kibler method (static, dynamic and</td>
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<td>Method</td>
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<td>Deng et al., 2017</td>
<td>102 patients (49M and 53F) with shoulder conditions (SIS: 28, cuff tear: 27, SLAP: 16, OA: 15, FS: 8, bicipital tendonitis: 8)</td>
<td>Rest (type I-III); 83 Anterflexion (type I-III); 37 Scaption (type I-III); 39 Abduction (type I-III); 36</td>
<td>Yes Kibler method</td>
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<td>Frizziero et al., 2018</td>
<td>32 individuals (27F and 5M)</td>
<td>Flexion and abduction with 1 or 2 kg weight and videotaped. Scapular movement was classified as: normal (both tests were evaluated as normal, or one movement is evaluated as normal and the other as slightly abnormal); slightly abnormal (both movements are evaluated as slight or uncertain abnormality); abnormal (one of the two movements is evaluated as severe abnormality)</td>
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<td>Hannah et al., 2017</td>
<td>40 healthy college aged participants (12M and 28F) *initial before age matched brought in to even SD numbers; mean age 22.2</td>
<td>Yes/no method</td>
<td>No Yes/no method</td>
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<td>Huang et al., 2015</td>
<td>60 patients (4 M and 15F) with unilateral shoulder condition</td>
<td>Kibler and McClure combined method</td>
<td>Yes</td>
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<td>Johansson</td>
<td>31 kayakers (20M and 11F) (17 with SPN and 14 without SPN)</td>
<td>Kibler and Sciasca method</td>
<td>Yes and No</td>
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Is it Time to Normalize Scapular Dyskinesis? The Incidence of Scapular Dyskinesis in Those With and Without Symptoms: a...
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<th>Authors and Year</th>
<th>Study Design</th>
<th>Participants</th>
<th>Methods</th>
<th>Results</th>
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<td>et al 2016</td>
<td>kayakists and relationship to ROM and SD</td>
<td>14 without SPN; F mean age 16.6; M mean age 18.2 (reported as individuals with SD)</td>
<td>SD No Pain: 4/14 had SD Total: 19/31 had SD</td>
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<td>Kawasaki et al 2012</td>
<td>Does SD effect Rugby players during a season</td>
<td>103M rugby players; mean age 24.6</td>
<td>103/103 used for primary analysis</td>
<td>Type I: 6 Type II: 4 Type III: 23 Total Yes: 33 Type IV (No): 70</td>
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<td>Lee et al 2017</td>
<td>Findings in asymptomatic elite volleyball players</td>
<td>26 elite indoor volleyball players</td>
<td>26/26 (dominant asymptomatic shoulders utilized)</td>
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<td>Madsen et al 2011</td>
<td>Training and SD in competitive swimmers</td>
<td>78 competitive swimmers (44F and 34M); mean age 17</td>
<td>78/78 (athletes with SD)</td>
<td>After first trial: 29 After half of training session: 53 Last three quarters of the training session: 57 Last quarter of the training session: 64</td>
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<td>Maor et al 2017</td>
<td>SD among competitive swimmers</td>
<td>20 competitive swimmers (6F and 14M); mean age 15.35</td>
<td>20/20 (athletes with SD)</td>
<td>Baseline: 6 1 hour of practice: 14 1.5 hours of practice: 17</td>
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<td>Nodehi et al 2020</td>
<td>Acromiohumeral distance and SD</td>
<td>44F (21 with RSP and 23 controls); mean age of control 22.43; mean age of RSP 22.95</td>
<td>44/88 (looked at dominant Total (shoulders) Flexion: 17</td>
<td>No Uhl yes/no method</td>
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<td>Study Reference</td>
<td>Study Type</td>
<td>Group Description</td>
<td>Number of Participants</td>
<td>Number of Shoulders with SD</td>
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<tr>
<td>Park et al, 2013</td>
<td>Athletic population assessment of SD</td>
<td>89 athletes (178 shoulders) (75 baseball players, 7 other overhead sports, 2 golf, and 5 occasional sport) SLAP: 15, SIS: 12, SLAP + SIS: 6, MCL: 22, SLAP + MCL: 2, VEO: 9, cuff tear: 5, glenoid OCD: 4, capitellum OCD: 4, multidirectional instability: 5, posterior labral tear: 5</td>
<td>89/178</td>
<td>Type I: 73</td>
</tr>
<tr>
<td>Park et al, 2014</td>
<td>Athletic population evaluation of SD</td>
<td>165 patients, 127 were baseball players, 5 were athletes of other overhead sports, 5 played golf, 2 played table tennis, 1 was a diver, 1 participated in bowling, 1 was an archer, and 26 enjoyed occasional sports activities. Elbow: MCL tear: 54, VEO: 40, OCD: 3, medial epicondylitis: 2, common flexor muscle strain: 3 Shoulder: SLAP: 49, multidirectional instability: 6, SLAP: 31, Bennett lesion: 3, internal impingement: 8, long head of biceps tendon tendonitis: 20, cuff tear: 3, impingement: 44, functional impingement: 8, sub coracoid impingement: 8, GIRD: 53, subscapularis tear: 1</td>
<td>165/330</td>
<td>Type I: 130</td>
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<td>Plummer et al 2017</td>
<td>Observational SD</td>
<td>135 individuals (67 with shoulder pain [33 F and 34 M] and 68 healthy controls [41 F and 27 M]; pain mean age 32.5; control mean age 27.4</td>
<td>135/135 (individuals with SD)</td>
<td>Flexion (87/135) Symptomatic: 45 Asymptomatic: 42 Abduction (81/135) Symptomatic: 45 Asymptomatic: 36</td>
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<td>Rabin et al</td>
<td>Shoulder</td>
<td>74 consecutive patients referred to an</td>
<td>74/74</td>
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<td>Year</td>
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<td>Number of Participants</td>
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<tr>
<td>2018</td>
<td>outpatient clinic</td>
<td>outpatient shoulder surgery unit (6F/68M)</td>
<td>Total-115</td>
<td>No</td>
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<td>2018</td>
<td>Sant et al 2018</td>
<td>25M semi-professional water polo players; study group mean age 23.3; control mean age 23.1</td>
<td>25/25 (individuals with SD)</td>
<td>23</td>
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<tr>
<td>2015</td>
<td>Seitz et al 2015</td>
<td>25 asymptomatic overhead athletes (swimming-5, volleyball-15, water polo-5); SD mean age 20.3; w/o SD mean age 20.5</td>
<td>25/25, dominant shoulder</td>
<td>14</td>
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<td>2016</td>
<td>Shah et al 2016</td>
<td>Musicians (guitar): presence of SD</td>
<td>40/40 (dominant shoulders only)</td>
<td>Asymmetrical (5 guitar players) (0 non guitar players) Dysskinetic (4 guitar players) (0 non guitar players)</td>
</tr>
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<td>2018</td>
<td>Silva et al 2018</td>
<td>Musicians: presence of SD</td>
<td>72/72 (26 from symptomatic group, 9 from control group)</td>
<td>36</td>
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<td>2014</td>
<td>Struyf et al 2014</td>
<td>Amateur sports, evaluating risk factors for developing SPN</td>
<td>113/113</td>
<td>Baseline no pain 25/113 developed pain within 2 years</td>
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<td>Study</td>
<td>Sport study (collegiate baseball)</td>
<td>Participants 1</td>
<td>Participants 2</td>
<td>Diagnostic Method</td>
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<tr>
<td>Tsuruike et al 2018</td>
<td>30M collegiate baseball players (13 pitchers)</td>
<td>30/30</td>
<td>14 (Mild SD in 7 pitchers + 7 position players)</td>
<td>No</td>
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<tr>
<td>Welbeck et al 2019</td>
<td>Link between thoracic rotation, SD, and pain among swimmers</td>
<td>34/34 (as individuals, not shoulders)</td>
<td>Total: 15 (6 male and 9 female)</td>
<td>No</td>
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<tr>
<td>Yesilyaprak et al</td>
<td>University research laboratory</td>
<td>148/296</td>
<td>87 (reported as individual shoulder: 87/296)</td>
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<td>Yüksel et al 2014</td>
<td>Reliability of SDT &amp; LSST</td>
<td>83/83</td>
<td>SDT detected 44 (53%), LSST detected 30 (36%), Both detected 20 (24%)</td>
<td>No</td>
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</table>

**Abbreviations:** AC; acromioclavicular, FS; frozen shoulder, GH; glenohumeral joint, GH OA; glenohumeral joint osteoarthritis, GIRD; glenohumeral internal rotation deficit, LSST; lateral scapular slide test, MCL; medial collateral ligament, OCD; osteochondritis dissecans, ROM; range of motion, ROTC; reserve officer training corps, RSP; rounded shoulder posture, SD; scapular dyskinesis, SDT; scapular dyskinesis test, SICK scapula; scapular malposition + inferior medial border prominence + coracoid pain and malposition + dyskinesis of scapular movement, SIS; shoulder impingement syndrome, SLAP; superior labrum anterior to posterior, VEO; valgus extension overload, M; Male, F; female, SPN; shoulder pain.
in instances were other diagnosis outside of shoulder conditions may have been considered as we were examining those studies that identify SD but could have been in a population of individuals with cervical or upper extremity conditions. The remaining study\textsuperscript{20} included individuals with neck pain only with a total number of 19 subjects. Within the studies for the symptomatic athletic and general orthopedic population there were 81% and 57% individuals with SD, respectively, and a total of 60% among both groups. The two studies within symptomatic athletic population that looked at both shoulders individually demonstrated a total of 79% of individuals with SD considering at least one shoulder. Within the studies for the asymptomatic athletic and general population there were 42% and 59% individuals with SD, respectively, and a total of 48% among both. The four studies within asymptomatic general population that looked at both shoulders individually there was a total of 42% of individuals with SD.

DISCUSSION

The purpose of this systematic review was to examine the available literature in order to report the prevalence of SD among both the symptomatic and asymptomatic population. The results of this systematic review indicate that there is an overall presence of SD of 60% among symptomatic individuals. Among the asymptomatic population there is an overall presence of SD of 48% among those studies that identify individuals with SD. The low number of studies that identified individuals with SD per shoulder makes it difficult to determine true differences between those with and without symptoms. Despite the overall prevalence of SD being higher among those with symptoms compared to those without, there is still a considerable number of those that present with SD (nearly half of those studied) that are asymptomatic which questions the relevance of this finding. Furthermore, the total number of symptomatic individuals, 650, within studies investigating SD was just over half the number of those studies inves-
Table 2. Joanna Briggs Institute critical appraisal checklist for studies reporting prevalence data

<table>
<thead>
<tr>
<th>Authors</th>
<th>1</th>
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</tr>
<tr>
<td>Seitz et al 2015</td>
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<td>1</td>
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<td>I</td>
</tr>
<tr>
<td>Shah et al 2016</td>
<td>1</td>
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<td>1</td>
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<td>0</td>
<td>1</td>
<td>1</td>
<td>I</td>
</tr>
<tr>
<td>Silva et al 2018</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>I</td>
</tr>
<tr>
<td>Struyf et al 2014</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>1</td>
<td>1</td>
<td>I</td>
</tr>
<tr>
<td>Tsuurike et al 2018</td>
<td>1</td>
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<td>0</td>
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<td>Welbeck et al 2019</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>Yesilyaprak et al 2016</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>I</td>
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<tr>
<td>Yüksel et al 2014</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>I</td>
</tr>
</tbody>
</table>

1=Yes, 0=No, Unclear, or Not Applicable, I=Included, E=Excluded; 1. Was the sample frame appropriate to address the target population? 2. Were study participants sampled in an appropriate way? 3. Was the sample size adequate? 4. Were the study subjects and the setting described in detail? 5. Was the data analysis conducted with sufficient coverage of the identified sample? 6. Were valid methods used for the identification of the condition? 7. Was the condition measured in a standard, reliable way for all participants? 8. Was there appropriate statistical analysis? 9. Was the response rate adequate, and if not, was the low response rate managed appropriately?

Testing SD among asymptomatic individuals, 1,048. This was reported for transparency in how the data were presented.

When considering the population of those with general shoulder pain there were a total of 582 individuals within the studies examined in this review. Among this population there was a higher percentage of individuals with SD (57%) compared to those without (43%). However, whether SD is contributing to the symptoms experienced by this population remains unclear. If SD is a contributing factor to the symptoms among the general orthopedic population with shoulder pain, then how is the high prevalence (57%) of SD
among the general population studied without symptoms explained?

There is considerable discussion in the literature regarding the presence of SD among overhead athletes with or without symptoms, as well as the presence of SD being a potential risk factor for sustaining injury in the future.\(^8,^9,^{31,32,57}\) The current findings from the current study support the high incidence of SD among athletes with shoulder symptoms. However, it is important to note that only three studies with a total of 68 individuals investigated the presence of SD within the symptomatic athlete population while 16 studies with a total of 657 individuals investigating the presence of SD in the asymptomatic athletic population were included. Given the larger number of asymptomatic athletes who were described as having SD (from 20%-92%) it is clear that a large number of athletes present with SD and have no symptoms. This may indicate that it is a possibility that SD may be a normal adaptation for those participating in overhead sports.

Additionally, the timing of measuring SD is not consistently reported among the studies that contain overhead athletes and may add further evidence that SD is a normal adaptation within this population. Two studies\(^31,32\) measured SD of asymptomatic competitive swimmers at various points of an individual training session. Both studies found that as training progressed, the number of individuals presenting with SD increased with a large number of participants presenting with SD at the end of the training session (82%\(^31\) and 85%\(^32\)). At first glance the initial perception may be that these results are suggestive of weakness or some compensatory mechanism that requires attention, however, it is possible that there is a normal adaptation related to the overall shoulder complex that causes this change to occur, particularly since these athletes were all competing at a high level without symptoms.

<table>
<thead>
<tr>
<th>Study</th>
<th>Individuals (n)</th>
<th>With Scapular Dyskinesis (n)</th>
<th>Percentage</th>
<th>Without Scapular Dyskinesis (n)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alves de Oliveira et al 2013</td>
<td>15</td>
<td>14</td>
<td>93%</td>
<td>1</td>
<td>7%</td>
</tr>
<tr>
<td>Johansson et al 2016</td>
<td>17</td>
<td>15</td>
<td>88%</td>
<td>2</td>
<td>12%</td>
</tr>
<tr>
<td>Sliva et al 2018</td>
<td>36</td>
<td>26</td>
<td>72%</td>
<td>10</td>
<td>28%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>68</strong></td>
<td><strong>55</strong></td>
<td><strong>81%</strong></td>
<td><strong>13</strong></td>
<td><strong>19%</strong></td>
</tr>
<tr>
<td>Study</td>
<td>Individuals (n)</td>
<td>With Scapular Dyskinesis (n)</td>
<td>Percentage</td>
<td>Without Scapular Dyskinesis (n)</td>
<td>Percentage</td>
</tr>
<tr>
<td>Balci et al 2016</td>
<td>53</td>
<td>22</td>
<td>42%</td>
<td>31</td>
<td>58%</td>
</tr>
<tr>
<td>Castelein et al 2016</td>
<td>19</td>
<td>9</td>
<td>47%</td>
<td>10</td>
<td>53%</td>
</tr>
<tr>
<td>Chen et al 2018</td>
<td>186</td>
<td>140</td>
<td>75%</td>
<td>46</td>
<td>25%</td>
</tr>
<tr>
<td>Christiansen et al 2017</td>
<td>40</td>
<td>18</td>
<td>45%</td>
<td>22</td>
<td>55%</td>
</tr>
<tr>
<td>Deng et al 2017</td>
<td>102</td>
<td>37</td>
<td>36%</td>
<td>65</td>
<td>64%</td>
</tr>
<tr>
<td>Huang et al 2015</td>
<td>41</td>
<td>29</td>
<td>71%</td>
<td>12</td>
<td>29%</td>
</tr>
<tr>
<td>Plummer et al 2017</td>
<td>67</td>
<td>45</td>
<td>67%</td>
<td>22</td>
<td>33%</td>
</tr>
<tr>
<td>Rabin et al 2018</td>
<td>74</td>
<td>33</td>
<td>45%</td>
<td>41</td>
<td>55%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>582</strong></td>
<td><strong>333</strong></td>
<td><strong>57%</strong></td>
<td><strong>249</strong></td>
<td><strong>43%</strong></td>
</tr>
<tr>
<td>Studies</td>
<td>Individuals (n)</td>
<td>With Scapular Dyskinesis (n)</td>
<td>Percentage</td>
<td>Without Scapular Dyskinesis (n)</td>
<td>Percentage</td>
</tr>
<tr>
<td><strong>Symptomatic Total</strong></td>
<td><strong>650</strong></td>
<td><strong>388</strong></td>
<td><strong>60%</strong></td>
<td><strong>262</strong></td>
<td><strong>40%</strong></td>
</tr>
</tbody>
</table>
Table 4. Asymptomatic Individuals (counted SD for an individual)

<table>
<thead>
<tr>
<th>Athletic / Musicians</th>
<th>Study</th>
<th>Individuals (n)</th>
<th>With Scapular Dyskinesis (n)</th>
<th>Percentage</th>
<th>Without Scapular Dyskinesis (n)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alves de Oliveira et al 2013</td>
<td>15</td>
<td>6</td>
<td>40%</td>
<td>9</td>
<td>60%</td>
</tr>
<tr>
<td></td>
<td>Bullock et al 2021</td>
<td>33</td>
<td>15</td>
<td>45%</td>
<td>18</td>
<td>55%</td>
</tr>
<tr>
<td></td>
<td>Da Silva et al 2008</td>
<td>53</td>
<td>23</td>
<td>43%</td>
<td>30</td>
<td>57%</td>
</tr>
<tr>
<td></td>
<td>Frizziero et al 2018</td>
<td>32</td>
<td>15</td>
<td>47%</td>
<td>17</td>
<td>53%</td>
</tr>
<tr>
<td></td>
<td>Johansson et al 2016</td>
<td>14</td>
<td>4</td>
<td>29%</td>
<td>10</td>
<td>71%</td>
</tr>
<tr>
<td></td>
<td>Kawasaki et al 2012</td>
<td>103</td>
<td>33</td>
<td>32%</td>
<td>70</td>
<td>68%</td>
</tr>
<tr>
<td></td>
<td>Lee et al 2017</td>
<td>26</td>
<td>7</td>
<td>27%</td>
<td>19</td>
<td>73%</td>
</tr>
<tr>
<td></td>
<td>Madsen et al 2011</td>
<td>78</td>
<td>29</td>
<td>37%</td>
<td>49</td>
<td>63%</td>
</tr>
<tr>
<td></td>
<td>Maor et al 2017</td>
<td>20</td>
<td>6</td>
<td>30%</td>
<td>14</td>
<td>70%</td>
</tr>
<tr>
<td></td>
<td>Sant et al 2018</td>
<td>25</td>
<td>23</td>
<td>92%</td>
<td>2</td>
<td>8%</td>
</tr>
<tr>
<td></td>
<td>Seitz et al 2015</td>
<td>25</td>
<td>14</td>
<td>56%</td>
<td>11</td>
<td>44%</td>
</tr>
<tr>
<td></td>
<td>Shah et al 2016</td>
<td>20</td>
<td>4</td>
<td>20%</td>
<td>16</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>Silva et al 2018</td>
<td>36</td>
<td>9</td>
<td>25%</td>
<td>27</td>
<td>75%</td>
</tr>
<tr>
<td></td>
<td>Struyf et al 2014</td>
<td>113</td>
<td>62</td>
<td>55%</td>
<td>51</td>
<td>45%</td>
</tr>
<tr>
<td></td>
<td>Tsuruike et al 2018</td>
<td>30</td>
<td>14</td>
<td>47%</td>
<td>16</td>
<td>53%</td>
</tr>
<tr>
<td></td>
<td>Wellbeck et al 2019</td>
<td>34</td>
<td>15</td>
<td>44%</td>
<td>19</td>
<td>56%</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>657</strong></td>
<td><strong>279</strong></td>
<td><strong>42%</strong></td>
<td><strong>378</strong></td>
<td><strong>58%</strong></td>
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</table>

<table>
<thead>
<tr>
<th>General Population</th>
<th>Study</th>
<th>Individuals (n)</th>
<th>With Scapular Dyskinesis (n)</th>
<th>Percentage</th>
<th>Without Scapular Dyskinesis (n)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Akodu et al 2018</td>
<td>77</td>
<td>54</td>
<td>70%</td>
<td>23</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>Camci et al 2013</td>
<td>64</td>
<td>40</td>
<td>63%</td>
<td>24</td>
<td>37%</td>
</tr>
<tr>
<td></td>
<td>Castelein et al 2016</td>
<td>19</td>
<td>8</td>
<td>42%</td>
<td>11</td>
<td>58%</td>
</tr>
<tr>
<td></td>
<td>Da Silva et al 2008</td>
<td>20</td>
<td>4</td>
<td>20%</td>
<td>16</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>Hannah et al 2017</td>
<td>40</td>
<td>27</td>
<td>68%</td>
<td>13</td>
<td>32%</td>
</tr>
<tr>
<td></td>
<td>Plummer et al 2017</td>
<td>68</td>
<td>42</td>
<td>62%</td>
<td>26</td>
<td>38%</td>
</tr>
<tr>
<td></td>
<td>Shah et al</td>
<td>20</td>
<td>0</td>
<td>0%</td>
<td>20</td>
<td>100%</td>
</tr>
</tbody>
</table>
This would not be unlike what is known regarding the increase in external rotation range of motion at the gleno-humeral joint within a single game and over the course of the season in a baseball pitcher. Within baseball pitchers this adaptation is not only normal, but necessary to perform at a high level.

LIMITATIONS

There are several limitations to this systematic review. The first limitation is that only included studies published in the English language were included which may have excluded published studies on this topic. Additionally, a very strict inclusion and exclusion criteria was applied in order to identify those studies that would provide the appropriate data for the purpose of this study. Lastly, there is a lack of consistency among how SD is measured across studies as well as populations, so it was not possible to perform a meta-analysis.

CONCLUSION

Within the symptomatic population, athletes have a higher percentage SD than the general orthopedic population. However, there are a considerable number of individuals with symptoms that do not present with SD. Perhaps more revealing is the number of asymptomatic individuals that present with SD, suggesting that SD may be a relatively normal finding among nearly half of the asymptomatic population studied within the literature. Until longitudinal studies are completed that monitor the predictive value of SD over time amongst asymptomatic populations, the relevance of this finding will remain uncertain.

ACKNOWLEDGEMENTS

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CONFLICT OF INTEREST DECLARATION

The authors declare no conflict of interest.

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REFERENCES


SUPPLEMENTARY MATERIALS

Supplemental File B

Supplemental File A
Systematic Review/Meta-Analysis

Vestibular Rehabilitation as an Early Intervention in Athletes Who are Post-concussion: A Systematic Review

Gabrielle Babula1, Edward Warunek, Katherine Cure, Grace Nikolski, Heather Fritz, Susan Barker

1 Physical Therapy, Misericordia University

Keywords: vestibular rehabilitation, concussion, mTBI, athletes, early intervention, physical therapy

https://doi.org/10.26603/001c.75369

International Journal of Sports Physical Therapy

Background

Sports-related concussions (SRC) are a common injury sustained by many athletes of all different age groups and sports. The current standard treatment is rest followed by aerobic activity. Minimal research has been done on the effects of vestibular rehabilitation for concussion treatment, especially in physical therapy practice.

Objective

The purpose of this study was to examine the effects of early intervention of vestibular rehabilitation (VRT) on an athlete's time to return to play compared to rest alone.

Study Design

Systematic Review

Methods

Two searches were conducted (August 2021 and January 2022) using databases: CINAHL complete, MEDLINE, PubMed, and Wiley online database. One hand search was performed to find relevant articles. Search terms included "vestibular rehabilitation" or "vestibular therapy" and "concentration" or "mild traumatic brain injury" or "mTBI" and "athletes" or "sports" or "athletics" or "performance", and "early interventions" or "therapy" or "treatment". Inclusion criteria were athletes with a SRC, incorporation of vestibular rehabilitation in athletes’ recovery, and early vestibular intervention tools. Tools used to assess quality and risk of bias were the PEDro scale and the Oxford Centre for Evidence-Based Medicine 2011 Levels of Evidence. The PRISMA method for determining inclusion and exclusion criteria.

Results

Eleven articles were included, six randomized control trials and five retrospective cohort studies. Various balance interventions, visual interventions utilizing vestibulo-ocular reflex (VOR), and cervical manual therapy were used during VRT for athletes’ post-concussion. Incorporating visual interventions and cervical manual therapy into early rehabilitation significantly reduced symptoms and time to return to sport. However, balance interventions did not have a significant effect on reducing time to return to sport when used as a sole intervention.

Conclusion

Addressing VRT deficits in the acute stages of a concussion may contribute to a quicker resolution of symptoms and a quicker return to sport. More research needs to be...
performed to determine the effectiveness of early intervention of VRT in concussion recovery.

**Level of Evidence**

1

**INTRODUCTION**

Sport-related concussions (SRC) are a common injury across all age groups. SRC was defined by McCrory\(^1\) in 2017 and adopted by athletic leagues including the National Collegiate Athletic Association and National Football League as a traumatic brain injury induced by biomechanical forces through either direct or indirect forces to the head causing neurological and cognitive dysfunction.\(^2,3\) Concussions involving loss of consciousness, and later symptoms of dizziness and confusion, is correlated with a prolonged recovery time. Dizziness during the acute stage of concussion is reported in up to 81% of cases.\(^4,5\)

Due to concerns that early activity such as quick return to contact sports and school related functions may disrupt healing and prolong return to sport post-concussion, the gold standard in concussion treatment is rest followed by various levels of aerobic activity.\(^6\) However, further research has shown that an extended period of rest after a concussion may result in prolonged recovery time.\(^7\) Recent literature has examined the efficacy of vestibular rehabilitation (VRT) in concussion treatment for the management of post-concussion symptoms. Using VRT as an early treatment for concussions in athletes has been shown to reduce severity of symptoms and duration, therefore decreasing recovery time to less than 21 days.\(^8,9\) This suggests that vestibular rehabilitation can be an effective early intervention for SRCs.\(^10,11\)

Despite the strong evidence found to support the use of VRT, results are conflicting regarding when to initiate this intervention and little is known about what is considered to be the best initial treatment for athletes who have experienced a concussion. Therefore, the purpose of this study was to examine the effects of early intervention of VRT on an athlete's time to return to play compared to rest alone.

**METHODS**

Prior to beginning research, a PICO question was developed to determine eligibility criteria and objective of the study. The PICO question asked, "Does vestibular rehabilitation decrease return to sports time in athletes who experienced a concussion?" This addressed:

- **Population**: Athletes of all ages ranging from 5-30 years old.
- **Interventions**: Vestibular rehabilitation tools involving the vestibular, somatosensory, and visual systems performed by physical therapists to athletes after sustaining a concussion.
- **Comparison**: Alternative treatments such as rest and aerobic activity.
- **Outcomes**: Time for resolution of symptoms and an athlete's time to return to play.

A computerized electronic search was performed to identify relevant articles from the following databases: CINAHL complete, MEDLINE, PubMed, and Wiley online database. Two searches were conducted: one in August 2021 and one in January 2022 as these were the available times the four researchers collectively searched and reviewed the literature. Articles were screened for randomized control trials and retrospective studies as these are primary studies that provide the best evidence for conducting a systematic review. The search terms included "vestibular rehabilitation" or "vestibular therapy" and "concussion" or "mild traumatic brain injury" or "mTBI" and "athletes" or "sports" or "athletics" or "performance", and "early interventions" or "therapy" or "treatment". One hand search from the included studies was performed to find additional relevant studies to the research question. The four primary researchers were responsible for article collection, screening, and selection and they established 100% consensus regarding inclusion. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methods were used throughout the search process to determine inclusion and exclusion criteria for the articles reviewed and to evaluate the effects of each research article (Figure 1).\(^12\)

Articles were included by author consensus after reviewing titles and abstracts of all relevant items that discussed SRC in athletes, vestibular interventions, and tools for early intervention and recovery and were in accordance with the systematic review protocol based on PRISMA. Exclusion criteria included articles published earlier than 2008, systematic reviews, and no discussion or mention of athletes or use of vestibular rehabilitation in the study. Other systematic reviews were not included as these are secondary sources and would not provide adequate information.

Risk of bias assessment was based on the PEDro scale which was determined as a consensus by each researcher. PEDro scores of 0-3 are considered 'poor', between 4-5 are 'fair', 6-8 is considered 'good', and a score of 9-10 is 'excellent'.\(^13\) All articles included in the review were analyzed using the Oxford Centre for Evidence-Based Medicine 2011 Levels of Evidence, a hierarchy of evidence scale.\(^14\) This scale was used to assess whether the evidence in the articles were relevant to the PICO criteria and question. Data were extracted regarding subject numbers and groups, interventions used in each article, assessment tools, outcomes, limitations, and conclusions.

**RESULTS**

Eleven studies met the inclusion criteria with nine articles utilizing VRT as a treatment to reduce post-concussion symptoms and two utilizing VRT to measure the severity of vestibular symptoms after sustaining a concussion. This review contains six RCTs and five retrospective cohort stud-
ies. The quality of the included studies, assessed using the PEDro scale, can be found in supporting file (Appendix 1). The scores of the included studies range from 4-8, indicating fair to good quality evidence.

The included RCTs utilized cervical manipulation, postural exercises, cervical ROM, rest, and vestibulo-ocular exercises as interventions for post-concussion symptoms in athletes and recovery time back to sports. Athletes from various contact sports such as soccer, football, field hockey, lacrosse, and snowboarding were observed in the research.

**VRT: BALANCE INTERVENTIONS AND OUTCOME MEASURES USED TO EVALUATE BALANCE**

Five studies utilized static and dynamic balance activities as concussion treatment in an athlete’s return to play. Balance deficits are caused by abnormal sensory processing following a concussion and these deficits are commonly used to treat athletes in their recovery. In the retrospective cohort study performed by Ahluwalia et al., dynamic balance training was observed in 23 patients with SRC. Researchers divided patients into two groups, early therapeutic intervention, and late therapeutic intervention. The Post-Concussion Symptom Scale (PCSS) was one of the outcome measures used by Ahluwalia et al. The PCSS is commonly used by clinicians to obtain objective data regarding patients’ perceptions of the severity of their symptoms. It is a 22-item questionnaire that ranks symptoms from none (0) to severe (6), with a maximum score of 132. A second outcome measure used was the number of days to initiate VRT. The PCSS was used to determine the resolution date of symptoms, return to play date, and return to learn date. Early therapy was defined as less than 30 days after injury and late therapy as more than 30 days after injury. Ahluwalia et al. found that the early therapy group achieved a 0 on the Post-Concussion Symptom Scale (PCSS) for balance deficits, meaning that symptoms were resolved by the time the athlete returned to play. The late therapy group achieved a 0.5 in balance deficits suggesting that the early rehabilitation group had a quicker return to play than those who participated in the late rehabilitation.

Schneider et al. recorded patient reports of improvements in standing balance exercises and dynamic balance exercises through the Activities-specific Balance Confidence Scale (ABC scale) at baseline and at time the athlete was cleared to return to sport. Athletes were separated into two groups, with the control group receiving conservative physical therapy interventions and the intervention group receiving VRT with additional balance interventions. Athletes who were not cleared to return to sport were re-eval-

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**Figure 1. Flow diagram of article identification following PRISMA guidelines**
uated at eight weeks after their initial measurement. Both groups received cervical range of motion, stretching, and postural exercises. The intervention group included balance exercises. After eight weeks of intervention, 30% of athletes in the control group were cleared to return to play, compared to 8% in the treatment group based on the ABC scale.16

Along with the ABC scale, the Balance error scoring system (BESS) was used throughout various studies observing concussion symptoms in athletes. The BESS is a common outcome measure used to assess postural stability. The test measures three different positions: double-leg stance with hands on hips and feet together, single-leg stance on non-dominant leg with hands on hips, and tandem stance with non-dominant foot behind the dominant foot. Each stance is measured on a firm surface, then a foam surface with eyes closed. The evaluator gives one point for every error made on each position. All six stances are allotted up to 10 points. The lower the score, the better the balance.17

Using these outcome measures to create balance interventions has shown to be more effective at improving balance related symptoms compared to the standard concussion treatment of rest.18 Storey et al19 reported athletes who completed the BESS at initial evaluation had an average score of 33.8, which decreased to 21.7 at final evaluation.19 After completing a tandem gait task and other balance exercises, 14.1% of athletes reported balance deficits at final evaluation compared to 65% at initial evaluation.19

The Modified Balance Error Scoring System (mBESS) is a balance measure used by researchers Kontos et al20 in their randomized control trial to assess postural stability during static balance stances in subjects’ post-concussion. The three balance stances used were: double leg stance, tandem stance, and single leg stance on the non-dominant leg. These assessments were also used to determine time to return to play. Upon initial clinical assessment, participants in the vestibular group received an mBESS score of 5.4 (+/- 5.6) and those in the control group received a score of 4.6 (+/- m 2.8). Post-intervention, those in the vestibular group received an mBESS score of -1.36 (+/- 0.61) and the control group received a score of -0.80 (+/- 0.64).8 No significant differences were found between groups, suggesting that the use of vestibular rehabilitation alone as an early intervention is not successful in reducing balance deficits related to concussion injuries. There was no significant difference in postural stability during balance between the vestibular and control group.

VRT: VISUAL INTERVENTIONS AND TOOLS TO MEASURE VISUAL OCULAR PERFORMANCE

Ten studies utilized visual interventions and testing for visual ocular function. These interventions consisted of near point convergence (NPC), horizontal saccades, vertical saccades, smooth pursuits, adaptation, habituation, hand-eye coordination, and gaze stabilization exercises often called the vestibulo-ocular reflex (VOR). Descriptions of each VOR test and normal findings are outlined in Table 1. These tests can be used as interventions to treat vestibular deficits.

To screen for visual impairments related to vestibular dysfunction, the Vestibular Ocular Motor Screening (VOMS) is used. The VOMS includes five domains: smooth pursuit, horizontal and vertical saccades, near point of convergence (NPC) difference, horizontal VOR, and visual motion sensitivity (VMS).10 The VOMS is scored using a 10-point Likert scale with 0 being no symptoms and 10 being severe symptoms. Mucha et al10 reported that athletes who receive a score of ≥ 2 indicates a concussion. Current research has identified the VOR and VMS components as being the most predictive of a concussion.10,11

Ellis et al24 studied smooth pursuits, near point convergence, horizontal and vertical saccades, and VOR in their retrospective review. Abnormalities of smooth pursuits were indicated by saccadic eye movements while abnormalities of near point convergence were defined as diplopia or inability to maintain fixation greater than 6 cm from the bridge of the patient’s nose.24 Overshooting or more than two saccadic corrections during testing was deemed abnormal when testing horizontal and vertical saccades. A report of worsening of vestibular and oculomotor symptoms during VOR testing were deemed abnormal. These results suggested that those who presented with vestibular-ocular dysfunction (VOD) had a longer recovery of 40 days compared to 20 days in those presenting without VOD.24 Similarly, Whitney et al.11 reported that in NCAA athletes scoring ≥ 2 on the VOMS, specifically in the smooth pursuits, saccades, and convergence components was correlated with a significantly longer recovery time. Those authors concluded that it is important to assess for vestibular eye dysfunction within three days of sustaining a concussion. However, Glendon et al20 reported that the VOMS should be incorporated within the initial two weeks following a SRC. In their data collection, the authors found that the average time to RTP was 22 days. The athletes that presented with VOM impairment were able to return to play within 50-51 days which was a 14-day difference compared to those without a VOM impairment.20

Ahuwalia et al15 also utilized gaze stabilization exercises and focused on convergence insufficiency, saccadic eye movements, and accommodative dysfunction. Their study discussed utilizing seated VOR exercises with progressions to standing balance exercises as part of the athlete’s treatment plan. Habituation and adaptation exercises were also used. This study found that patients who started late therapy (after 50 days) took longer to return to play and achieve visual symptom resolution. The early therapy group had a mean score of 1 (IQR: 0, 5.5) in the ocular score and blurred vision on the PCSS whereas the late therapy group also had a mean score of 1 (IQR: 0, 2) on the PCSS.15

Reneker et al,21 utilized vestibular rehabilitation techniques that included habituation, adaptation, oculomotor control, neuromotor control (including proprioceptive and kinesthetic awareness), as well as balance exercises as indicated by the six therapists in charge of rehabilitation. These interventions were used to promote symptomatic recovery and medical clearance for return to play. These authors found that the vestibular treatment group recovered 1.99 times faster when compared to the control group. These re-
Table 1. VRT Tests\textsuperscript{10,11,15,16,20–23}

<table>
<thead>
<tr>
<th>Tests</th>
<th>Description</th>
<th>Normal result</th>
<th>Abnormal results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near point convergence</td>
<td>Ability to focus on an object as it moves closer to the bridge of the nose</td>
<td>Focusing on specified object at 6cm or closer</td>
<td>Diplopia or inability to maintain fixation greater than 6 cm from the bridge of the patient’s nose</td>
</tr>
<tr>
<td>Horizontal and vertical saccades</td>
<td>Ability to quickly shift gaze right to left (horizontally) or up and down (vertically) while maintaining a stationary head position.</td>
<td>Quickly changing focus between two objects without having to correct eye position</td>
<td>Overshooting or more than two saccadic corrections during testing</td>
</tr>
<tr>
<td>Smooth pursuits</td>
<td>Ability to coordinate smooth eye movements right and left (horizontally) and up and down (vertically) while maintaining a stationary head position.</td>
<td>Slowly following an object through all visual fields with consistent normal eye movements</td>
<td>Saccadic eye movements present</td>
</tr>
<tr>
<td>Adaptation</td>
<td>Ability to focus gaze on a stationary object while moving head right and left (horizontally) and up and down (vertically).</td>
<td>Maintaining focus on an object while moving heading</td>
<td>Patient experiences dizziness or inability to keep eyes focused with head movement</td>
</tr>
<tr>
<td>Habitation</td>
<td>Use of repeated exposure to symptom-provoking positions or movements to reduce dizziness overtime.</td>
<td>Symptoms will lessen as practice with stimuli continues</td>
<td>No change in stimulus effect over time</td>
</tr>
<tr>
<td>Hand-eye coordination</td>
<td>Activities incorporating simultaneous use of hands and eyes, such as throwing darts, juggling, or catching a ball.</td>
<td>Good communication between visual cues and voluntary muscles allowing task completion.</td>
<td>Inability to perform various tasks that require precision</td>
</tr>
<tr>
<td>Gaze stabilizations /Vestibulo Ocular Reflex (VOR)</td>
<td>Patient fixates on an object 0.5–1 meter from the bridge of the nose and shakes their head back and forth 30° from midline for 5–10 seconds. An attempt to ‘recalibrate’ connection between eyes and ears</td>
<td>No change in symptoms</td>
<td>A report of worsening of vestibular and oculomotor symptoms indicates an abnormal result</td>
</tr>
</tbody>
</table>

Results indicate those in the experimental group were medically cleared to return to sport at a faster rate than those in the control group, and that the experimental intervention is safe and feasible to perform. It also found that those with a prior history of concussion recovered faster than those who have no history.\textsuperscript{21} The intervention in the Schneider et al\textsuperscript{16} study included an individualized program consisting of habituation, gaze stabilization, adaptation exercises, and canalith repositioning maneuvers as needed. Dizziness or balance deficits are caused by abnormal sensory input, so the study focused on maintaining proper orientation. This is done by having equal and consistent visual, vestibular, and proprioceptive input through interactions with the environment.\textsuperscript{16} These authors also addressed cervical spine dysfunction with either manual techniques or a combination of neurological and sensory motor aspects. Their findings suggest that individuals with persistent post-concussion symptoms are more likely to be medically cleared to return to sport within eight weeks of concussion when using a multimodal approach to treatment.\textsuperscript{16}

Storey et al.\textsuperscript{19} utilized a standard visuo-vestibular examination including smooth pursuits, horizontal and vertical saccades, horizontal and vertical gaze stability, tandem gait, near point of convergence (NPC), and accommodation. Interventions were created based on the findings of these examinations. Interventions included VOR and balance techniques to improve deficits found during initial examination. Their results indicated that 74% of participants no longer had deficits at final evaluation.

Integrated cervical, vestibular, and visual treatment were utilized by Wong et al.\textsuperscript{22} Visual interventions included smooth pursuits, saccades, complex motor tasks including divided attention and laterality, and vergences. Results indicated significant improvement for convergence however, no significant changes in divergence and abnormal saccades were found between baseline and final evaluation.\textsuperscript{20} Additionally, 55.6% people who had cervical dysfunction at initial evaluation were cleared with normal cervical ROM, and 100% diagnosed with BPPV symptoms were cleared with full resolution of symptoms.\textsuperscript{22}

Majerske et al observed concussion symptom resolution with repeated measures of neurocognitive performance in athletes.\textsuperscript{25} The authors found that younger athletes had more difficulty with visual memory, visual motor speed, and reaction time compared to the older athletes. However, the study did not examine whether these symptoms resulted in a longer RTP. Rather, the authors concluded that a well-rounded treatment plan of vestibular, cognitive, and behavioral management should be included in an athlete’s recovery, but more research needs to be conducted on how
soon after injury these interventions should be incorporated.\textsuperscript{25}

**VRT AND CERVICAL MANUAL THERAPY**

Three studies used cervical manual therapy in combination with VRT to treat vestibular symptoms.\textsuperscript{16,21,22} Cervical manual therapy (CMT) treatments included soft tissue release, joint mobilization, and manipulation techniques, cervical neuromotor retraining exercises, and cervical stretching. CMT is used in conjunction with VRT to treat headaches that may occur from whiplash or force trauma that can occur at the time of a concussion.\textsuperscript{16} Due to whiplash and/or biomechanical forces cervicogenic headaches are a common symptom.\textsuperscript{16,22}

The use of CMT in conjunction with VRT has been shown to increase cervical ROM, decrease average time until medical release,\textsuperscript{21} decrease average days until symptom resolution when using the Post-Concussion Scale (PCS).\textsuperscript{21} Acute concussion was defined as up to 14 days post-concussion in a study by Reneker et al.\textsuperscript{21} Subjects were eligible for examination and to begin therapy treatment at 10 days post-concussion. The average time of treatment until medical release for those in the experimental group was 15.5 days, and 26 days for those in the control group. The average number of days to recover when using the Post-Concussion Scale (PCS) was 15.5 days for the experimental group and 17 days for the control group. Additionally, participants who received treatment for cervical dysfunction and vestibular dysfunction demonstrated significant improvements in cervical ROM (55.6\%) and post-concussion symptoms.\textsuperscript{22}

In the study by Schneider et al,\textsuperscript{16} the intervention group received both cervical and thoracic manual therapy as well as vestibular rehabilitation whereas the control group underwent conventional physical therapy interventions, not including CMT or VRT. Cervical spine interventions were performed prior to providing vestibular rehabilitation during each session. Objective outcome measures used included the Sport Concussion Assessment Tool (SCAT) and the Dizziness Handicap Inventory (DHI). The SCAT is a standardized tool used for evaluating suspected concussions that was first published in 2004 by the Concussion in Sport Group.\textsuperscript{25} Since then, it has been continuously updated leading to the development of the SCAT 5 in 2017. Although the SCAT employs a baseline neurological screen, it does not utilize adequate vestibular or oculomotor testing.\textsuperscript{25} The DHI is a 25 item self-assessment designed to evaluate the self-perceived handicapping effects imposed by dizziness.\textsuperscript{26} Of the participants that completed the study, one of fourteen participants (7.1\%) in the control group was cleared to return to sports within the eight weeks of treatment while eleven of fifteen participants (75.3\%) in the intervention group were cleared,\textsuperscript{16} and 64\% of participants that were medically cleared reported no cervical pain. Participants who did not complete the study were included in final data analysis and these results suggest that 55\% more of the participants in the treatment group would be cleared to return to sport within 8 weeks. These statistics suggest that utilizing vestibular rehabilitation and cervical manual therapy to treat concussions makes athletes 10.27 times more likely to be medically cleared to return to sport within 8 weeks of initial concussion onset.\textsuperscript{16} Additionally, participants in the intervention group who were medically cleared to return to sport showed greater improvements in Sport Concussion Assessment Tool-2 total score and the Dizziness Handicap Inventory (DHI) score as compared to those participants that were not medically cleared to return to sport.

**DISCUSSION**

The aim of this systematic review was to evaluate the benefit of early vestibular rehabilitation therapy in reducing symptoms of post-concussion syndrome and return to sports time compared to rest. The randomized control trials and retrospective cohort studies mentioned in this review provide evidence that monitoring these symptoms is effective at revealing concussions and assisting with the development of a recovery timeframe. However, not all results showed beneficial outcomes between vestibular exercises and an early return to sport.

**VRT: BALANCE INTERVENTIONS**

Ahluwalia et al\textsuperscript{15} utilized various progression of balance loads with the addition of gaze stability and VOR exercises, however, specifics were not mentioned in the study. Delaying VTR initiation more than 30 days post-injury appears associated with prolonged times to RTP and achievement of symptom resolution.\textsuperscript{15} However, more research should be conducted to determine effects of early initiation of VRT on return to learn rather than just return to play. Return to learn indicates when an athlete is allowed back to normal school functions such as sitting in a classroom with bright lights, using tablets/screens/computers, and focusing on the usual schoolwork/studying. This is important to note as it can dictate an athlete’s post-concussion symptoms and whether they are ready to also return to their specified sport. Schneider et al\textsuperscript{16} concluded that a combination of cervical and vestibular physiotherapy decreased time to medical clearance to return to sport in youth and young adults with persistent symptoms of dizziness, neck pain and/or headaches following a sport-related concussion.\textsuperscript{16} Although this particular study discussed the residual effects of post-concussion symptoms, little is known as to when it is safe to begin VOR and balance exercises immediately after a concussion. Story et al. indicated that even young children with persistent dizziness and balance deficits after concussion can tolerate and potentially benefit from a course of vestibular rehabilitation.\textsuperscript{19} Yet again, the time frame to include these types of exercises is not outlined in a 'return to play' protocol for athletes. Kontos et al. demonstrated that adolescents who receive early (<21 days from injury) vestibular rehabilitation intervention following concussion experience more pronounced clinical improvement in vestibular items (as measured by the VOMS) than a behavioral management control group.\textsuperscript{8}
Based on the results from these studies, there is no clear timeline as when to begin balance activities to treat vestibular symptoms during concussion recovery.

**VRT: VISUAL INTERVENTIONS AND CERVICAL MANUAL THERAPY**

Ellis et al. discussed that patients with VOD take twice as long to recover following acute SRC compared to those without VOD. The identification of the presence of VOD at initial consultation is important to prevent prolonged recovery and development of PCS. Based on the results interpreted from Wong et al., visual and vestibular rehabilitation improved clinical and patient-reported outcomes for all systems. Therefore, it is important to assess for vestibular symptoms within the first three weeks following injury to improve recovery time. Patients with physical symptoms at 10 days post-concussion may benefit from PT interventions consisting of individually prescribed manual techniques, vestibular rehabilitation, oculomotor, and neuro-motor retraining. These should be performed much earlier than one week into an athlete's recovery from a concussion to prevent chronic physical symptoms from developing.

Based on the results from different studies, balance interventions alone were not proven to be an effective treatment at significantly reducing early concussion symptoms if used without other vestibular interventions. Solely using balance interventions does not address the other systems (visual and vestibular) that are highly affected during a concussion. However, there were no positive or negative significant differences between groups, indicating they did not hinder an athlete's performance. Visual interventions along with cervical manual therapy showed significant improvements in concussion symptoms when performed early (10–30 days after onset of injury) as compared to performing these interventions at a late onset of injury (after 30 days). This is due to the idea that multiple systems need to be addressed when treating for concussion symptoms as multiple systems are injured when a concussion is sustained. While some appear to recover from concussions in a relatively short time frame it appears that those who display vestibular symptoms require the most time to reach full recovery secondary to the thought that several systems must work together to achieve equilibrium in a person's body. Patients with vestibular signs on initial evaluation, along with those who experienced prior concussions take a significantly longer time to return to sport. These patients also achieved worse scores on computerized neuropsychological testing and require longer recovery times. Although more research and data collection studies need to be done to determine the effectiveness of early intervention of VRT for SRC; using VRT in conjunction with a standard protocol can reduce post-concussion symptoms and reduce an athlete's time to return to play.

**LIMITATIONS**

This systematic review had several limitations related to the amount of available data on the topic of VRT and SRC, including a limited number of randomized controlled, and differences in the age groups and genders of the athletes represented in each study. The age of participants ranged from five to thirty years. This is a large age range and represents vast differences in brain development which may affect recovery from a concussion or a mild traumatic brain injury. Additionally, there was an absence of consistency within the included articles with the type of sport (contact vs non-contact) played when the athlete sustained the concussion, the severity of the concussion and related symptoms, and a lack of a consistent definition for defining medical release for the athlete to return to sport.

**CONCLUSION**

Beginning vestibular rehabilitation therapy as early as 10 to 14 days post-concussion does not appear to be detrimental to an athlete's healing and may help to reduce recovery time and time to return to sports. However, more data collection is needed to further determine the effectiveness of VRT as an early intervention in reducing post-concussion symptoms and decreasing recovery time before return to sport. Leaving vestibular symptoms untreated is shown to have long term effects and a prolonged return to play interval. Therefore, incorporating vestibular rehabilitation therapy into concussion recovery protocols is beneficial for the athlete's long-term health.

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**COI STATEMENT**

All authors of this manuscript declare that they have no financial or non-financial conflicts of interest to disclose.

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REFERENCES


Appendix 1

Background and Purpose

The Expanded Cutting Alignment Scoring Tool (E-CAST) is a two-dimensional qualitative scoring system that has demonstrated moderate inter-rater and good intra-rater reliability for the assessment of trunk and lower extremity alignment during a 45-degree sidestep cut. The primary purpose of this study was to examine the reliability of the quantitative version of the E-CAST among physical therapists and to compare the reliability of the quantitative E-CAST to the original qualitative E-CAST. The hypothesis was that the quantitative version of the E-CAST would demonstrate greater inter-rater and intra-rater reliability compared to the qualitative E-CAST.

Study Design

Observational cohort, repeated measures reliability study

Methods

Twenty-five healthy female athletes (age 13.8±1.4 years) performed three sidestep cuts with two-dimensional video capturing frontal and sagittal views. Two physical therapist raters independently scored a single trial using both views on two separate occasions. Based on the E-CAST criteria, select kinematic measurements were extracted using a motion analysis phone application. Intraclass correlation coefficients and 95% confident intervals were calculated for the total score, and kappa coefficients were calculated per kinematic variable. Correlations were converted to z-scores and compared to the six original criteria for significance (α<0.05).

Results

Cumulative intra- and inter-rater reliability were both good (ICC=0.821, 95% CI 0.687-0.898 and ICC=0.752, 95% CI 0.565-0.859). Cumulative intra-rater kappa coefficients ranged from moderate to almost perfect, and cumulative inter-rater kappa coefficients ranged from slight to good. No significant differences were observed between the quantitative and qualitative criteria for either inter- or intra-rater reliability (Z_{obs(intra)}= -0.38, p=0.352 and Z_{obs(inter)}= -0.30, p=0.382).
Conclusion
The quantitative E-CAST is a reliable tool to assess trunk and lower extremity alignment during a 45-degree sidestep cut. No significant differences were observed in reliability of the quantitative versus qualitative assessment.

Level of evidence
3b

INTRODUCTION
An estimated 2.5 million sports-related knee injuries occur in adolescents annually in the United States, resulting in significant time loss from sports participation for young athletes.1–4 Female athletes are disproportionately more susceptible to sport-related knee injury than males, having a two to ten times greater risk for sustaining severe ligamentous injuries such as an anterior cruciate ligament (ACL) rupture.5–7 ACL injuries impose a significant burden on young athletes, including time away from sports and peers, extended rehabilitation and high healthcare costs, thus, injury prevention interventions have been sought to reduce injury risk.8 The use of clinical screening tools and preventive interventions to address modifiable injury risk factors has been recommended to reduce the overall incidence of knee injuries in this population.7
Up to 70% of all ACL injuries occur via a non-contact mechanism commonly involving deceleration and/or a direction change on a planted foot.9 Specifically, neuromuscular deficits at the trunk and lower extremity (LE) have been identified as key modifiable risk factors for ACL injury during changes in direction or cutting maneuvers.10–13 However, clinical screening tools analyzing movement patterns during a cutting maneuver are currently limited. Weir et al. reported fair to excellent inter-rater reliability and poor to excellent inter-rater reliability for a quantitative two-dimensional (2D) assessment of a 45-degree sidestep cut in 15 junior and 15 elite senior female field hockey players.14 In their study, angular measurements demonstrated higher reliability compared to displacement measures such as foot-pelvis distance and knee valgus displacement.14 Alternatively, the Cutting Movement Assessment Score (CMAS), a qualitative assessment, was found to be a reliable and valid tool to assess movement patterns during a 90-degree cutting task in collegiate athletes.15 Another qualitative assessment, the Cutting Alignment Scoring Tool (CAST), reported good inter-rater and intra-rater reliability for assessing trunk and LE alignment in the frontal plane during a 45-degree sidestep cut in young athletes (age = 14.7±1.2 years).16 The CAST was further developed with the Expanded Cutting Alignment Scoring Tool (E-CAST) which added sagittal plane assessments at the knee and ankle.17 This more comprehensive E-CAST demonstrated moderate inter-rater reliability and good intra-rater reliability when assessing trunk and LE alignment in the frontal and sagittal planes during a 45-degree sidestep cut.17

While these 2D screening tools were developed to assess a cutting maneuver using either quantitative or qualitative 2D assessment criteria, it is unknown which type of 2D assessment (quantitative versus qualitative) is more reliable for clinical movement evaluations during a cutting task. To the author’s knowledge, there is only one study that compared the reliability between quantitative and qualitative 2D assessments of the LE during athletic tasks. Simon et. al assessed the reliability between quantitative measurement of frontal plane projection angle and qualitative visual assessment of dynamic valgus during a lateral step down task and found higher reliability with the quantitative assessment.18 However, given differences in reliability and validity of 2D assessment tools between different athletic tasks, the results of this study may not be generalizable to cutting and pivoting maneuvers.19 Thus, to fill this knowledge gap, the authors of the current study developed a quantitative version of the E-CAST, using a 2D kinematic assessment. The purpose was to examine the reliability of the quantitative version of the E-CAST among physical therapists and to compare the reliability of the quantitative E-CAST to the original qualitative E-CAST. Specifically, this study consisted of three aims: 1) to assess the inter- and intra-rater reliability of the quantitative version of the E-CAST; 2) to examine rater agreement of each component of the quantitative version of the E-CAST; and 3) to compare the reliability of the quantitative version of the E-CAST to the original qualitative scoring tool. Given these aims, the hypotheses were: 1) there would be good to excellent inter- and intra-rater reliability; 2) there would be good to almost perfect agreement in the assessed variables, including cut width, trunk lean, knee flexion and valgus, and, plantarflexion; and 3) the quantitative version of the E-CAST would demonstrate greater inter-rater and intra-rater reliability compared to the qualitative E-CAST.

MATERIALS AND METHODS
STUDY DESIGN
A repeated measures study design was used. The study protocol was developed based on the Declaration of Helsinki and ethical standards in sport and exercise science research.20 Institutional Review Board approval was obtained prior to commencement of the study.

PARTICIPANTS
A total of 25 adolescent female athletes were recruited for participation in the study from local middle school, high school, and club sport teams. These were the same participants from the original work of Butler et al.17 A review of current research in this area led to the sample size selection. Participants were included if they were between the ages of 12 and 17 years and were active participants in sports requiring cutting and pivoting within the prior 12
months. Participants were excluded from the study if they had a LE injury within the prior six months, a history of LE surgery, a positive response on the Physical Activity Readiness Questionnaire (PAR-Q+), or a history of scoliosis. The PAR-Q+ was used to determine the participants’ readiness and safety for physical activity. A positive response of the PAR-Q+ indicates the need to seek further advice from a physician prior to engaging in physical activity. Written parental informed consent and participant informed assent were obtained prior to the start of the study.

### DATA COLLECTION

Data collection was performed in a movement science laboratory at a local sports medicine center. A 5-minute warm up on an exercise bike (Matrix Fitness, Cottage Grove, WI) was performed prior to performing the 45-degree sidestep cut. Participants practiced the sidestep cut three times in each direction or until they felt comfortable performing the maneuver. They were instructed to sprint at 80% of their maximum speed in a forward direction toward the “opponent cone” and plant to perform a sidestep cut (Figure 1). This procedure was modeled by a testing protocol described by McLean et al which requires participants to decelerate, plant on the stance foot, and cut between two cones placed on their contralateral side along a 45-degree line of progression.12 (Figure 1).

Participants completed three trials planting on the right foot and three trials planting on the left foot, and a trial was considered “good” if the participants’ foot landed within the stance/pivot area such that video data successfully captured the cutting maneuver. The testing order was standardized for all participants following the protocol by Butler et al.16 Video data were captured at 60 frames per second with 1080p quality using three Sony RX10 IV cameras adjusted to 56 inches tall. Two cameras were positioned 156 inches from either side of the stance/pivot area, and one camera was positioned 146 inches in front of the stance/pivot area. A total of six cutting maneuvers were performed by each participant with one trial randomly selected for analysis. All videos were slowed by 50% for visual analysis and participants’ faces were blurred using VideoStudio.

### QUANTITATIVE 2D ASSESSMENT TOOL

The quantitative assessment tool was devised based on the previously reported qualitative scoring system (E-CAST).17 The original six-item assessment criteria from the E-CAST were adapted and re-defined to utilize a motion analysis application on a smart phone that allowed for the extraction of 2D kinematic measurements. The quantitative scoring tool involved a dichotomous rating system, with scoring defined as “1” when a movement fault was present and “0” when optimal movement patterns were observed. Frontal and sagittal plane variables were assessed. Frontal plane variables included: trunk lean opposite of the cut direction, increased cut width, knee valgus at initial load acceptance (static valgus) and knee valgus throughout the cutting task (dynamic valgus). Sagittal plane variables included: ankle plantarflexion and knee flexion. The quantitative 2D assessment tool is shown in Table 1.

### RATERS

Two raters who were doctors of physical therapy in a pediatric sports medicine department were chosen based on their clinical roles in treating young athletes. The raters belong to the same medical institution, and each had seven years of clinical experience. Both raters provided their informed consent to participate in the study and independently viewed 25 videos. This study was performed by two different raters than those who participated in the original work of Butler et al.17

### PROCEDURES

One video for each participant was provided to each rater along with a reference sheet containing images that demonstrated 1) how to take the 2D kinematic measurements using the smartphone application and 2) the adapted definitions for each original qualitative variable (see document, supplementary digital content 1, adapted checklist reference sheet). The raters were instructed to view the videos independently. They were allowed to review the videos and take as many measurements as they felt necessary. All videos were evaluated using each rater’s personal smart phone device and a free publicly available motion analysis application (Hudl Technique Version 7.0.0.0). The raters were given one week to complete the first reliability session followed by a two-week wash-out period. Then, the second reliability session was performed, using the same method outlined for the first reliability session. The sequence of videos was randomized in the second reliability session using a web-based randomization tool and both raters were blinded from their previous ratings recorded in the first reliability session.

### STATISTICAL ANALYSIS

Reliability was determined by calculating intraclass correlation coefficients (ICC) for the scoring tool total scores, with a 2-way mixed-effects model and 95% confidence intervals (95% CIs) for inter- and intra-rater reliability. For the first aim, the individual and cumulative inter-and intra-rater reliabilities were calculated within the first and second reliability sessions. ICC values less than 0.50, between 0.50 and 0.75, between 0.75 and 0.90, and greater than 0.90 were defined as poor, moderate, good, and excellent reliability, respectively.23 To attain study aim 2, a kappa coefficient was calculated for each of the scoring tool variables using the formula $\kappa = Pr(a) - Pr(e)/1 - Pr(e)$, where $Pr(a)$ represented relative observed agreement between raters and $Pr(e)$ represented hypothetical probability of chance agreement.24 The kappa coefficient was interpreted based on the scale of Landis and Koch with 0.01–0.20 as slight, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 good, and 0.81–1.00 almost perfect agreement.25 Correlations were converted to $z$ scores using the following Fisher $Z$-transformation equation ($z' = 0.5[ln(1+r) – ln(1-r)]$) to compare the quantitative...
assessment criteria to the original qualitative assessment criteria for significance ($\alpha < 0.05$). All statistical analyses were conducted using SPSS Statistics 22 (IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp).

RESULTS

A total of 25 adolescent female athletes (age $13.8 \pm 1.4$ years, body mass $52.4 \pm 9.5$ kg, height $161.7 \pm 6.0$ cm) participated. (Table 2)

Intra-rater reliability for Rater 1 was moderate (ICC: 0.667, 95% CI 0.255-0.852) and intra-rater reliability for Rater 2 was excellent (ICC: 0.900, 95% CI 0.777-0.956; Table 3). The cumulative intra-rater reliability of both raters was good (ICC: 0.821, 95% CI 0.687 – 0.898; Table 5). Cumulative intra-rater kappa coefficients of all variables ranged from moderate to almost perfect ($\kappa = 0.505-0.875$; Table 3). Inter-rater reliability for the first reliability session was moderate (ICC: 0.747, 95% CI 0.436- 0.888) and inter-rater reliability for the second reliability session was good (ICC: 0.760, 95% CI 0.463-0.894). The cumulative inter-rater reliability of both sessions was good (ICC: 0.752, 95% CI 0.565-0.859). Cumulative inter-rater kappa coefficients of all variables ranged from fair to good ($\kappa = 0.336-0.751$; Table 4). To compare correlations, Fisher’s r to z transformation was utilized. This transformation is done so that the z-scores can be compared and analyzed for statistical significance by determining the observed z test statistic. The z-score comparing inter-rater reliability was -0.3 with a corresponding p-value of 0.382. With an alpha level of 0.05, we were able to conclude that there was no statistically significant difference between inter-rater reliability when comparing the qualitative and quantitative assessments. The z-score comparing intra-rater reliability was -0.38 with a corresponding p-value of 0.352 leading to the conclusion that there was also no statistically significant difference between intra-rater reliability when comparing the qualitative and quantitative assessments.

DISCUSSION

The purpose of this study was to assess the intra-rater and inter-rater reliability of a quantitative version of the E-CAST among physical therapists. The quantitative assessment tool demonstrated good intra-rater reliability (cu-
Table 1. Adapted Checklist

<table>
<thead>
<tr>
<th>Item</th>
<th>View</th>
<th>2-D Kinematic Measurement Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk lean to opposite direction of cut</td>
<td>Frontal</td>
<td>At the time point of initial load acceptance, draw a line connecting the athlete’s right and left ASIS* (hip line), Next, draw a line from the center of the head to the midpoint of the hip line (trunk line). Measure the angle formed between the trunk line and vertical. If the trunk line is deviated greater than 10° score 1 (YES). If the trunk line is deviated less than or equal to 10° score 0 (NO).</td>
</tr>
<tr>
<td>Increased cut width</td>
<td>Frontal</td>
<td>At the time point of initial load acceptance, draw a line down from the lateral most aspect of the athlete’s stance leg hip, if the line appears to fall more than one shoe width medial to the foot score 1 (YES). If not, score 0 (NO).</td>
</tr>
<tr>
<td>Static valgus</td>
<td>Frontal</td>
<td>At the time point of initial load acceptance measure the angle formed between the stance limb hip, knee and ankle joint centers. If the angle formed is greater than 8° score 1 (YES). If the angle formed is less than or equal to 8° score 0 (NO).</td>
</tr>
<tr>
<td>Dynamic valgus</td>
<td>Frontal</td>
<td>Measure the angle formed between the stance limb hip, knee and ankle joint centers at the maximum point of knee valgus during the cut. If the angle formed is greater than 8° score 1 (YES). If the angle formed is less than or equal to 8° score 0 (NO).</td>
</tr>
<tr>
<td>Decreased knee flexion angle</td>
<td>Sagittal</td>
<td>At the time point of initial contact, measure the angle formed between the lateral hip, lateral knee and lateral malleolus. If the angle formed is less than 30° score 1 (YES). If angle formed is greater than or equal to 30° score 0 (NO).</td>
</tr>
<tr>
<td>Decreased plantar flexion angle</td>
<td>Sagittal</td>
<td>At the time point of initial contact, measure the angle formed between the lower leg and the bottom sole of the shoe. If the angle formed is less than 90° score 1 (YES). If the angle formed is greater than or equal to 90° score 0 (NO).</td>
</tr>
</tbody>
</table>

*anterior superior iliac spine

Table 2. Participant demographics

<table>
<thead>
<tr>
<th></th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>BMI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>12.0</td>
<td>150.0</td>
<td>40.8</td>
<td>16.4</td>
</tr>
<tr>
<td>Maximum</td>
<td>16.3</td>
<td>172.5</td>
<td>72.6</td>
<td>26.3</td>
</tr>
<tr>
<td>Average</td>
<td>13.8</td>
<td>161.7</td>
<td>52.4</td>
<td>19.9</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>1.4</td>
<td>6.0</td>
<td>9.3</td>
<td>2.6</td>
</tr>
</tbody>
</table>

Table 3. Intra-rater reliability (*ICC, 95% CI, cumulative values) and intra-rater reliability for adapted checklist variables

<table>
<thead>
<tr>
<th>Raters</th>
<th>ICC</th>
<th>95% CI</th>
<th>Cut Width</th>
<th>Trunk Lean</th>
<th>Dynamic Valgus</th>
<th>Static Valgus</th>
<th>Knee Flexion</th>
<th>Plantar Flexion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rater #1</td>
<td>0.667</td>
<td>0.255-0.852</td>
<td>0.364</td>
<td>0.595</td>
<td>0.865</td>
<td>0.865</td>
<td>0.606</td>
<td>0.503</td>
</tr>
<tr>
<td>Rater #2</td>
<td>0.900</td>
<td>0.777-0.956</td>
<td>0.694</td>
<td>0.457</td>
<td>0.884</td>
<td>0.803</td>
<td>0.684</td>
<td>0.481</td>
</tr>
<tr>
<td>Cumulative</td>
<td>0.821</td>
<td>0.687-0.898</td>
<td>0.532</td>
<td>0.558</td>
<td>0.875</td>
<td>0.831</td>
<td>0.658</td>
<td>0.505</td>
</tr>
</tbody>
</table>

*Intra class correlation coefficient; †confidence interval; ‡kappa coefficient

Table 4. Inter-rater reliability for adapted checklist variables

<table>
<thead>
<tr>
<th>Rating Session</th>
<th>Cut Width (k*)</th>
<th>Trunk Lean (k*)</th>
<th>Dynamic Valgus (k*)</th>
<th>Static Valgus (k*)</th>
<th>Knee Flexion (k*)</th>
<th>Plantar Flexion (k*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.595</td>
<td>0.627</td>
<td>0.651</td>
<td>0.694</td>
<td>0.448</td>
<td>0.493</td>
</tr>
<tr>
<td>2</td>
<td>0.816</td>
<td>0.194</td>
<td>0.865</td>
<td>0.752</td>
<td>0.532</td>
<td>0.157</td>
</tr>
<tr>
<td>Cumulative</td>
<td>0.733</td>
<td>0.394</td>
<td>0.751</td>
<td>0.722</td>
<td>0.493</td>
<td>0.336</td>
</tr>
</tbody>
</table>

*Kappa coefficient

These findings support the first hypothesis that the quantitative assessment tool would demonstrate good to excellent inter and intra-rater reliability. The second hypothesis was not supported as only moderate agreement was found.
for the cut width variable, fair to moderate agreement for trunk lean and plantar flexion variables, and moderate to good agreement for dynamic valgus and knee flexion variables. Static valgus was the only variable that demonstrated good to almost perfect agreement. Furthermore, the current findings did not support the third hypothesis as there was no significant difference in intra- and inter-rater reliability between the quantitative assessment tool and the qualitative E-CAST ($Z_{\text{obs}} = -0.46$ and $Z_{\text{obs}} = -0.30$). This was likely a result of the small difference between actual values. For inter-rater reliability, there was only a 0.042 difference between the qualitative and quantitative assessments and for intra-rater there was a 0.041 difference.

Although the quantitative assessment tool resulted in slightly higher reliability compared to the qualitative E-CAST, which reported moderate inter-rater reliability (cumulative ICC: 0.71, 95% CI 0.50-0.91) and good intra-rater reliability (cumulative ICC: 0.78, 95% CI 0.59-0.96), this difference was not significant. From a clinical standpoint this suggests that the use of app based measurements may not be necessary to reliably assess trunk and LE alignment during change of direction maneuvers. This is an important finding given the time restrictions in the clinic setting. While both the quantitative and the qualitative assessment tools demonstrated adequate reliability, the original qualitative E-CAST may be more efficient. These findings also indicate that quantitative tools may still be subject to variability in time point and landmark identification which likely contributed to this variation in reliability. Valgus variables demonstrated the highest intra- and inter-rater reliability when utilizing either quantitative or qualitative assessment. Interestingly, lower intra and inter-rater reliability were found for the variables of trunk lean and plantarflexion with the quantitative assessment (Table 3). Similarly, lower inter-rater reliability was observed for the static valgus variable using the quantitative versus the qualitative assessment (Table 3). This may be a result of the differences in the operational definitions used for these variables between the two assessments. Specifically, for the trunk lean variable, the qualitative E-CAST uses a horizontal line reference while the quantitative assessment uses an angle measurement off a vertical line as a reference. Additionally, for plantarflexion, the qualitative E-CAST uses a point of first contact (toe-to-heel vs. heel-to-toe) definition, while the quantitative assessment uses an angle measurement that requires the rater to visually identify the sole of the shoe. Thus, it is possible that variability in landmark identification may have decreased rater agreement. Similarly, the variable of static valgus requires identification of the time point of initial load acceptance. When using a quantitative 2D measurement, differences in time point identification may contribute to poorer agreement between raters and may also explain the differences in intra-rater reliability of each rater in this study.

The findings of this study are generally in agreement with the work of Weir et al. who reported fair to excellent intra-rater reliability and poor to excellent inter-rater reliability for their quantitative 2D assessment tool. There are however important differences between the two studies. First, the study by Weir et al. assessed the reliability of joint and segment angle measurements, which are continuous variables. In the current study, 2D measurements were used to determine if the movement fault was "present" or "not present", resulting in dichotomous variables. Variability in the reported rater agreement between the two studies may be attributed to differences in statistical assessment of agreement between continuous and dichotomous variables. Assessing agreement between two dichotomous variables may be more challenging given the strict response of present or not present compared to continuous variables, which allow for a wider range of potential responses and possibly more opportunity for agreement. Furthermore, the dichotomous variable derived from the 2D kinematic assessment may be more sensitive to human error than the qualitative assessment given that the extracted variables were highly influenced by landmark identification. Additionally, the study by Weir et al used an unplanned 45-degree sidestep cut compared to a planned cutting task which was used in this study. Unplanned cutting tasks have been shown to result in higher knee joint loads, which may make movement faults easier to visually identify. When comparing the findings of this study to other qualitative assessments of cutting, similar results are reported. For the CMAS, excellent intra-rater reliability (ICC=0.95) and moderate inter-rater reliability (ICC= 0.69) were reported when utilizing a qualitative scoring system to evaluate a 90-degree cutting maneuver. While the current study reported slightly lower intra-rater reliability (ICC=0.82) and slightly higher inter-rater reliability (ICC= 0.75), these slight differences are likely not clinically significant.

Time limitations have been previously reported as a barrier to movement screenings. If quantitative 2D assessment does not significantly improve reliability compared to qualitative assessment, then clinicians should consider ease and efficiency when choosing the type of assessment tool to use. Given the simplicity of qualitative visual assessments, this might support their use over more complex and technology-dependent quantitative measurements.

LIMITATIONS

This study has several limitations. First, the adapted checklist evaluated reliability among two physical therapists using a two-way mixed effects model which reduces the generalizability. Future studies should consider assessing reliability amongst a larger group of raters using a two-way random effects model. Furthermore, coaching staff and athletic trainers in school or club sport settings are likely best positioned to perform movement screenings, thus, reliability of this tool should be assessed in non-clinically trained personnel. Providing coaching staff with reliable and valid assessment tools will help them to identify athletes at the highest risk for injury and thus the best candidates for preventive interventions. However, it should be noted that not all coaches have the background knowledge to perform this type of assessment. Additional training for coaches on how to utilize this assessment tool may be necessary. Also, of note, this study used a planned cutting...
task. Unplanned cutting tasks have been shown to result in greater knee joint loads compared to planned cutting maneuvers.\textsuperscript{27} However, video assessment of an unplanned cutting maneuver requires an additional camera view (two sagittal views compared to one). Adding more cameras increases the complexity of set up and may result in decreased utilization of the tool. Additionally, this study only assessed the reliability between two raters, future studies should evaluate the tool’s reliability between multiple raters. Lastly, it is unknown if 2D qualitative or quantitative tools can predict those at risk for ACL injury. Future studies should aim to determine the sensitivity and specificity of the assessment tools in identifying athletes who are at high risk for an ACL injury. The concurrent validity of 2D qualitative and quantitative tools with 3D motion capture is also unknown and should be studied further.

CONCLUSION

The results of this study suggest that qualitative 2D assessment is comparable in reliability to more complex quantitative 2D analysis when evaluating trunk and LE alignment during a 45-degree sidestep cut. These findings highlight the potential for more efficient and feasible screening methods to identify high-risk movement patterns during cutting tasks. Additional work is needed to determine the concurrent validity of both the qualitative assessment (E-CAST) and the adapted quantitative checklist.

FUNDING SOURCE

No funding.

ETHICS APPROVAL

This study was approved by the Western International Review Board for human subjects’ research and by the University of Texas Southwestern Institutional Review Board for human subjects’ research.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

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REFERENCES


Altered Knee Loading Following Primary ACL Repair versus ACL Reconstruction

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Keywords: ACL repair, ACL reconstruction, biomechanics, single-limb squat, quadriceps strength

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Background

ACL repair (ACL-r) has recently gained renewed clinical interest for treatment of ACL tears. ACL-r has several potential benefits over ACL reconstruction (ACL-R) including maintaining the native ACL innervation and blood supply, no graft site morbidity, and possible improved knee biomechanics and decrease in osteoarthritis. The purpose of this study was to assess for differences in metrics of knee joint loading during a single limb squat task between individuals following a primary ACL-r versus those who underwent a standard ACL-R with a patella bone-tendon-bone autograft.

Study type

Case Control Study

Methods

The ACL-r group [n: 15, age(yrs): 38.8±13.9] sustained a proximal ACL disruption that was amenable to repair, while the ACL-R group [n: 15, age(yrs): 25.60±1.7] underwent primary reconstruction with patella bone-tendon-bone autograft. At 12-weeks post-operation, both groups completed the IKDC questionnaire and biomechanical testing during performance of the single limb squat. Bilateral peak knee extension moment and total knee joint power as a measure of eccentric loading (contraction) during the descent phase of the squat were calculated on the surgical and non-surgical limb and averaged across the middle three of five trials. Participants also completed quadriceps strength testing on both limbs three months after surgery on an isokinetic dynamometer at 60°/sec. LSI (Limb Strength Index) was calculated for all variables. Separate ANCOVAs were performed on each biomechanical variable to examine differences between groups.

Results

The ACL-r had a significantly greater peak knee extension moment LSI (ACL-r: 78.46±5.79%; ACL-R: 56.86±5.79%; p=0.019, ηp²=.186) and total knee joint power LSI (ACL-r: 72.47±7.39%; ACL-R: 39.70±7.39%, p=0.006, ηp²=.245) than the ACL-R group. The ACL-r also had a significantly greater quadriceps LSI than the ACL-R group (ACL-r: 66.51±4.61%, ACL-R: 48.03±4.61%, p=0.015, ηp²=.206).

Conclusions

Individuals following ACL-r demonstrate increased knee joint loading symmetry during a single leg squat task and greater quadriceps strength symmetry at 12 weeks post-surgery compared to those who underwent ACL-R.
Level of Evidence

INTRODUCTION

Anterior Cruciate Ligament reconstruction (ACL-R) is typically recommended following ACL injury for patients planning to return to running, jumping, or cutting activities. ACL-R is thought to help improve excessive anterior tibial translation, improve rotational stability and restore proper joint kinematics resulting in improved pain, instability, and function.1–3 While ACL-R remains the gold standard for the management of ACL injuries, recent reviews examining the short- and long-term outcomes following reconstruction demonstrate that outcomes may not be as favorable as previously thought.4–8

Patients have high expectations following ACL-R with 91% expecting to return to the same level of sport/activity.9 Unfortunately, the results for return to sport (RTS) do not match these expectations with only 81% of people returning to any sport, 65% returning to their preinjury level of sport and 55% returning to competitive level sport.4 Of those who do return to sports, up to 20-50% sustain a contralateral ACL tear or graft re-rupture.7,8 Furthermore, approximately 50% of athletes who suffer an ACL injury will develop knee joint osteoarthritis (OA) in the 5–15 years following the initial injury.10–12

Weakness of the quadriceps following ACL-R has been directly linked to the development of patient dysfunction,5,15 knee osteoarthritis5,11 and lower likelihood of returning to same level of sport.14,15 Following ACL-R, patients can have diminished quadriceps strength long after expected time of RTS with average side to side quadriceps strength deficits of 23% and 14% at 6 and 12 months respectively.16 The diminished quadriceps strength following ACL-R may be related to several factors including graft site morbidity, post-operative swelling and pain,17,18 decreased knee extension range of motion,19 quadriceps atrophy20 and neural changes in the sensory and motor pathways.18,21–23 Quadriceps strength deficits cannot be solely attributed to graft site morbidity because patients with hamstring autografts also display quadriceps weakness, although to a lesser degree.24 Studies continue to demonstrate the prevalence of quadriceps strength deficits following ACL-R despite evidence showing the importance of restoring quadriceps strength.16

There is a recent renewed interest in the ACL repair (ACL-r) procedure as a potentially more joint friendly procedure, with less surgical trauma and preservation of the native ACL. ACL repair was previously abandoned following the study by Feigen et al. in 1976 which showed poor midterm outcomes with nearly a 50% re-tear rate.25 However, several limitations exist in these older studies including the use of an open technique, repair of all tear types, use of antiquated techniques with absorbable sutures and cast immobilization for up to six weeks following surgery, all of which may have contributed to poor outcomes.25–27 On reanalysis of these results, proximal ACL tear types performed better compared to midsubstance tears.25 Newer early to midterm data on ACL repair demonstrates that ACL repair re-tear rates may be similar to ACL reconstruction in select patients and tear types.28 More recently, in several animal models and in human clinical data, ACL remnant preservation and ACL entire ligament repair/preservation has been shown to benefit knee biomechanics, proprioception, and clinical outcomes.24,26,28,29 However, there is limited data on the newer ACL-r techniques and further study is needed to validate the efficacy of this procedure.

Therefore, the purpose of this study was to assess for differences in metrics of knee joint loading during a single limb squat task between individuals following a primary ACL-r versus those who underwent a standard ACL-R with a patella bone-tendon-bone autograft. The single leg squat task was chosen as this is a movement readily implemented throughout the rehabilitation process. The single leg squat is utilized as both an exercise to improve lower extremity strength and neuromuscular control, and as a screening tool to assess readiness for return to running and sport.30–32 The authors hypothesized that there would be improved surgical limb knee loading in ACL-r compared to ACL-R at the three-month post-operative time point.

METHODS

PARTICIPANTS

A total of 30 individuals who met the inclusion criteria were included in this study. All participants were tested at three months following surgery as part of a larger ongoing ACL study examining biomechanical and clinical outcomes across the continuum of care (Figure 1). Participants were considered eligible for the study if they were between the ages of twelve and sixty years old, sustained a primary ACL injury, elected to undergo either an ACL-R or ACL-r procedure, were considered a recreational or professional athlete participating in sport at least 50 hours/year and were attempting to return to their activity. All surgeries were performed by a single surgeon.

Participants did not complete formal pre-rehabilitation with a physical therapist or athletic trainer; rather, pre-rehabilitation education was completed by the treating surgeon. Participants in the ACL-r group all sustained a proximal ACL disruption (Sherman Classification Type 1 or 2) that was amenable to repair and underwent primary ACL repair with suture fixation.33 Participants in the ACL-R group all underwent a primary ACL-R with patella bone-tendon-bone autograft. Participants were excluded from the study if they had previously injured their ACL, had full thickness chondral injuries, had a grade II or III injury of the medial collateral ligament (MCL), lateral collateral ligament (LCL), posterior collateral ligament (PCL) injuries, or simultaneous fracture with ACL tear. Meniscal pathology was treated as deemed appropriate by the treating surgeon. There was no significant meniscal pathology in either group that necessitated altering the post operative reha-
bilitation protocol. Following surgery all participants completed formal physical therapy guided by the rehabilitation protocol of the surgeon. The rehabilitation protocol can be seen in Appendix 1 and further described by Bousquet et al.\textsuperscript{34}

Following the screening process, if the subjects were eligible, they were invited to participate in the study. All participants gave informed consent to participate and the rights of each person were protected. If the participants were a minor, parental consent and child assent were attained. The Institutional Review Board of Texas Health Resources approved the research procedures. Following enrollment of the study, demographic information, injury history, sports participation, and International Knee Documentation Committee (IKDC) Subjective Knee Form scores were collected from each participant.

ACL-R SURGICAL TECHNIQUE

ACL-r was performed under arthroscopic visualization with two or three standard portals in a technique similar to that described by DiFelice et al.\textsuperscript{26} but modified by the senior author to include only one 4.75mm SwiveLock (Arthrex, Naples, FL) secured in the anterior aspect of the native footprint on the medial wall of the lateral femoral condyle. Indications for repair were similar to that described by DiFelice et al.\textsuperscript{26}

ACL-R SURGICAL TECHNIQUE

Participants in the ACL-R group all underwent a primary ACL-R with patella bone-tendon-bone autograft. The autograft bone blocks were crimped to 9mm and then two 10mm femoral and tibial tunnels created for the graft. An independent tunnel technique, utilizing the medial portal for creation of the femoral socket within the native ACL

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**Figure 1. CONSORT Flow Diagram**

![ CONSORT Flow Diagram ](image-url)
femoral attachment site, was performed in all ACL-R patients.

BIOMECHANICAL INSTRUMENTATION

A 10-camera Motion Capture System (Qualisys AB, Göteborg, Sweden) with a sampling rate of 120Hz was used to capture joint motions in all three planes during the single limb squat. Thirty-three reflective markers were adhered to each participant’s skin/clothing with double-sided tape. Retrospective markers were attached to the spinous process of the seventh cervical vertebra, twelfth thoracic vertebra, sternum, bilateral acromion process, anterior superior iliac spine, posterior superior iliac spine, greater trochanter, anterior thigh, medial and lateral epicondyles of the femur, anterior shank, medial and lateral malleoli, calcaneous, and first and fifth metatarsal heads. Three additional retrospective markers were attached on the sacrum as a cluster. Two ATMI force plates capturing at 1200Hz (Advanced Mechanical Technology, Inc., Watertown, MA) collected ground reaction force data utilized to calculate joint kinetics and were synchronized to the cameras allowing accurate time sequencing during data collection and data processing.

SINGLE LIMB SQUAT

The single limb squat task was chosen as it has been utilized throughout the literature to look at sagittal, frontal, and transverse plane kinematics in both healthy and injured cohorts to help assess movement quality. The single limb squat task is a foundational movement pattern in rehabilitation following ACL injury and performance during a single limb squat is used as a proxy to assess lower extremity strength and readiness to return to running. Participants were allowed to warm up until they felt comfortable with the given activity. Participants were asked to stand on one foot with their toes facing straight forward with their hands on their waist with their contralateral hip and knee flexed to 90 degrees. They were instructed to perform five consecutive single limb squats. A metronome set at 60 bpm was used to ensure consistent pace across testing as participants completed the five single limb squats. Participants were asked to squat to their best possible depth without losing balance but squat depth was not normalized. If a participant experienced a loss of balance, then the capture period was repeated until five consecutive single limb squats could be completed. The mean of the middle three squats was used for data analysis. All participants completed testing on their non-surgical limb followed by their surgical limbs.

ISOKINETIC QUADRICEPS STRENGTH TESTING

The Biodex Multi-Joint Testing and Rehabilitation System (Biodex Medical Systems, Shirley, NY) was used for testing concentric extensor peak torque. For the purpose of this study, extensor peak torque will be referred to throughout the manuscript as quadriceps strength. Quadriceps strength was measured at 60°/s and the protocol used has previously been described in the literature. All subjects completed testing on their non-surgical limb followed by their surgical limb.

DATA PROCESSING AND REDUCTION

Peak quadriceps strength (Nm) was averaged across five trials and were normalized to body mass (Nm Kg⁻¹). Three-dimensional joint coordinates were estimated from the trajectories of the reflective markers. All kinematic and force data were exported into Visual3D software (C-Motion, Inc. Germantown, MD) to process and reduce data. The markers and force data were filtered via a fourth-order low-pass Butterworth filter with a zero-phase lag at 12 Hz. Peak knee extension moment (Nm BW°Ht⁻¹) was calculated using inverse dynamic approach during the descent phase of the single limb squat. Knee energy absorption (J BW°Ht⁻¹) was calculated as an integration of the negative area of the knee joint power curve as a measure of eccentric loading (contraction) during the descent phase of a single limb squat which may be able to show greater differences in knee loading between groups compared to concentric contraction. Both variables were collected from surgical and non-surgical limbs during middle three trials of the five squats and normalized to height and body weight of the participants. A limb symmetry index (LSI) (surgical/non-surgical X 100) was calculated for all dependent variables.

STATISTICAL ANALYSES

Independent t-tests were used to compare between group differences in demographic variables. Variables with significant difference would be used as covariate for the analyses. For the three variables of interest an analysis of covariance (ANCOVA) with a p-value set at p<0.05 was used for analysis, Bonferroni adjustment was included for adjustment of multiple comparisons. Partial Eta Squared effect sizes were calculated with standard thresholds used for strength of effect.

RESULTS

There were no differences in height (p=0.996), mass (p=0.996), IKDC score (p=0.886) or time between injury and surgery dates (p=0.912) between the groups. There was a significant difference in age (ACL-r: 38.87 ±13.9, ACL-R: 25.60±11.78; p=0.009) with the ACL-r being significantly older. (Table 1)

There were significant between group differences in all variables of interest while controlling for age (Table 2). The ACL-r had a significantly greater peak knee extension moment LSI (ACL-r: 78.46±5.79%; ACL-R: 56.86±5.79%; p=0.019, η²p=.186 and net knee joint power LSI (ACL-r: 72.47±7.39%; ACL-R: 39.70±7.39%; p=0.006, η²p=.245) than the ACL-R group during the single limb squat. The ACL-r also had a significantly greater quadriceps LSI than the ACL-R group (ACL-r: 66.31±4.61%, ACL-R: 48.05±4.61%; p=0.015, η²p=.206). No patients experienced any major
complications at final follow up including hospitalization, DVT or infection.

**DISCUSSION**

The results of this study indicate that individuals following ACL-r demonstrate differing loading strategies during a single leg squat and greater quadriceps strength symmetry in isokinetic testing compared to those who undergo ACL-R. The ACL-r group demonstrated greater limb symmetry in peak knee extension moment, quadriceps strength and knee energy absorption than the ACL-R group during a single limb squat. These measures are related but different and contribute to changes in both peak joint loading (knee extension moment) and loading over the entire movement (energy absorption), both of which may be important for joint health and function. These outcomes are unique and to our knowledge this study is the first to compare kinetics between ACL-r and ACL-R cohorts at the three-month time point.

Quadriceps deficits at three months following ACL-R have been associated with continued quadriceps deficits at time of return to sport. Persistent quadriceps strength deficits are associated with poor self-reported outcomes, altered biomechanics and increased risk of secondary injury. It is worth noting that the magnitude of difference in joint loading was large with knee joint power LSI of 72% vs 39% and quadriceps strength LSI of 66% vs 48% in the repair vs reconstruction group respectively. This was despite the fact that the repair group was significantly older compared to the reconstruction group which we expected to have a slower recovery of strength. Based on previous studies that demonstrates long term quadriceps strength deficits following ACL reconstruction, the authors expect this gap in loading and strength between the two cohorts to diminish but persist at longer term follow up. Prior studies have also demonstrated faster recovery of objective measures in ACL-r vs ACL-R. Van der List et al. demonstrated ACL-r patient had faster return of normal knee ROM with a trend towards decreased complications in the repair group (2% vs 9%).

The strength symmetry data in the ACL-r group is significantly greater than previous work following ACL-R at three months after surgery in which the LSI reached 55% and was directly related to the ability to load the surgical limb knee. This improvement in strength may simply be related to the less traumatic nature of the ACL-r procedure resulting in less post-operative swelling, edema, and no associated graft site morbidity. Graft site morbidity is likely not the only contributing factors as previous studies have demonstrated decreased quadriceps strength following ACL-R with hamstring autograft and allograft. Other factors that warrant further investigation are potential differences between the two procedures in resultant arthrogenic muscle inhibition and differences in afferent signaling from the knee joint because of leaving the native ACL in place (during the ACL-r procedure). Lee et al. reported on 26 subjects who underwent ACL-R with remnant tibial stump preservation compared to 22 subjects who underwent standard ACL-R without remnant preservation. They found that at approximately 2 years following surgery, those in the remnant preservation group had significantly better results on tests of proprioception (reproduction of passive positioning and threshold to detection of passive motion) compared to the standard group. If the findings of remnant preservation are extrapolated to leaving the entire native ACL in place, as is done in the ACL-r procedure, it may be plausible that there would similarly be an improved proprioceptive response in ACL-r patients compared to ACL-R.

Efferent signaling to the quadriceps muscle has been shown to be modulated by afferent input from the joint. The changes in afferent signaling from the joint and sur-

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**Table 1. Participant Demographics (N=50)**

<table>
<thead>
<tr>
<th></th>
<th>ACL-r (15)</th>
<th>ACL-R (15)</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>38.87±13.9</td>
<td>25.60±11.78</td>
<td>0.009*</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.4±10.0</td>
<td>173.5±10.3</td>
<td>0.996</td>
</tr>
<tr>
<td>Mass (Kg)</td>
<td>77.9±17.5</td>
<td>75.4±15.6</td>
<td>0.996</td>
</tr>
<tr>
<td>Sex (M/F)</td>
<td>5/10</td>
<td>8/7</td>
<td>0.269</td>
</tr>
<tr>
<td>IKDC</td>
<td>67.82</td>
<td>68.52</td>
<td>0.886</td>
</tr>
<tr>
<td>Injury to Surgery (Days)</td>
<td>55.33±47.6</td>
<td>57.43±53.7</td>
<td>0.912</td>
</tr>
</tbody>
</table>

*Indicates significance difference between groups; IKDC: International Knee Documentation Committee Short Form

**Table 2. Limb Strength Index Results**

<table>
<thead>
<tr>
<th></th>
<th>ACL-r</th>
<th>ACL-R</th>
<th>p</th>
<th>η²</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak knee extension moment LSI (%)</td>
<td>78.46±5.79</td>
<td>56.86±5.79</td>
<td>0.019*</td>
<td>0.186</td>
<td>[3.79, 39.42]</td>
</tr>
<tr>
<td>Net Knee Joint power LSI (%)</td>
<td>72.47±7.39</td>
<td>39.70±7.39</td>
<td>0.006*</td>
<td>0.245</td>
<td>[10.04, 55.50]</td>
</tr>
<tr>
<td>Quadriceps LSI (%)</td>
<td>66.318±4.61</td>
<td>48.03±4.61</td>
<td>0.013*</td>
<td>0.206</td>
<td>[4.11, 32.47]</td>
</tr>
</tbody>
</table>

*Indicates significant differences at a .05 evaluation; η²: partial eta squared effect size
rounding tissues contribute to the known mechanisms of arthrogenic muscle inhibition including alterations in muscle resting motor thresholds, changes in the discharge of articular sensory receptors, altered reflex excitability (affecting the group I non-reciprocal (Ib) inhibitory pathway, the flexion reflex and the gamma loop) and abnormal cortical activity (intracortical inhibition and a requirement for greater frontal cortex theta power in basic movement and joint position sense tasks). With less overall trauma to the knee joint, it is possible that those individuals who received an ACL-r were better able to restore joint homeostasis, and thus maintain better afferent and efferent signaling in the respective joint.

Prior research has established that greater peak joint loading is related to decreased collagen turnover in individuals following ACL-R. In a total of 19 subjects who were on average three years post-operative ACL-R, greater peak vGRF during gait was associated with lower type II collagen breakdown. Similarly, Wellstandt et al. reported on frontal plane joint kinetics in 22 individuals (15-without OA, 7- with OA) five years following primary ACL-R which found that decreased surgical limb knee joint loading during walking was associated with early OA. Both of these studies support the notion that decreased knee joint loading is associated with OA following ACL-R during walking. Although the current study only examines joint loading at three months post operatively, quadriceps deficits could have an effect on long term joint health if weakness persists.

This study is not without limitations. A relatively small sample was examined with short term follow up. Longer term follow-up on this cohort is needed to examine if these loading differences persist. There is also a difference in age between the two patient groups which could bias the results. It is possible that the younger patient population could have a more robust inflammatory response leading to a greater degree of quadriceps deactivation. Given the study design the authors cannot determine a direct relationship between ACL-r and improved joint loading. Further work is needed to better elucidate the risks and benefits of performing ACL-r vs ACL-R.

CONCLUSION

The results of this study indicate that individuals following ACL-r demonstrate increased knee joint loading symmetry during a single leg squat task and greater quadriceps strength symmetry at 12 weeks post-surgery compared to those who underwent ACL-R. ACL-r may result in improved early knee joint loading and proprioception compared to ACL-R.

CONFLICTS OF INTEREST

The authors have no relevant conflicts of interest to disclose.

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REFERENCES


SUPPLEMENTARY MATERIALS

Appendix 1
Implementation of 2D Running Gait Analysis in Orthopedic Physical Therapy Clinics

Tiffany Barrett, Kai-Yu Ho, Justin Rasavage, Micah Wilson, Melissa Goo-Tam, Tristan Trumbull

1 Department of Physical Therapy, University of Nevada, Las Vegas

Keywords: 2D motion analysis, runners, implementation, running assessment

Background
Despite 2D motion analysis deemed valid and reliable in assessing gait deviations in runners, current use of video-based motion analysis among orthopedic physical therapists is not prevalent.

Purpose/Hypothesis
To investigate clinician-perceived effectiveness, adherence, and barriers to using a 2D running gait analysis protocol for patients with running-related injuries.

Study Design
Survey

Methods
Thirty outpatient physical therapy clinics were contacted to assess interest in participation. Participating therapists were trained on 2D running gait analysis protocol and given a running gait checklist. The Reach, Effectiveness, Adoption, Implementation, and Maintenance (RE-AIM) framework was used to assess the implementation process by collecting a baseline survey at the beginning of the study, effectiveness and implementation surveys at two months, and a maintenance survey at six months.

Results
Twelve of the 15 responding clinics met eligibility criteria, giving a Reach rate of 80%. Twelve clinicians from 10 different clinics participated, giving an Adoption rate of 83%. For Effectiveness, the majority of clinicians valued having a checklist, and reported the protocol was easy to conduct, the methodology was reasonable and appropriate, and patients saw the benefits of using the protocol. Assessing Implementation, 92% performed all steps of the protocol on all appropriate runners. Average time spent conducting the protocol was 32 minutes. With respect to Maintenance, 50% reported continuing to use the protocol, while 50% answered they were not to continue use.

Conclusion
Clinicians expressed a perceived benefit of implementing a running gait analysis protocol with common themes of ease of use, being a useful adjunct to evaluating a patient, and increased satisfaction with treating injured runners. Potential barriers for not using the protocol included not having an appropriate clinic setup, time constraints, and not having adequate caseload.

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INTRODUCTION

It has been reported that 19% - 79% of runners experience running-related injuries, and up to 40 million Americans experience running injuries each year. Although running has many benefits, such as reduced risks for cardiovascular disease and cancer mortality, it is associated with various musculoskeletal injuries, including medial tibial stress syndrome, Achilles tendinopathy, plantar fasciitis, and patellofemoral pain. The risk factors associated with sustaining running-related injuries include abnormal running mechanics, prior running injury, higher weekly mileage, and increased frequency of running. Given that running in faulty forms are associated with musculoskeletal injuries, implementation of running gait analysis in orthopedic/sports physical therapy settings has been suggested to help identify abnormal mechanics in runners and combat the occurrence of these injuries.

Two-dimensional (2D) motion analysis is an affordable, time-efficient method for analyzing running mechanics in runners. For runners, 2D motion analysis is comparable to 3D motion analysis in quantifying sagittal plane kinematics of the hip, knee, and ankle during running. 2D analysis has also been shown to provide reliable results for assessing running gait kinematics. Identification of gait events and common kinematic variables, including rearfoot position, foot-strike pattern, tibial inclination angle, knee flexion angle, knee separation, and forward trunk lean, were found to be highly reproducible. Excellent intra- and inter-tester reliability was demonstrated with contralateral pelvic drop and hip adduction angles in the frontal plane, as well as with sagittal plane measures, regardless of clinician experience. A recent systematic review concluded that 2D video analysis is a reliable method for assessing foot strike pattern and quantifying step rate. The information obtained from these 2D running gait analyses can be utilized by clinicians to inform their plan of care with the goal of improving a patient’s running mechanics to decrease their risk of injury.

Despite the benefits of using 2D motion analysis, current use of video-based motion analysis among orthopedic physical therapists is not prevalent: less than 50% of orthopedic physical therapists use it in their routine caseload. Therefore, there is a need to investigate the process and effects of implementing 2D running gait analysis in clinical physical therapy settings. Therefore, the purpose of this study was to investigate clinician-perceived effectiveness, adherence, and barriers of using a 2D running gait analysis protocol for patients with running-related injuries. An additional aim of this study was to evaluate the value of implementing 2D running gait analysis by examining the associations between the plan of care, usefulness of routine use, clinicians’ satisfaction, patient-perceived benefit, time spent on the 2D motion analysis, and/or clinician perceived usefulness for making treatment plan decisions.

METHODS

2D MOTION ANALYSIS METHODS

The physical therapists that participated in this study were instructed to use the specific setup and procedures below. CoachNow (Shotzoom Software LLC, Tempe, Arizona, https://coachnow.io), a free, 2D motion analysis smartphone application that supports video recording and analysis with slow motion playback and dynamic annotation was used to analyze the videos collected from a smartphone. A similar smartphone application (Coach’s Eye), which has been retired, has been shown to be a valid and reliable tool for analyzing various running gait kinematics. Specifically, Moussavi and colleagues showed excellent intra- and inter-rater reliability with the use of Coach’s Eye during treadmill running (ICCs ranged from 0.87-0.99). When compared to 3D motion analysis, they reported fair to excellent validity for measuring hip, knee, ankle, and foot kinematics, with ICCs ranging from 0.51 to 0.79. The sagittal view was taken with the camera placed two meters from the side of the treadmill, while the posterior view was taken with the camera 1.5 meters from the back of the treadmill. For both views, the camera was one meter off the ground, horizontally secured into the tripod, and orthogonally positioned relative to the plane of interest in order to reduce skewing of angles during analysis.

Standardized patient setup included patients being asked to wear running shorts, a tank top or sports bra for females and no shirt for males in order to facilitate optimal marker placement and observation of key landmarks. The markers used were round, 1-inch diameter, fluorescent 2D stickers placed at the C7 spinous process, posterior superior iliac spines, greater trochanters, lateral knee joint lines, knee joint center, lateral malleoli, midpoints of the calf, superior and inferior portions of the heel shoe counter, and the fifth metatarsals heads (Figure 1).

Patients were instructed to warm up on the treadmill at a self-selected speed for six to ten minutes at 0% incline. After the warm-up period, two 25-second videos were recorded in succession for each view.

Once recording was complete, each video was uploaded and analyzed with CoachNow. Analysis included viewing the footage in slow motion, pausing and using a scroll bar to identify precise gait events, and annotating still frame images to better visualize joint and body positions. Gait events to be identified were initial contact, defined as the first contact of the shoe on the treadmill belt, and midstance, defined as the instance the swing knee was adjacent to the stance knee. In addition, a running gait checklist that researchers adapted from the work of Pipkin et al. was provided to assess the alignment during the initial contact of the sagittal plane and midstance of the frontal and sagittal planes (Table 1 and Appendix 1).
Table 1. Running Gait Checklist.

<table>
<thead>
<tr>
<th>Plane</th>
<th>Gait phase</th>
<th>Variable</th>
<th>Description</th>
<th>Scoring</th>
<th>Clinical significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frontal</td>
<td>Midstance</td>
<td>Trunk sidebend</td>
<td>Line from T1-S1 relative to true vertical</td>
<td>-Excessive ipsilateral</td>
<td>-Increased trunk motion in either direction related to low back pain</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Mild ipsilateral</td>
<td>-Ipsilateral sidebend may occur in attempt to unload lateral hip of stance limb</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Approximate (vertical)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Mild contralateral</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Excessive contralateral</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lateral pelvic drop</td>
<td>Line through posterior superior iliac spines relative to true horizontal</td>
<td>-Appropriate (male= 3 degrees-5</td>
<td>Increased contralateral pelvic drop related to IT band syndrome, anterior knee pain,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>degrees; female= 4 degrees-7</td>
<td>lateral hip pain on stance limb</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>degrees)</td>
<td></td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>-Mild</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Excessive contralateral</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knee center position</td>
<td>Position of knee center relative to line connecting hip and ankle centers</td>
<td>-Excessive lateral</td>
<td>Both medial and lateral positions of knee related to patellofemoral pain</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Mild</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Appropriate (mid-line)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Mild medial</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Excessive medial</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knee separation</td>
<td>Distance between the medial aspect of knees</td>
<td>-Excessive narrow</td>
<td>-Narrow suggestive of dynamic varus</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Mild narrow</td>
<td>-Wide suggestive of dynamic valgus</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Appropriate (slight separation)</td>
<td>-Can be related to anterior knee and hip pain</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Mild wide</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Excessive wide</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Foot-to-center of mass (COM) position</td>
<td>Mediolateral distance of medial heel to vertical line from center of sacrum</td>
<td>-Excessive crossover</td>
<td>Crossover associated with medial tibial stress syndrome and IT band syndrome</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Mild crossover</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Appropriate (medial shoe adjacent to line)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Mild wide</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Excessive wide</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rearfoot position</td>
<td>Angle created by midline of rearfoot relative to midline of lower leg</td>
<td>-Excessive pronation</td>
<td>-Increased pronation associated with anterior knee pain, Achilles tendinopathy,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Mild pronation</td>
<td>medial tibial stress syndrome</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Appropriate</td>
<td>-Increased supination associated with bone stress injuries</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Mild supination</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Excessive supination</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Forefoot position</td>
<td>Position of forefoot relative to heel</td>
<td>-Excessive abduction</td>
<td>-Increased abduction related to Achilles tendinopathy and plantar fasciopathy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Mild abduction</td>
<td>-Increased adduction related to bone stress fractures</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Appropriate</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Mild adduction</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Excessive adduction</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heel-height symmetry</td>
<td>Highest point of heel during swing phase</td>
<td>-Left heel lower</td>
<td>Asymmetrical heel height associated with unequal power generation from lower extremities</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Appropriate (symmetrical)</td>
<td></td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Plane</th>
<th>Gait phase</th>
<th>Variable</th>
<th>Description</th>
<th>Scoring</th>
<th>Clinical significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Midstance</td>
<td>Ankle dorsiflexion angle</td>
<td>Angle created by midline of lower leg relative to sole of foot</td>
<td>-Right heel lower</td>
<td>Increased inclination related to Achilles symptoms</td>
</tr>
<tr>
<td>Sagittal</td>
<td></td>
<td>Knee flexion angle</td>
<td>Angle created by midline of thigh relative to midline of lower leg</td>
<td>-Appropriate (20 degrees of flexion)</td>
<td>Increased knee flexion associated with increased patellofemoral joint load and risk of anterior knee pain</td>
</tr>
<tr>
<td></td>
<td>Initial contact</td>
<td>Knee flexion angle</td>
<td>Midline of thigh relative to midline of lower leg</td>
<td>-Excessive decrease</td>
<td>Associated with overstriding and risk of anterior knee pain and lateral hip pain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Foot strike pattern</td>
<td>Sole of foot relative to running surface at moment of contact</td>
<td>-Heel strike</td>
<td>Heel strike associated with anterior knee pain and lower leg injury</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tibial inclination</td>
<td>Midline of lower leg relative to true vertical</td>
<td>-Appropriate (within 5 degrees of vertical)</td>
<td>Increased inclination associated with bone stress injuries of lower leg</td>
</tr>
</tbody>
</table>
RE-AIM MODEL FOR ASSESSING THE IMPLEMENTATION OF 2D RUNNING ANALYSIS

The process of implementing 2D running gait analysis into physical therapy clinics was assessed using the RE-AIM (Reach, Effectiveness, Adoption, Implementation, and Maintenance) framework.\textsuperscript{13–17} The RE-AIM model provides a comprehensive evaluation framework to improve public health and community-based interventions by facilitating the translation of scientific advances into practice.\textsuperscript{18,19} Specifically, Reach is defined as the extent to which implementation reached the targeted population, measured by the percentage of outpatient orthopedic clinics deemed eligible compared to those approached. Adoption is defined as the extent to which implementation is adopted in the clinical setting and by providers, measured by the percentage of orthopedic clinics willing to participate compared to those deemed eligible. Effectiveness is defined as the impact of an intervention on important outcomes by analyzing how often therapists used information gained from running analysis, and perceived utility of using the protocol. Implementation is defined as the extent to which the intervention is implemented as intended by analyzing therapists’ adherence to the protocol. Maintenance is defined as the sustainability of implementation over time by analyzing therapists’ persistence to using the protocol.

SURVEYS TO ASSESS THE RE-AIM MODEL

To assess the five dimensions of RE-AIM, the researchers created four surveys (i.e., baseline survey, effectiveness survey, implementation survey, and maintenance survey) using Qualtrics XM (Qualtrics Software Company, Provo, Utah). All surveys were validated by a panel of five experts. Face and content validity of the surveys were determined by a panel of two physical therapy educators who specialize in orthopedics, two physical therapists with specialty certification in running analysis, and one physical therapist who is a generalist. These experts provided a breadth of knowledge related to video gait analysis and the practicality of using video analysis in a clinic setting. They were asked to assess the overall face and content validity by examining the language used and relevance of each item in the questionnaire. Upon review of each survey question, each item was deemed valid by all experts, and no changes were made to the surveys.

The baseline survey gathered information about clinician specialization, such as being a clinic or regional director, prior running gait analysis training, current perceptions of running gait analysis to assist with treatment of patients, overall interest in the study, if they would be participating in the study, and reasons for non-participation. The baseline survey allowed the team to assess "Reach" and "Adoption" rates of implementation.

For the effectiveness survey, a 5-point Likert scale was used for the questions, where 1 represented a response of "not at all" and 5 a response of "very much". Specifically, this survey asked for a rating of difficulty to conduct the protocol, if the protocol set up was reasonable, if the running gait checklist was useful for analyzing running gait patterns, if the protocol was worth routine use, if they felt the patients saw the benefit of using this analysis in their evaluation, and if implementing the protocol affected their overall satisfaction with treating running patients. Additional questions asked for a rating and an explanation for each answer. The questions included in this survey were as follows: "Is the methodology reasonable and appropriate? Is the protocol helpful in making decisions in treatment plans? Does the protocol influence your plan of care?"

The implementation survey contained questions that assessed the frequency in which the physical therapists performed the protocol and to what extent they accurately followed the protocol. These included a numerical value for number of times conducting the protocol in the last month and average time in minutes conducting each individual running gait analysis. A yes or no answer was used for questions asking if the amount of time spent performing the analysis was reasonable, if each runner warmed up for the appropriate time, if all videos were taken for at least 25 seconds, if the CoachNow application was used to analyze video footage for each runner, and if the running gait checklist was used to interpret the findings for each runner. Additional yes and no questions with an explanation box if the participant answered "no" were used for the following questions: "Was the protocol performed on all appropriate patients? Were the stickers used on each landmark for each runner? Were all videos taken from the specified setup criteria? Was CoachNow used as instructed? Was the running gait checklist used as instructed?"

The maintenance survey assessed how well the physical therapists maintained the use of the 2D running analysis protocol. Questions asked in this survey were: "Have you maintained use of the protocol? Have any adaptations been made to the protocol? Will you continue to use the protocol in the future? Do you have any further input or suggestions about the protocol?"
PROCEDURE

The baseline survey was sent to 30 outpatient physical therapy clinics that are affiliated with the University of Nevada, Las Vegas, to assess interest and eligibility in study participation. To be eligible for the study, participating clinics did not have a current 2D running gait analysis protocol in place, had to have a licensed physical therapist and treadmill available within the facility, and had to be currently treating at least one patient with a running-related injury. Once the participating clinics were identified, researchers visited each clinic to train participating physical therapists in performing the 2D running gait analysis using aforementioned methods. The physical therapists were asked to perform this protocol at initial evaluations and re-evaluations on their appropriately designated patients, defined as any patient with a running-related injury that was willing and deemed safe by the evaluating therapist to perform treadmill running for gait analysis. The therapists were also advised to use their findings to help inform their treatment plan.

The effectiveness and implementation surveys were sent to all participating physical therapists after two months of participating in the study and contained questions pertaining to the protocol taught to therapists. The maintenance survey was completed four months after the effectiveness and implementation surveys were sent. All activities in this study were approved by the review board of University of Nevada, Las Vegas (IRB 1712677-5). Informed consent was obtained for all subjects and participating facilities.

STATISTICAL ANALYSIS

The data collected from the four surveys were de-identified for confidentiality. Reach and Adoption were evaluated using descriptive statistics through the baseline survey. Effectiveness and Implementation were assessed using descriptive statistics and qualitative analysis of information gathered from their respective surveys. Maintenance was evaluated using descriptive and qualitative statistics from the maintenance survey. For descriptive statistics, we reported available mean, standard deviation, frequency (percentage), and range. For quantitative analyses, Spearman’s rho correlation analysis (one-tailed, significance level=0.05) was also conducted, where correlation strength (r) was adapted based off general guidelines and defined as weak (r < 0.4), moderate (0.4 < r < 0.7), and strong (r > 0.7) for this study.²⁰ Quantitative data was analyzed in SPSS statistical package (SPSS version 27.0, IBM Corp., NY, USA), while qualitative data was assessed using ATLAS.ti.

RESULTS

REACH AND ADOPTION

Of the 30 clinics contacted, 15 clinics responded to the baseline survey. Twelve of these 15 clinics met the eligibility criteria for this study, giving a reach value of 80%. The remaining three clinics were not eligible to participate with two of them stating they did not have the correct patient population, and one reporting having an existing running gait analysis protocol in place. Of the 12 eligible clinics, 10 of them participated in the study, giving an adoption value of 83%. The two clinics that chose not to participate indicated time constraints and lack of cases to support effective use of the protocol as reasons for non-participation. Ultimately, 12 physical therapists from 10 different clinics participated in this study (Table 2). The age range of participating physical therapists was 28-57 years old, with a mean age of 41 years old. Eight of the 12 physical therapists were clinical or regional directors. Half of the therapists reported having prior standardized training with running gait analysis, while the other half had no prior training (Table 2).

Common reasons for participation included gaining knowledge and improving clinical skills in order to provide better treatment to runner patients and contributing to research for the advancement of the physical therapy profession. Five therapists’ initial perception of running gait analysis was that “it can be useful if time permits and when used with the appropriate population”. Four therapists acknowledged that running gait analysis would be most beneficial when used by trained and well-versed clinicians in running mechanics and that running analysis should not be used in isolation, but rather as part of a full patient assessment. One therapist stated that running gait analysis was useful for breaking down phases of gait, identifying biomechanical faults and possible contributing factors towards injury, tracking progress, and when used in conjunction with patient education.

EFFECTIVENESS

Table 3 details the effectiveness survey results regarding how the 12 included physical therapists ranked each survey question. The four questions that received the highest rating were “Is the protocol easy to conduct?”, “Is the methodology reasonable and appropriate?”, “Is the provided Running Gait Checklist useful for analyzing running gait patterns?”, and “Do the patients see the benefit of using this in their evaluation?”, with a score ranging between 4.0 and 4.6. Two questions received somewhat ambivalent/negative ratings, including “How useful was the protocol in helping you make decisions about your treatment plans?” and “Is the level of usefulness enough to make the protocol worthy of routine use?” with a score of 3.2 and 3.0, respectively. The remaining three questions scored intermediately between 3.7 and 3.8, including “Are the setup criteria reasonable?”, “Does using 2D running gait analysis influence your plan of care for patients?”, and “How has implementation of the protocol affected your overall satisfaction with the treatment you provide your running patients?”. A significant moderate positive correlation was found between the rating of the protocol’s influence on plan of care and the rating of usefulness of routine use (r=.516, p=.043). The rating of clinicians’ satisfaction of implementing the 2D motion analysis in the provided treatment demonstrated positive moderate correlations with the rating of the protocol’s influence on plan of care (r=.509, p=.045), and with the rating of patient perceived benefit of using the protocol (r=.524, p=.040).
Table 2. Demographics of eligible physical therapists, participating and non-participating.

<table>
<thead>
<tr>
<th>Therapist #</th>
<th>Age</th>
<th>Clinical position</th>
<th>Prior training</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28</td>
<td>Physical therapist</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>28</td>
<td>Physical therapist</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>32</td>
<td>Physical therapist</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>32</td>
<td>Clinic director</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>34</td>
<td>Clinic director</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>36</td>
<td>Physical therapist</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>41</td>
<td>Clinic director</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>47</td>
<td>Clinic director</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>47</td>
<td>Clinic director</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>51</td>
<td>Regional director</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>56</td>
<td>Clinic director</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>57</td>
<td>Regional director</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Mean Age</td>
<td>41</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>% Therapists</td>
<td>--</td>
<td>67% director position</td>
<td>50%</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Effectiveness survey results.

<table>
<thead>
<tr>
<th>Survey Question</th>
<th>Likert Score = 1 (# of PTs)</th>
<th>Likert Score = 2 (# of PTs)</th>
<th>Likert Score = 3 (# of PTs)</th>
<th>Likert Score = 4 (# of PTs)</th>
<th>Likert Score = 5 (# of PTs)</th>
<th>Mean Likert Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the protocol easy to conduct?</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4.0</td>
</tr>
<tr>
<td>Are the set up criteria reasonable?</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>3.7</td>
</tr>
<tr>
<td>Is the methodology reasonable and appropriate?</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>6</td>
<td>4.4</td>
</tr>
<tr>
<td>Is the provided Running Gait Checklist useful for analyzing running gait patterns?</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>7</td>
<td>4.6</td>
</tr>
<tr>
<td>How useful was the protocol in helping you make decisions about your treatment plans?</td>
<td>0</td>
<td>2</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>3.2</td>
</tr>
<tr>
<td>Does using 2D running gait analysis influence your plan of care for patients?</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>3.7</td>
</tr>
<tr>
<td>Is the level of usefulness enough to make the protocol worthy of routine use?</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>3.0</td>
</tr>
<tr>
<td>Do the patients see the benefit of using this in their evaluation?</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>8</td>
<td>2</td>
<td>4.0</td>
</tr>
<tr>
<td>How has implementation of the protocol affected your overall satisfaction with the treatment you provide your running patients?</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>7</td>
<td>1</td>
<td>3.8</td>
</tr>
</tbody>
</table>

* Likert Score Rating: 1 = not at all, 5 = very much; unless otherwise specified
IMPLEMENTATION

During the first month of implementation, six therapists conducted a single running analysis, two therapists conducted two analyses, three therapists conducted three, and one therapist conducted four analyses, for a total of 23 analyses (mean = 2 analyses). All therapists reported performing the protocol on every appropriate runner with a running-related injury except for one therapist who was unable to conduct the protocol on one runner due to complications with setup in the clinic at the time. Therefore, therapists performed the protocol on 23 of the 24 appropriate runners, a rate of 96%. The average time therapists spent performing each protocol was 52 minutes (range = 10-75 minutes), with 50% of the therapists spending between 25-30 minutes on each running analysis. 75% of the therapists felt the time spent conducting each analysis was reasonable, including those who spent 45 and 75 minutes on each analysis. The remaining three therapists who felt the time spent was unreasonable reported conduction times ranging from 25-60 minutes. A significantly moderately positive correlation was found between average amount of time spent conducting protocol and the rating of clinician perceived usefulness for making treatment plan decisions (r=0.663, p<0.009).

As shown in Table 4, 83% of therapists reported placing markers on every designated landmark for each runner. Of the remaining two therapists, one reported placing markers for the frontal, but not sagittal view as their clinic setup did not allow them to obtain a sagittal view. Another therapist reported not needing markers at all. The majority of runners who had a running gait analysis performed, warmed up for the designated time of 6-10 minutes, an adherence rate of 96%. Therapists were asked whether all videos were taken from the specified distance, height and angles provided in the protocol, eight therapists (67%) answered yes. The four therapists who answered "no" gave responses related to setup and time efficiency as reasons for making modifications. Specific issues with setup involved clinic layout not allowing for a sagittal view, treadmill handlebars obstructing the sagittal view, and differences in magnification between devices. 92% of therapists reported recording all videos for at least 25 seconds, and 100% of therapists used either the Coach's Eye application or CoachNow application to analyze video footage for each runner. Eleven of the 12 therapists used the applications as instructed while one therapist did not, and instead used the application's line tool to draw a plumbline from which they could emphasize angles, alignment, and contact points. All therapists used the running gait checklist to interpret findings for each runner, with 11 of 12 therapists using the checklist in the manner that was instructed. One therapist reported skipping through some of the checklist for efficiency.

MAINTENANCE

Of the 12 clinicians completing the study (Table 5), six therapists (50%) reported continuing to use the running gait analysis protocol, while six therapists (50%) answered "no" to continuing use. Comments from the group of clinicians answering "yes" about why they continued to use the protocol included two therapists reporting general interest in using the analysis to analyze patient's running gait, two therapists reporting the protocol being useful for patient education, and one therapist feeling the protocol was quick to set up and easy to use. Reasons reported by the group answering "no" to continuing protocol use included five therapists reporting not having adequate case load to continue use, one therapist reporting time restraints, and one therapist reporting clinic set up not allowing adequate use of protocol. Overall, only one out of 12 therapists (8%) reported making adaptations to the protocol. The adaptation reported was "did not take every measurement to shorten the protocol to focus on specific patient goals".

When asked "Will you continue to use the protocol in the future?", seven therapists answered "Probably yes", four answered "Might or might not", and one answered "Probably not". Additional comments related to the protocol were: 1) the protocol would be useful in a cash pay setting rather than a busy outpatient setting, 2) the protocol is useful if not limited by time restraints, 3) having more appropriate patient populations would allow for more use, and 4) using the stickers can be cumbersome to put on and have limitations in their use.

DISCUSSION

Previous research has shown that more than 50% of surveyed orthopedic physical therapists do not use video-based motion analysis in clinical practice. To understand the actual implementation of 2D running analysis and barriers of implementation in clinical physical therapy setting, we aimed to examine the clinician-perceived notions of implementing a running gait analysis protocol into their practice via a RE-AIM model. The RE-AIM framework used in this study allowed us to understand the details of the implementation process. The "Reach" and "Adoption" rates in the beginning of this study were 80% and 83%, respectively, suggesting that we were able to reach and initiate the adoption of the 2D running gait analysis in the majority of outpatient orthopedic clinics. However, as 15 clinics did not respond to the provoked survey, the reach and adoption rates observed in this study may have been different if those clinics responded to the baseline survey.

With respect to the effectiveness of implementing the 2D running analyses, the majority of the clinicians that participated in this study valued having a protocol with a checklist in which they could quantitatively analyze their patient's running gait pattern with a reported mean score of 4.6 on a five-point Likert scale. Additionally, most therapists reported that the protocol was easy to conduct, the methodology was reasonable and appropriate, and the patients saw the benefits of using the protocol in their evaluation. However, the questions about the level of usefulness for making the protocol worthy of routine use and for helping clinicians make decisions about the treatment plan received neutral rating (around 3.0). This may be attributed to time constraint and patient's competing needs in an out-
Table 4. Implementation survey results.

<table>
<thead>
<tr>
<th>Survey Question</th>
<th>Yes (# of PTs)</th>
<th>No (# of PTs)</th>
<th>Compliance Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Was the protocol performed on all appropriate runners with running-related injuries?</td>
<td>11</td>
<td>1</td>
<td>91.7%</td>
</tr>
<tr>
<td>Is the amount of time spent on each running gait analysis reasonable?</td>
<td>9</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Were markers placed on every landmark for each runner?</td>
<td>10</td>
<td>2</td>
<td>83.3%</td>
</tr>
<tr>
<td>Did each runner warm up for the appropriate amount of time?</td>
<td>11</td>
<td>1</td>
<td>91.7%</td>
</tr>
<tr>
<td>Were all videos taken from the specified distance, height, and angles provided in the protocol?</td>
<td>8</td>
<td>4</td>
<td>66.7%</td>
</tr>
<tr>
<td>Were all videos taken for at least 25 seconds?</td>
<td>11</td>
<td>1</td>
<td>91.7%</td>
</tr>
<tr>
<td>Was either the Coach’s Eye or CoachNow application used to analyze video footage for each runner?</td>
<td>12</td>
<td>0</td>
<td>100%</td>
</tr>
<tr>
<td>If yes, was it used as instructed? (as follow-up to the above question)</td>
<td>11</td>
<td>1</td>
<td>91.7%</td>
</tr>
<tr>
<td>Was the Running Gait Checklist used to interpret the findings for each runner?</td>
<td>11</td>
<td>1</td>
<td>91.7%</td>
</tr>
<tr>
<td>If yes, was it used as instructed? (as follow-up to the above question)</td>
<td>11</td>
<td>0</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 5. Maintenance survey results.

<table>
<thead>
<tr>
<th>Survey Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have you maintained the use of the 2D running gait analysis protocol?</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>Since the end of the study, have any adaptations been made to the protocol in order to accommodate the specific needs of your clinic?</td>
<td>17%</td>
<td>83%</td>
</tr>
<tr>
<td>Survey Question</td>
<td>Definitely not</td>
<td>Probably not</td>
</tr>
<tr>
<td>Will you continue to use the protocol in the future?</td>
<td>0%</td>
<td>8%</td>
</tr>
</tbody>
</table>

patient setting. Of the clinicians who chose to elaborate on why they felt that the protocol was or was not worthy of routine use, all of them stated that time was the significant factor in why it might not be. Interestingly, a moderately positive correlation was found between the amount of time spent conducting the protocol and clinician perceived usefulness in developing a treatment plan, suggesting that the increased amount of time taken to properly conduct the protocol could benefit therapists’ in developing individualized treatments for their patients. One possible strategy to alleviate the time required for administering the 2D motion analysis is to have other clinic personnel assist with the camera setup and marker placements to shorten the amount of time taken to perform the entire protocol.

One potential barrier to implementing this protocol expressed by clinicians was not having appropriate clinic setup to accommodate performing this protocol. One clinician stated that their clinic space did not allow for sagittal views, one reported having a treadmill with handlebars that obstructed the field of view, and one clinician stated that different [video recording] devices displayed different magnification settings, which may require clinicians to adjust the distance to the treadmill that videos are taken from in order to get all markers within view.

It is also important to acknowledge that some clinicians who might attempt to implement this protocol may not have access to video technology or access to the application used to analyze running gait in this study, which could limit their ability to conduct this analysis. Although all clinics were deemed eligible prior to implementation, change in clinic setup or in clinician video devices could have created barriers to using the running analysis. Having a consistent manner to record videos and perform analysis is essential, meaning clinicians will need to assess their own setups to decide if they are able to perform the analysis.

When asked if the protocol influenced their plan of care, therapists most frequently stated that it helped to provide patient education and to design treatment plans based on their patient’s gait abnormalities. Importantly, associations were found between the protocol’s influence on plan of care and usefulness of routine use, and between clinicians’ satisfaction of implementing the 2D motion analysis and the protocol’s influence on plan of care/patient perceived benefit. Multiple clinicians also expressed the importance of this protocol being used in conjunction with other examination strategies, rather than using this protocol as a standalone assessment. Further research will need to be conducted to assess what strategies would best be incorporated with performing a running gait analysis. Since visual feedback is al-
ready a common use of video-based motion analysis among clinicians that use cameras to analyze their patient’s movement,11 the integration of patient education along with visual feedback when using this protocol has the potential to be a significant benefit of using this 2D running gait analysis.

Half of the clinicians involved in this study reported not continuing protocol use after the six-month maintenance survey. This rate is similar to that of a larger-scale survey study that assessed the prevalence of using 2D motion analysis in orthopedic physical therapy clinics.11 However, the majority of clinicians reported that they would or probably would use the protocol in the future. This shows that even though clinicians did not remain consistent after six months, they are open to using it again when needed. Clinicians expressed that the main hinderances to continued use are not having a sufficient patient caseload to continue use and time restraints due to their clinic setting. No clinicians reported discontinuing use of the protocol due to any specific protocol reasons or feeling that the protocol was not useful, leading the researchers of this study to believe that a much higher retention rate would have been plausible if clinicians worked with more patients that were runners or had more time to evaluate each patient. Also, only minimal reports of changes or suggestions were made by clinicians about the protocol, demonstrating that the protocol itself may not be the reason for the low retention rate.

Lastly, while many clinicians stated that the protocol was useful in designing their treatment plans, it is unclear if the change in treatment resulted in improved function as patient outcomes were not assessed. Nevertheless, these results suggest using this protocol in a clinical setting with an appropriate patient population, sufficient amount of time to evaluate each patient, and proper clinic set-up may provide clinicians an effective tool to help guide patient evaluations and design treatment plans.

The study has several limitations. First, given that this study was only conducted in the Las Vegas area, the findings may not be generalizable to other areas. Another limitation of the current study is that patient outcomes or perspectives were not assessed. This study focused solely on the clinicians’ views of implementing 2D running gait analysis, but evaluating patient outcomes could provide useful information and should be considered for future research. A third limitation in the current study was that many of the therapists had high caseloads. Time constraints and inadequate patient population were commonly reported barriers in this study; thus, the results could potentially be different if the study was done with different clinician populations.

CONCLUSION

The results of this study provide evidence that 2D running gait analysis is a potentially valuable intervention that can be utilized by outpatient physical therapy clinicians to assist with evaluating injured running patients and devising treatment plans. Clinicians that participated in this study expressed a perceived benefit of implementing a running gait analysis protocol with common themes of ease of use, being a useful adjunct to evaluating a patient, and increased satisfaction with treating injured runners. Potential barriers presented in this study included clinicians not having appropriate clinic setup, being restricted by time constraints, and not having adequate patient populations. The use of a 2D running gait analysis protocol in outpatient physical therapy settings may be improved by eliminating the barriers identified in this study.

DISCLOSURES

The authors report no conflicts of interest.

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REFERENCES


SUPPLEMENTARY MATERIALS

Appendix

Comparison of the Frontal Plane Projection Angle and the Dynamic Valgus Index to Identify Movement Dysfunction in Females with Patellofemoral Pain

Lori A Bolgla, Haley N Gibson, Daniel C Hannah, Tiana Curry-McCoy

Keywords: kinematics, patella, receiver operating characteristic curve, sensitivity, specificity

https://doi.org/10.26603/001c.74269

Background
Clinicians typically measure the knee frontal plane projection angle (FPPA) during a single-leg squat to identify females with patellofemoral pain (PFP). A limitation of this measure is minimal attention to movement of the pelvis on the femur that can create knee valgus loading. The dynamic valgus index (DVI) may be a better assessment.

Hypothesis/Purpose
The purpose of this study was to compare the knee FPPA and DVI between females with and without PFP and determine if the DVI better identified females with PFP than the knee FPPA.

Study Design
Case-control

Methods
Sixteen females with and 16 without PFP underwent 2-dimensional motion analysis when performing five trials of a single-leg squat. The average peak knee FPPA and peak DVI were analyzed. Independent t-tests determined between-group peak knee FPPA and peak DVI differences. Receiver operating characteristic (ROC) curves determined the area under the curve (AUC) scores for sensitivity and 1 - specificity of each measure. Paired-sample area difference under the ROC curves was conducted to determine differences in the AUC for the knee FPPA and DVI. Positive likelihood ratios were calculated for each measure. The significance level was p < 0.05.

Results
Females with PFP exhibited a higher knee FPPA (p = 0.001) and DVI (p = 0.015) than controls. AUC scores were .85 (p = 0.001) and .76 (p = 0.012) for the knee FPPA and DVI, respectively. Paired-sample area difference under the ROC curves showed a similar (p = 0.10) AUC for the knee FPPA and DVI. The knee FPPA had 87.5% sensitivity and 68.8% specificity; the DVI had 81.3% sensitivity and 81.0% specificity. Positive likelihood ratios for the knee FPPA and DVI were 2.8 and 4.3, respectively.

Conclusion
The DVI during a single-leg squat may be another useful tool for discriminating between females with and without PFP.

Level of Evidence
3a
INTRODUCTION

Patellofemoral pain (PFP) is one of the most common knee problems experienced by young adults. Individuals with PFP complain of retro- or peri-patellar pain during activities requiring weight bearing on a flexed knee like running, squatting, or stair ambulation. Powers has theorized that increased hip adduction, hip internal rotation, and knee abduction can cause increased knee valgus loads that stress patellofemoral joint structures. He has referred to these combined lower extremity kinematics as the dynamic quadriceps angle (Q-angle).

Clinicians have quantified the dynamic Q-angle by measuring the knee frontal plane projection angle (FPPA) via 2-dimensional (2-D) video analysis. An increased knee FPPA would suggest greater knee valgus loading. A limitation of this approach has been a sole focus on knee kinematics. Increased hip adduction from excessive contralateral pelvic drop relative to the femur also can increase patellofemoral joint loads. However, the knee FPPA does not directly account for this faulty hip movement pattern. To address this concern, Scholtes and Salsich developed the dynamic valgus index (DVI), a comprehensive measure combining the hip and knee FPPA. They also have reported differences in the DVI during a SLS in females with and without PFP.

Gwynne and Curran examined the ability of the knee FPPA during a SLS to identify subjects with and without PFP. Their findings showed that the knee FPPA had fair sensitivity and specificity. A more comprehensive measure, like the DVI, may better discriminate between those with and without PFP. Therefore, the first purpose of this study was to compare the knee FPPA and DVI during a SLS between females with and without PFP. The second purpose was to determine if the DVI better identified females with PFP than the knee FPPA. We hypothesized the following: 1) females with PFP would demonstrate a higher knee FPPA and DVI during a SLS and 2) the DVI would be more accurate than the knee FPPA in discriminating between females with and without PFP.

METHODS

PARTICIPANTS

An a priori power analysis was conducted using G*Power 3.1.9.711 based on published data. Using an effect size of .90, α = .05, and β = .20, a minimum of 16 subjects was required for each group. Subjects were recruited in the greater Central Savannah River Area by placing flyers on two campuses of a local university, at area fitness clubs, and at an academic medical center sports medicine clinic. Sixteen females with PFP and 16 controls participated (Table 1). Subject’s age ranged from 18 to 54 years. This age range was selected because of an increased prevalence of osteoarthritis onset after age 40. Inclusion and exclusion criteria were based on prior works. All subjects were recreationally active, defined as exercising at least 30 minutes three times a week for at least the prior six months. Subjects with PFP met additional criteria regarding their anterior knee pain: a) rated at least a 3 on a 10-cm visual analog scale during activities of daily living or recreation (e.g., running, walking, squatting, stair ambulation) over the previous week, b) insidious onset for at least four weeks, c) provoked by at least three of the following: during or after activity, prolonged sitting, stair ambulation, or squatting. None of the subjects with PFP had sought rehabilitation or undergone any prior movement retraining program to improve SLS mechanics. Individuals with the following were excluded from study participation: a) previous lower extremity surgery or significant injury, b) recurrent patella dislocation or subluxation, c) patella tendon or iliotibial band tenderness, and d) hip or lumbar spine referred pain. The most painful knee was tested for subjects with PFP; controls used the limb that was determined in a random fashion. Five subjects with PFP reported bilateral symptoms. Subjects were enrolled consecutively as they met the inclusion criteria and signed an informed consent document approved by the university Institutional Review Board.

PILOT TESTING

Prior to data collection, pilot testing was conducted for measuring the knee FPPA and DVI in 10 individuals who did not participate in the current study. For this purpose, these individuals were measured on two separate occasions, three to five days apart, by different examiners. Using procedures outlined below, measurement reliability was acceptable based on intraclass correlation coefficients (ICC [2,1]) of .88 and .89 for the knee FPPA and DVI, respectively.
Table 1. Means ± standard deviations for participant demographic data.

<table>
<thead>
<tr>
<th></th>
<th>PFP (n = 16)</th>
<th>Control (n = 16)</th>
<th>p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>23.4 ± 2.6</td>
<td>21.6 ± 2.9</td>
<td>0.08</td>
</tr>
<tr>
<td>Mass, kg</td>
<td>60.8 ± 17.5</td>
<td>62.2 ± 12.5</td>
<td>0.81</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.8 ± 0.6</td>
<td>1.7 ± 0.7</td>
<td>0.49</td>
</tr>
<tr>
<td>Pain, cm</td>
<td>3.6 ± 1.4</td>
<td>----</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* Between-group comparisons made using independent t-tests.

MOTION ANALYSIS

Twelve-mm spherical retroreflective markers were placed on the anterior surfaces of the following landmarks: left and right anterior superior iliac spine (ASIS), midpoint of the knee on the test extremity (midpoint of the distance between lateral and medial epicondyle measured using a tape measure), and the midpoint of the ankle (midpoint of the distance between lateral and medial malleoli measured using a tape measure) on the test extremity. Markers also were placed on the greater trochanter, lateral knee joint line, and lateral malleolus to measure knee flexion. For testing, subjects stood 2.5 m away from two cameras, one positioned in the sagittal plane and the other in the frontal plane. Subjects performed the SLS barefooted. The investigator instructed subjects to cross their arms over their chest and to squat as low as possible; they received no instruction on hip, knee, or foot position. Subjects squatted at least 50° of knee flexion (determined by visual inspection) to the beat of a metronome set at 40 beats per minute. They performed 3 practice and 5 test trials of the SLS. A video-based 2-D motion capture system (Simi Motion®, Unterschleißheim, DEU), operating at 100 Hz, recorded all data.

DATA PROCESSING AND REDUCTION

Video data were tracked and smoothed with a 2nd-order low-pass filter, using a 6 Hz cutoff frequency. Knee FPPA and DVI were measured at the point of peak knee flexion (the angle between the greater trochanter, lateral knee joint line, and lateral malleolus). The knee FPPA (Figure 1) was 180° minus the angle between the ASIS and mid-point of the knee and the mid-point of the knee to the mid-point of the ankle on the test limb. The DVI (Figure 1) was 90° minus the angle between the ipsilateral and contralateral ASIS and ipsilateral ASIS and the mid-point of the distal femur plus the FPPA. The average of the five trials for peak knee flexion angle, peak knee FPPA, and peak DVI was used for statistical analysis.

STATISTICAL ANALYSIS

Means, standard deviations, and 95% confidence intervals (95% CI) were calculated for average peak knee flexion, peak knee FPPA, and peak DVI. Separate independent t-tests were used to determine if significant differences existed between females with PFP and controls. Receiver operating characteristic (ROC) curves were used to determine the area under the curve (AUC) for sensitivity and 1-specificity for the knee FPPA and DVI. We also compared the AUC between the knee FPPA and DVI using methods described by Hanley and McNeil. AUC scores ranged from 0 to 1.0; a 1.0 signified perfect discrimination. Obuchowski interpreted the AUC as follows: weak (< .50), fair (.60 to .70), good (.80 to .90), and excellent (.9 to 1.0). The AUC data also had various cut-off scores with their associated sensitivity and 1-specificity values. An optimal cut-off score to distinguish between females with and without PFP was the one that would maximize the true positive and minimize the false positive rate. To make this determination, we used Youden’s index by calculating (sensitivity + specificity – 1) for each cut-off score from the knee FPPA and DVI ROC curves. The optimal cut-off score for the knee FPPA and DVI was the one with the highest Youden’s index. Next, we used the sensitivity and specificity for the knee FPPA and DVI optimal cut-off score to calculate positive likelihood ratios (LR+). A LR+ greater than 1 implied a positive test result would be associated with disease presence; tests with a higher LR+ would provide even greater evidence for disease presence with a positive finding.

RESULTS

No between-group differences existed with respect to peak knee flexion. Subjects with PFP demonstrated 2.0 times higher peak FPPA and 1.3 times greater peak DVI than controls. Table 2 summarizes these data.

The AUC scores from the ROC analyses (Figure 2) for the knee FPPA and DVI were .85 [95% CI (.71, .98); p = 0.001] and .76 [95% CI (.58, .94); p = 0.01], respectively. These findings suggested that the knee FPPA had good sensitivity and specificity for discriminating between females with and without PFP. The DVI had a lower AUC, which can be interpreted as fair-to-good sensitivity and specificity. However, paired-sample area difference under the ROC curves was .07 (95% CI (-.02, .19); p = 0.10), suggesting similar AUC between the knee FPPA and DVI. The optimal cut-off score was 8.2˚ (Youden index = .56; sensitivity = 87.5%; specificity = 68.8%) for the knee FPPA and 33.6˚ (Youden index = .65; sensitivity = 81.3%; specificity = 81.0%) for the DVI. LR+ were 2.8 and 4.5 for the knee FPPA and DVI, respectively.

DISCUSSION

The purpose of this study was to 1) compare the knee FPPA and DVI during a SLS between females with and without PFP and 2) determine if the DVI better identified females with PFP than the knee FPPA. It was hypothesized that females with PFP would demonstrate a higher peak knee FPPA and peak DVI during a SLS and that the DVI would better discriminate between females with and without PFP. Findings from this study supported our hypotheses. Subjects with PFP exhibited a higher knee FPPA and DVI.
Table 2. Means ± standard deviations and (95% confidence intervals) for all dependent measures.

<table>
<thead>
<tr>
<th></th>
<th>Patellofemoral Pain</th>
<th>Control</th>
<th>p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee flexion, degrees</td>
<td>59.4 ± 7.6 (55.3, 63.4)</td>
<td>58.3 ± 5.4 (55.5, 61.2)</td>
<td>0.67</td>
</tr>
<tr>
<td>Knee FPPA†, degrees</td>
<td>13.7 ± 6.5 (10.2, 17.1)</td>
<td>6.8 ± 4.2 (4.6, 9.1)</td>
<td>0.001</td>
</tr>
<tr>
<td>DVI‡, degrees</td>
<td>38.1 ± 9.5 (33.0, 43.1)</td>
<td>28.8 ± 10.7 (23.1, 34.5)</td>
<td>0.015</td>
</tr>
</tbody>
</table>

* Between-group comparisons made using independent t-tests.
† Frontal plane projection angle
‡ Dynamic valgus index

Figure 2. Receiver operating characteristic (ROC) curve for identifying females with patellofemoral pain based on the peak knee frontal plane projection angle (FPPA) and dynamic valgus index (DVI).

DVI also had a higher LR+ for identifying females with PFP than the knee FPPA.

KINEMATICS

The current findings aligned with other studies that have reported an increased knee FPPA during a SLS in those with PFP.6,7,9,10 The 13.7° magnitude of knee FPPA also agreed with values from prior works with values ranging from 11.5° to 16.8°.7-9,10 Regarding the DVI, Scholtes and Salsich9 were the only ones to compare the DVI between females with and without PFP. Like the current study, females with PFP in their study demonstrated a significantly higher DVI than controls. Subjects with PFP in the current study exhibited an average DVI of 38.1° compared to 31.1° reported by Scholtes and Salsich.9 Although a small discrepancy existed between values, subjects with PFP had a higher knee FPPA and DVI than controls.

Gwynne and Curran10 used a ROC analysis to examine the sensitivity and specificity for using the knee FPPA during a SLS to identify subjects with PFP. They reported an AUC equal to .73, which was lower than the AUC (.85) found in the current study. Gwynne and Curran10 did not report their optimal cut-off point, which prohibited our ability to compare sensitivity, specificity, and LR+. Although the AUC for the DVI (.76) was lower, the paired-sample area difference under the ROC curves test showed equal AUC for the knee FPPA and DVI. The DVI had a higher LR+ (4.3) than the knee FPPA (2.8) in the current study.

CLINICAL IMPLICATIONS

Clinicians have used the knee FPPA to distinguish between individuals with and without PFP.6-8 Findings from the current study suggest that the DVI may be another viable approach than the more commonly used FPPA. However, caution must be taken using results solely from hip and/or knee kinematics during a SLS to diagnose those with PFP. Thus, clinicians should consider other sources of anterior knee pain like patellar tendinopathy, patellar instability, and plica syndrome.22

The current results show that females with PFP exhibit a higher DVI during a SLS, which may reflect decreased hip and knee neuromuscular control. Recent findings have shown improvements in the DVI for those with PFP following a movement retraining intervention.23,24 Assessing the DVI may be better than the FPPA when deciding to implement movement retraining because it incorporates both hip and knee movement. However, this conclusion is speculative and additional investigations are needed to make this determination.

LIMITATIONS

This study has limitations that deserve attention. First, only females participated, which limited extrapolation of results to males. Second, the knee FPPA and DVI was only assessed during a SLS. Subjects with PFP who did not exhibit a higher knee FPPA and DVI during a SLS might have done so during other dynamic tasks like sit-to-stand transitions and stair ambulation. Finally, PFP is a multifactor problem with various impairments; not all individuals with PFP may exhibit an increased dynamic Q-angle. Clinicians must consider other impairments such as strength, flexibility, and overuse when examining this patient cohort.22
CONCLUSION

In summary, 2-D motion analysis is useful for identifying females with PFP who exhibit altered lower extremity kinematics. Although clinicians have primarily used the FPPA, the DVI may be useful because it accounts for altered hip and knee movements, both of which can contribute to increased knee valgus loading. Additional studies are needed to further examine the usefulness of the DVI in discriminating between multiple sources of anterior knee pain.

FUNDING

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HUMAN SUBJECT APPROVAL

This study was approved by the Augusta University Institutional Review Board #1480126.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

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REFERENCES


Isokinetic Assessment of Knee Flexor and Extensor Strength and Lower Extremity Flexibility Assessment of an NCAA Division III Men’s Soccer Team

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Keywords: Flexibility assessment, hamstring injury, isokinetic testing, screening

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International Journal of Sports Physical Therapy

Background
Strength imbalances and flexibility deficits of the hamstrings and hip flexors have been identified as potential risk factors for hamstring injuries, but research on athletes at the Division III level are limited, potentially due to a lack of resources and technology.

Purpose
The purpose of this study was to conduct isokinetic and flexibility assessments to screen male soccer athletes at risk of sustaining a hamstring injury.

Study Design
Observational cohort

Methods
Standardized isokinetic testing of concentric muscle performance, measured by peak torque of the quadriceps and hamstrings and hamstrings-to-quadriceps ratios, was conducted using a Biodex isokinetic dynamometer at speeds of 60 and 180°/sec. Additionally, the Active Knee Extension (AKE) test and the Thomas test were performed bilaterally to objectively measure flexibility. Paired sample t-tests were used to compare left and right lower extremities for all outcomes, with the level of significance set at p<0.05. Participants were ranked for risk and given a set of exercises sourced from the FIFA 11 Injury Prevention Program.

Results
At 60°/sec, the mean PT/BW bilateral deficit was 14.1% for extension and 12.9% for flexion. At 180°/sec, the mean deficit was 9.9% for extension and 11.4% for flexion. The team’s average for left and right H:Q ratios for each speed were 54.4 and 51.4 at 60°/sec and 61.6 and 63.1 at 180°/sec, respectively. The team’s average AKE range of motion was 158° for the left leg and 160° for the right leg. The mean Thomas test measurements were 3.6° away from the neutral position on the right and 1.6° on the left, with nine positive tests. There were no statistically significant differences between left and right knee extension or flexion PT/BW or H:Q ratios at either speed. There was no significant difference between left and right AKE measurements (p=0.182).

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Conclusion

The results of this screening suggest that isokinetic testing and flexibility testing may be useful to identify non-optimal strength ratios and flexibility deficits in male collegiate soccer players. The benefits of this research have direct implications, as participants received both their screening data and a set of exercises aimed to help decrease their injury risk, in addition to the offering data that is useful for determining what normative values for flexibility and strength profiles might look like for Division III male soccer players.

Level of Evidence

Level 3

INTRODUCTION

Hamstring injuries are among the most common injuries in soccer, accounting for 5–15% of all soccer-related injuries.1,2 These injuries can be frustrating for players and coaches as there are high rates of reinjury, with a recurrence rate of up to 68%.1 Since 2001, there has been an observed annual average increase of 2.3% in hamstring injuries in professional soccer.3 Injury tends to occur during activities like running and sprinting as the hamstrings develop tension while lengthening as they quickly transition their function from eccentrically decelerating the lower leg to concentrically contracting as active hip extensors.4–7 The impact of these injuries is widespread and can affect individuals both physically and psychologically. There is very little research related to screening and prevention of hamstring injuries at the Division III level due to a lack of time and resources.

It is important to identify risk factors for hamstring injuries in order to prevent them for the benefit of the athlete, the team, and the institution/team for which they play. Identification of risk factors is a significant first step in primary prevention, where the injury is prevented before it happens. It is also necessary to utilize secondary and tertiary prevention strategies for those who may have already sustained a hamstring injury. Utilizing the scientific literature to develop and implement an injury prevention screening with valid, reliable, and objective methods can help identify those at-risk individuals who would most benefit from effective exercise interventions. As a university looking to recruit talented prospective players, monitoring risk factors and taking steps to prevent injury emphasizes that the institution cares about athletes and their well-being. If teams can prevent any of the 15 muscle injuries that research has shown teams of 25 players are expected to suffer each season, such prevention could result in better team performance, more wins, and greater fan attendance.8 This study serves as a first step in enacting injury prevention by screening Division III athletes for known risk factors.

The literature identifies multiple risk factors that may be predictive of hamstring injuries. Meta-analytic reviews conducted between 2009 to 2020 have confidently identified non-modifiable factors like previous injury and older age as risk factors for hamstring injuries, but the consensus is lacking regarding modifiable risk factors.9–13 One such modifiable factor that has been described is strength imbalance. In relation to the lower extremities, the main muscles involved in extension and flexion of the knee are the hamstrings and the quadriceps. Croisier et al. investigated strength imbalances in professional soccer players, and found that 47% of elite players had a strength imbalance, which they defined as having bilateral differences of more than 15% or a hamstring-to-quadriceps (H:Q) ratio of less than 0.47.4 Players identified as having a strength imbalance in the preseason screening were four to five times more likely to suffer a hamstring strain during the season, suggesting that a player’s strength profile could be a predictor of injury and addressing identified imbalances could reduce the frequency of these injuries.4 Orchard et al. studied Australian professional soccer athletes and found that participants’ injured legs were all significantly weaker in their H:Q muscle peak torque ratio compared to the uninjured leg.14 Those researchers also identified the hamstring muscle side-to-side peak torque ratio as a good predictor (.880 for injured legs and 1.005 for uninjured legs).14 Similarly, a meta-analysis identified quadriceps peak torque as a potential predictor for hamstring injury.10 Other authors who have used isokinetic testing at 60°/sec and 240°/sec have also reported that athletes with lower H:Q ratios (below .505) are more likely to sustain hamstring injuries, which indicates that an imbalance in strength between this antagonistic muscle pair, could leave an individual susceptible to injury.15 Authors have suggested that the ideal H:Q ratios are 60% at 60°/sec and 75% at 180°/sec.15,16–18 Further research indicates that a bilateral strength difference of over 15% can lead to injury, making this parameter a useful way to define a strength imbalance, in addition to H:Q ratios.15,16,17

Another commonly studied modifiable factor is flexibility. Researchers have found that male athletes have less flexible hamstrings and iliopsoas muscles than female athletes and that their lack of flexibility has been associated with knee injuries.19 Corkery et al. offers normative values for iliopsoas flexibility in college-age students using the Thomas test, finding a mean hip flexion angle of 2.5° (SD=1.9°).20 Additionally, Gabbe et al. and Ocarino et al. identified decreased quadriceps flexibility, particularly of the rectus femoris, which is involved in knee extension and hip flexion, as a risk factor for hamstring injury.21,22 In professional soccer, elite players that suffered hip or knee flexors were less flexible during preseason screening compared to players that remained healthy, further suggesting lack of flexibility as a predictor or risk factor for injury.23 Similarly, Witvrouw et al. found that professional players injured dur-
ing the season had significantly less flexible hamstrings (measured with a goniometer in the preseason) compared to uninjured players (88.1° and 94.6° respectively).24 Other authors have also corroborated or noted the correlation between hamstring flexibility and risk of injury.5,25,26

However, solid consensus in the literature regarding the potential etiological factors related to hamstring injury does not exist. Authors have reported that muscle strength imbalances and flexibility were only weak factors for hamstring injury.10,27 Only low quadriceps concentric strength and low hamstring eccentric strength, both adjusted for bodyweight, were identified as risks factor for injury in a study that utilized isokinetic testing to examine professional soccer players.27 Conversely, the meta-analysis by Freckleton and Pizzari identified increased quadriceps peak torque but neither eccentric nor concentric strength as risk factors.10 Regardless of conflicting studies on risk factors, there is evidence that implementing interventions, particularly consisting of eccentric hamstring exercises, significantly decreases hamstring injury rates if the program has good compliance rates.28–30

In professional soccer, it has been shown that there is a need for the utilization of isokinetic testing in the preseason followed by an intervention aimed at reducing the number of injuries teams and players will suffer from.4 At lower levels of play there is a significant lack of resources and time available to be proactive rather than reactive to hamstring injuries, and there is little existing research on isokinetic testing at the Division III level. The current study aimed to fill some of this gap by identifying left to right differences in isokinetic peak torque of the quadriceps and hamstrings, hamstring-to-quadriceps ratios, and quadriceps and hamstring length in Division III male soccer players. Therefore, the purpose of this study was to conduct isokinetic and flexibility assessments to screen male soccer athletes at risk of sustaining a hamstring injury.

METHODS

Prior to the start of the testing, approval was received from the Institutional Review Board to conduct research with human subjects and participants gave their informed consent. Players were screened so that those who had prior hamstring injuries were identified, as prior injury is a risk factor for future injury.10–12 Any players that felt any pain or discomfort during isokinetic testing discontinued testing and were excluded from the study. Leg dominance was determined by asking participants what leg they would use if they were to kick a ball.24

ISOKINETIC TESTING

A Biodex isokinetic dynamometer (Biodex, Shirley, NY) was used to measure participants’ hamstring and quadriceps torque output bilaterally throughout the range of motion (0–90°). Participants were secured in the seat by per manufacturer protocol to isolate movement of the lower extremity (Figure 1). Prior to testing, the knee range of motion and gravity correction were set for each patient. Especially when these measures are taken, isokinetic testing has been found to be a reliable way to measure muscle strength throughout the range of motion.31–34 Pincivero et al. found that values for peak torque, peak torque/ body weight, work, and power are highly reliable, in addition to stating that isokinetic testing should be the method used if there is an interest in assessing and comparing bilateral muscle groups or antagonistic muscle pairs.33

Participants were provided with a practice session to help familiarize them with the machine and necessary movements, consisting of three submaximal contractions and three maximal contractions before the start of the test. Once the participants reported that they had completed their last maximal contraction and indicated that they were ready to begin, the test started with five repetitions at a speed of 60°/sec, followed by a 60 second rest period. After the rest period, participants received the same practice session as prior and were then tested at 180°/sec for 15 repetitions. Both speeds and the number of repetitions have been found to produce reliable data while preventing excessive fatigue for the participant.31,35

The flexibility portion of the study utilized the Thomas test and active knee extension (AKE) test. These tests are commonly used in clinical practice and have been found to be reliable measures of hamstring and hip flexor flexibility.19,36,37 For each flexibility test, three trials for the right and left leg were conducted. Measurements were taken using a standard goniometer. As intrarater measurements are more reliable than interrater measurements, all measurements were recorded by the same registered physical therapist with over 25 years of experience in goniometric measurement.38 Because error is common in goniometric measurements, an emphasis was placed on the standardiza-

![Figure 1. Isokinetic testing set-up on Biodex isokinetic dynamometer](image-url)
tion of procedures to ensure proper reliability and validity of the results.38

ACTIVE KNEE EXTENSION TEST

To measure hamstring flexibility, participants were asked to lay down supine on an examination table while the leg not being tested was secured to the table. The tested leg was raised to 90° of hip flexion and held at that position by the researcher. The participant was then placed in 90° of knee flexion as a starting point and instructed to extend their knee to the point that they felt stretching in the hamstrings, and that angle was recorded by the researcher. The goniometer was placed with the axis at the center of the knee on the lateral side, the stationary arm in line with the shaft of the femur, and the moving arm in line with the lateral malleolus.20

THOMAS TEST

Participants were instructed to lay supine on the table, holding their opposite knee as close to their chest as possible to keep the lumbar spine flat on the table.39 The leg being tested remained extended on the table. The goniometer was placed on the lateral side of extended leg with the axis on the greater trochanter of the femur, the stationary arm parallel to the table, and the moving arm in line with the lateral condyle of the femur to get a measurement of iliopsoas flexibility.19,21,22,39

INTERVENTION

Based on the results of the screening procedures, the researchers opted to intervene with players who were identified as having a strength or flexibility deficit and provided instructions detailing three exercises that aimed to stretch and strengthen the hamstrings. The exercises were intended to be integrated into the athlete’s usual off-season workouts, and they were sourced from the FIFA 11 injury prevention program, which has been found to improve isokinetic knee flexor and extensor strength and reduce injury rates.28,40–42

STATISTICAL ANALYSIS

Means, standard deviations, and ranges for were calculated for all outcomes. Imbalance between right and left limbs were calculated for each variable by the formula (Right leg − Left leg/ Right leg × 100). Balance between dominant (D) and non-dominant (ND) limbs was calculated using (D − ND/ D × 100) and hamstring-to-quadriceps (H:Q) peak torque ratios were analyzed for each leg. The Grubb’s test was also used to see if any of the subjects were significantly different in their agonist/antagonist ratio compared to the other subjects.43 Using all three measurements taken during the AKE test, the Two-Way Analysis of Variance model was used with two fixed effects (leg and trial). Paired sample t-tests were used to compare left and right lower extremities for all outcomes.44 A p<0.05 value was set for the level of significance.

Table 1. Descriptive statistics for participants

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<tr>
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<th>Mean</th>
<th>Std. Dev.</th>
<th>Min.</th>
<th>Max.</th>
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</thead>
<tbody>
<tr>
<td>Age (years)</td>
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<td>0.89</td>
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<td>22</td>
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<tr>
<td>Height (m)</td>
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<td>Weight (kg)</td>
<td>73.9</td>
<td>4.96</td>
<td>63.5</td>
<td>83.9</td>
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</tbody>
</table>

RESULTS

Twenty collegiate athletes on a Division III men’s soccer team participated in this study (Table 1). Researchers recruited participants with the help of the head coach, who relayed information about the screening to all players.

ISOKINETIC TESTING

Due to technical issues, the isokinetic data for three of the participants was lost, so the isokinetic results are reported on data from the remaining 17 participants. Of those 17 participants, three players indicated that they had sustained a prior hamstring injury.

At 60°/sec, the mean PT/BW bilateral deficit was 14.1% for extension and 12.9% for flexion. At 180°/sec, the mean deficit was 9.9% for extension and 11.4% for flexion. Figure 2 shows the number of participants in each left-to-right deficit range at each speed. Additionally, the mean ratios were less than the ideal ratios H:Q ratios at both 60°/sec and 180°/sec (Figure 3). On the left at 60°/sec, 82% of participants had low H:Q ratios and this number rose to 88% on the right. Ratios were also low at 180°/sec, with 88% of participants falling short both on the left and right. The number of participants in each category for H:Q ratios at both speeds can be seen in Figure 4.

The results show that at a speed of 60 °/sec, there were not significant differences between left and right knee extension PT/BW (p=0.51) or flexion PT/BW (p=0.95). At 180 °/sec, there also was not a significant difference between left and right knee extension PT/BW (p=0.62) or flexion PT/BW (p=0.62). Similarly, there were no significant differences between left and right leg hamstring/quadriceps (H:Q) ratios at 60°/sec (p=0.25) or 180°/sec (p=0.56). For the left leg, Subject 4, who had suffered a prior injury to this leg, had values that differed the most in isokinetic strength compared to the other participants, with a maximum H:Q ratio of 73.9, but this result was not significantly different (p=0.06). Similarly, Subject 7 differed the most from the team, though not significantly, for the right leg (p=0.19), as well as for both legs (p=.08).

FLEXIBILITY ASSESSMENTS

All participants’ flexibility assessments data were included in the analysis (n=20). The average range of motion during the AKE was 158° for left leg extension and 160° for right leg extension (Table 3). During the Thomas test, on average, participants were 5.6° away from the neutral position on the right and 1.6° on the left (Table 4). There were nine positive tests (participants couldn’t reach a hip neutral po-
DISCUSSION

Nine participants (45%) had positive Thomas tests, indicating those participants had tight hip flexors. The found averages from the Thomas test (R: 3.6°; L: 1.6°) can be compared to the normative values for male college students established by Corkery et al. (R: 2.8°; L: 2.4°).20 These values suggest that the athletes in this study have less flexible iliopsoas muscles on the right than the typical healthy male college student. The current results can further be compared to prior research that also utilized the AKE test; Witvrouv et al. found that having less than full extension (180°) left participants more likely to sustain a hamstring injury.24 All the participants in the current study were below that benchmark, both individually and as a group, which highlights hamstring flexibility as a potential area players need to work on. While the researchers prioritized the standardization of procedures to establish proper reliability and validity of the results, it is of note that these mean values are within the margin of measurement error for goniometry (generally accepted as +/- 5 degrees).38
Figure 4. Number of participants over/under the ideal Hamstring:Quadriceps ratio at 60°/sec and 180°/sec
Previous research has determined that a bilateral deficit in PT/BW of greater than 15% indicates that an individual is at risk for injury.\textsuperscript{16} Mean deficits in the current study were less than this established value at 60 °/sec (extension: 14.1%; flexion: 12.9%). However, when examined qualitatively 41.2% of participants had bilateral deficits of over 15% during leg extension, while 35.3% had this deficit during leg flexion. At 180 °/sec, 17.6% of participants had a deficit above this threshold for extension and that percentage rose to 29.4% for flexion.

Another important finding was that most participants – over 80% of players at each speed and in each leg – were below the ideal H:Q ratios, established by prior research as 60% at 60°/sec and 75% at 180°/sec.\textsuperscript{17,18} Statistical analysis identified two participants as having the greatest difference in isokinetic strength from the rest of the team due to their low H:Q ratios, but those results were not significant; one of these participants indicated that they had suffered a prior hamstring injury, which is a risk factor for reinjury.\textsuperscript{10–12} These bilateral differences in strength and lower-than-ideal H:Q ratios show that there were multiple players in this study who are likely at risk for injury or reinjury and are most likely to benefit from intervention.

While the current results align with those of past research, a large portion of the literature on hamstring injuries in soccer and potential risk factors is centered around elite or professional athletes, with little focus on the collegiate level, especially Division III.\textsuperscript{4,6,8,14,22,24,25} As a result, many of the strength or flexibility profiles seen in prior research are likely representative of a different demographic than the current study. As Division III athletes differ from those at elite levels of play, the resources and time devoted to injury prevention are also different, which can create differences in fitness between Division III athletes and those at higher levels. The Division I level typically has the means to provide their athletes with nutritionists, strength coaches, and supervised training.\textsuperscript{45} Due to the scarcity of these resources at lower levels, previous research suggests that the neuromuscular profiles of Division III soccer players may be closer to those of non-athletes than to Division I athletes.\textsuperscript{45} For this reason, having access to the necessary technology to conduct this research at the Division III level may be an opportunity to fill some of this gap in the existing body of research and help determine what normative values for flexibility and strength profiles at this level might look like.

The main limitation of this study was the lack of follow-up testing. The exercises distributed to players were provided as a means of participant education on how to prevent injury, but prior research has shown the importance of coupling baseline testing with follow-up testing when implementing an intervention.\textsuperscript{11,46,47} A re-test allows for injury risk to be better monitored and may encourage athletes to comply with the exercises if they know that they will be tested again.\textsuperscript{11,46,47} This indicates the need for further research, where researchers should consider incorporating follow-up sessions to investigate the effectiveness of any given intervention as well as collection of injury surveillance data that would be necessary to determine if the injury predictors identified in the initial screening were prevalent in players that suffered injuries.

CONCLUSION

The results of the current study suggest that isokinetic testing and flexibility testing may be useful for identifying non-optimal strength ratios and flexibility deficits in male collegiate soccer players. Similar research is not often performed at the Division III level, giving this study the opportunity to fill a gap in the existing research.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

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REFERENCES


Effect of a Balance Adjustment System on Postural Control in Patients with Chronic Ankle Instability

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Keywords: Balance adjustment system, Chronic ankle instability, Postural control, Randomized control trial

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Background/Purpose
This study aimed to evaluate how a two-week program using the in-phase mode of a balance adjustment system (the BASYS) affected postural control in participants with chronic ankle instability (CAI). It was hypothesized that the in-phase mode on the BASYS would lead to improved postural control compared with training on a balance disc.

Study Design
Randomized control trial.

Methods
Twenty participants with CAI were recruited. The participants were divided into two intervention groups: the BASYS (n = 10) and Balance Disc (BD; cushion type, n = 10). All participants underwent six supervised training sessions over a two-week period. Static postural control during single leg standing with closed eyes was assessed for the CAI limb. We collected COP data while participants balanced on the BASYS. The test was performed for 30 sec, and the total trajectory length and 95% ellipse area were calculated.

In the assessment of dynamic postural stability, Y-Balance tests—antero-, posteromedial, and posterolateral directions were measured on the CAI limb for all participants and normalized to the individual’s leg length. Participants were recorded at three instances: pretraining (Pre), post-training 1 (Post1: after the first training), and post-training 2 (Post2: after the last training).

Results
There was an effect on time in the COP total trajectory length of the BASYS group, which was significantly decreased for Post 1 and Post 2 than for the Pre (p = 0.001, 0.0001). Group differences and time-by-group interactions were not observed for either of the Y-balance test reach distances.

Conclusions
The study's primary finding was that two weeks of intervention in the in-phase mode on the BASYS improved static postural control in participants with CAI.

Level of Evidence
Level I, randomized control trial

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INTRODUCTION

Ankle sprains are among the most common injuries in the general population and are the most frequently reported injuries by competitive athletes.1-3 The prevalence of lateral ankle sprains (LASs), coupled with high rates of reinjury, persistent symptoms, and self-reported reduced ankle function, makes LASs and their sequelae a public health concern.4 Residual symptoms from an initial LAS are identified as chronic ankle instability (CAI). Doherty et al5 conducted a prospective study on patients with first-time ankle sprains who sought treatment at the emergency department in a hospital and found that 40% had developed CAI at the 12-month follow-up. CAI describes a combination of mechanical and functional instability with the following residual ankle sprain symptoms6,7: pain, swelling, weakness, instability, and repeated episodes of “giving way”.8 These potential long-term consequences highlight the need for suitable treatments for these conditions.

Balance training has been reported to be an effective modality for the rehabilitation and prevention of recurrent sprains in individuals with CAI. In their systematic review and meta-analysis, Schifan et al.9 concluded that balance training effectively reduces the risk of ankle sprain in sports participants with a history of ankle sprains. Balance training generally involves maintaining a standing posture on an unstable surface. Training on unstable surfaces has been suggested to be a valuable aid for ankle sensory-motor rehability.10,11 Previous studies suggested that training on stable ground may correspond with enhanced static postural control, whereas instability training may improve dynamic postural control.12,13

A real-time postural feedback system called the "balance adjustment system BASYS (MPF-S050B; Tec Gihan Co., Ltd., Kyoto, Japan)" was developed to establish a novel rehabilitation strategy for addressing postural control. The device adjusts between voluntary movements and reflects adjustments in an individual's standing posture adjustment. In other words, the device helps the individual make the necessary physical adjustments to their posture, while also allowing their body to make automatic reflex adjustments as needed. By doing so, the device can assist the individual in maintaining a healthy and stable standing posture. Additionally, the BASYS can implicitly modulate an individual’s body sway, decreasing (in-phase mode) or increasing (anti-phase mode) it in real-time. Especially the in-phase mode differs from traditional balance training and constitutes an entirely new interventional stimulation method (Figure 1). Traditional balance training on unstable surfaces improves postural control by imposing sway on the patient. However, the in-phase mode of the BASYS supports standing postural adjustment and reduces sway by moving the plate in the same direction as the individual’s sway. These stimulations could be more effective than traditional balance training in treating the balance deficits that have been reported in patients with CAI and postural control disorder.

To the authors’ knowledge, the BASYS has been used primarily in elderly individuals and patients with neurodegenerative diseases; however, it has not been studied in younger individuals or patients with CAI. So far, it has been used in clinical practice, but there has been no detailed investigation of the BASYS device. Therefore, this study aimed to evaluate how a two-week program using the in-phase mode of the BASYS affects postural control in participants with CAI. The authors’ hypothesized that the BASYS (in in-phase mode) might lead to improved postural control compared with training on a balance disc.

METHODS

PARTICIPANTS

Twenty participants with CAI were recruited from several intercollegiate sports teams. Selection criteria for patients with CAI14 included participants who reported a history of at least one substantial ankle sprain (the most recent injury must have occurred more than three months before study enrollment), two or more episodes of the ankle “giving way” in the six months before the study, and a score ≤25 on the Japanese version of the Cumberland ankle instability tool.15 In participants with bilateral ankle instability, the ankle with the lower score was selected. The exclusion criteria were as follows: a history of previous surgery involving the musculoskeletal structures of either lower extremity; fracture in either lower extremity requiring realignment; or acute musculoskeletal injury to the joints of the lower extremity in the three months before the study, affecting joint integrity and function, and resulting in at least one lost day of desired physical activity.14
G*Power (Version 3.1.9.7) was used to determine the sample size. The calculation was based on the F test, with an alpha level of 0.05. The type II error rate was set at 80% power and the effect size of 0.3 of the primary outcome variable was taken from similar previous studies.10,11 The appropriate sample size for this study was determined to be 20 participants. The subjects gave informed consent to participate in the study. The participant flow chart as per the CONSORT statement is shown in Figure 2.

PROCEDURES

This study was a randomized clinical trial that compared two types of balance training over two weeks by measuring static and dynamic balance. The study was approved by an institutional review board or similar committee. Participants with CAI were randomly assigned to one of two training groups: in-phase mode on the BASYS or Balance Disc (BD; cushion type, Khands Training). A simple randomization procedure (sequentially numbered draws from containers) was used to allocate study participants. Participants were assessed at three instances: pretraining (Pre), post-training 1 (Post1; after the first training session), and post-training 2 (Post2; after the last training session). In this study, static and dynamic postural control were considered dependent variables, while the groups and time were the independent variables (Pre, Post1, and Post2). Assessment of both groups before and after the two-week intervention period consisted of the center of pressure (COP) measurements during single leg standing with closed eyes and Y-balance test reach scores (YBT; anterior [A], posteromedial [PM], and posterolateral [PL] directions).

STATIC POSTURAL CONTROL

To assess static postural control, all participants stood on an instrumented BASYS (MPF-5050B; Tec Gihan Co., Ltd., Kyoto, Japan) in a single-limb stance (CAI limb only) with their hands crossed in front of their chest and their eyes closed (Figure 3). They were given the following instructions: “Remain as motionless as possible for 30 sec, and if you move out of position, please return to the original position as soon as possible and continue the trial.” The test was performed for 30 sec, and the following outcomes were then calculated from the resulting COP data: total trajectory length and 95% ellipse area. The test was conducted three times, with a 60-sec rest provided between the trials. Data were filtered using a low-pass digital filter with a cutoff frequency of 10 Hz using the software included with the BASYS. The total trajectory length of the COP refers to the length of the path taken by the center of the foot’s pressure distribution, based on data recorded from changes in pressure applied to the foot. Additionally, the 95% ellipse area represents the area of an ellipse that approximates the trajectory of the COP. In this study, when the load balance on the sole of the foot is good, the total trajectory length is shorter, and the 95% ellipse area is smaller. Conversely, when the load balance is poor, the total trajectory length is longer, and the 95% ellipse area is larger. The averages of the values recorded in the trials were used for the analysis.

DYNAMIC POSTURAL CONTROL

Dynamic postural control was tested using the YBT test apparatus (FunctionalMovement.com; Functional Movement Systems, Danville, VA). The YBT has been shown to be reliable (composite ICC = 0.89)16 in the measurement of in-
Individual reach directions: A, PM, and PL. The orientation of the reach direction was determined relative to the stance limb. Participants stood on the involved limb with the great toe behind the line on the platform located at the center of the three diverging lines. Measurements were taken as the participant pushed the target plate along the polyvinyl chloride pipe with the opposite leg. The participants were instructed to return to the starting position without losing balance after each trial. The test was conducted three times, with a 60-sec rest provided between the trials. The average values of the three trials were used for the analysis. The reached distances were normalized to the participant’s leg length, which was measured in centimeters from the anterior-superior iliac spine to the distal tip of the medial malleolus. The composite score (percentage) was calculated by taking the average of the three reached-distance average values divided by the participant’s limb length, multiplied by 100. The obtained value was used for statistical analysis.\textsuperscript{17}

**BALANCE TRAINING INTERVENTION**

After baseline testing, the participants were randomly assigned to one of the two groups (BASYS or BD) in a 1:1 ratio. All participants then underwent a total of six supervised training sessions over a two-week period. Participants of both groups performed single-limb balance training sessions with their eyes open. During the task, they were instructed to cross their arms in front of their body and to look at the black curtain in front of them to avoid any visual effects.\textsuperscript{18} The black curtain was placed 70 cm in front of the participants. The training program consisted of one session of three 30-sec exercises with a 60-sec rest between the exercises. All exercises were carried out only on the unstable ankle and were performed barefoot. Participants in the BASYS group trained using the in-phase mode on the BASYS (Figure 3), whereas participants in the BD group trained with the DynaDisc on the floor. The BASYS used the anterior-posterior position of the COP in the standing position as a feedback signal to immediately move the floor surface in the front-back direction. The in-phase mode of the BASYS suppressed postural sway by moving the floor in the same direction as the sensed COP. The vibration of the BASYS floor movement could be set at 5%, 10%, or 15% of the sensed COP. In this study, COP was increased by 5% in each of the three exercises.

The training program (number of times, rest periods, number of sets, etc.) implemented in this study was based on the authors’ experience in clinical practice.

**STATISTICAL ANALYSIS**

Group demographics were compared using independent samples t-tests. A two-way repeated-measures analysis of variance was performed for all outcome variables to analyze the interaction among groups (BASYS, BD) and the time of assessment (Pre, Post1, and Post2). When the differences were established, a post hoc Bonferroni multiple comparisons test was used. The effect size (ES) was calculated for all pairwise comparisons according to the formula proposed by Glass et al.\textsuperscript{19} When a pairwise comparison was performed between the BASYS and BD groups, a pooled standard deviation for the calculations was used. The magnitude of the ES was interpreted using the scale devised by Cohen: small (<0.2), medium (0.5), and large (>0.8).\textsuperscript{20} All data are presented as means ± standard deviations. The α level was set at 0.05. Statistical analysis was performed using SPSS (version 26.0; IBM Corp, Armonk, NY).

**RESULTS**

Descriptive characteristics of the participants (11 females and 9 males; age, 20.9 ± 1.1 years; height, 165.2 ± 7.1 cm; mass, 62.5 ± 5.6 kg), after randomization into their corresponding training groups, are provided in Table 1. Independent t-tests indicated no group differences in age (p = 0.509), height (p = 0.198), or mass (p = 0.635) All randomized participants completed the entire study as allocated as shown in Figure 2, and none were harmed in the process. CAI participants were recruited from February 2021 to July 2021 and attended lab visits at the time of assessment and during the two-week intervention.

**STATIC POSTURAL CONTROL**

Results for static postural control are presented in Tables 2 and 3. There was a significant primary effect on time in the COP total trajectory length of the BASYS group (p = 0.055), but not for the 95% ellipse area (p = 0.126). The BASYS group total trajectory was significantly decreased for Post1

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**Figure 3. Subject position for the balance training intervention on the BASYS (opened-eye) and testing position for static postural control (closed-eye)**

BASYS, balance adjustment system

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and Post2 values than the Pre value (Pre-Post1: \( p = 0.001, \) ES [95%CI] = 0.88 [-0.08,1.75]; Pre-Post2: \( p = 0.0001, \) ES [95%CI] = 1.02 [0.05,1.90]).

**DYNAMIC POSTURAL CONTROL**

Results for dynamic postural control are presented in Tables 4 and 5. Group differences (\( p > 0.05 \)) and time-by-group interactions (\( p > 0.05 \)) were not observed for either of the YBT reach distances.

**DISCUSSION**

The primary finding of this study was that two weeks of intervention with the in-phase mode of the BASYS improved static postural control in participants with CAI. Overall, these results support the use of balance training with the in-phase mode of the BASYS to address static postural control impairments in individuals with CAI. It was also hypothesized that dynamic postural control could be improved with intervention in the in-phase mode of the BASYS, however this hypothesis was not supported due to no changes in any post-intervention YBT reach distances variables.

The results showed that training using the in-phase mode of the BASYS decreased the total trajectory length of COP (\( p = 0.001, \) 0.0001) while there was no effect of training the BD for the same measure (\( p = 0.092, \) 0.676). Furthermore, the effect sizes from Pre to Post1 and Post2 were moderate to large for static postural control variables due to the intervention using the BASYS.

Static postural control was defined as the ability to balance on a stable surface without intentional movement by the participant, like a measure of postural sway on a force plate.\(^{21}\) The interventional stimulation in the in-phase mode of the BASYS can be performed with an extremely small movement in the front-back direction and with a small amplitude load while the ground surface remains horizontal for the participant’s COP. A single-legged stance on a firm surface evokes the lowest overall muscle activity levels for EMG.\(^{22}\) In addition, the use of a uniaxial balance board showed that, based on foot orientation, the agonist-antagonist co-activation can be controlled to some degree.\(^{22}\) Therefore, in this study, the intervention of stimulation by the BASYS in the in-phase mode may have contributed to the coordination of fine body movements of participants with CAI, reducing the postural control demands and improving the total trajectory length of COP.

Regarding dynamic postural control variables, no differences were found between the intervention in the in-phase mode of the BASYS and the intervention on unstable surfaces, indicating that the intervention utilized in this study did not improve dynamic postural control. The authors chose to incorporate isolated exercises, whereas a more comprehensive rehabilitation program addressing mechanical restrictions, plantar cutaneous deficits, strength, and static postural control may be more appropriate for improving reach distances and result in better functional outcomes.\(^{17}\) Further research in patient populations with CAI is necessary to evaluate the possible additional benefit of intervention in the in-phase mode of the BASYS.

Importantly, there was a significant decrease in the total trajectory length of static balance with intervention in the in-phase mode of the BASYS within a brief treatment period, from immediately after the intervention to two weeks after. This result was initially due to exercising in the in-phase mode on the BASYS, which may be considered for inclusion in a rehabilitation program for CAI. In previous studies, improvements were evident in postural control in four-week other intervention programs for participants with CAI.\(^{23–25}\) McKeon et al,\(^{26}\) who studied individuals with both new and recurrent ankle sprains, noted a substantial increase of up to approximately 70% in the probability of returning to play on day three following an injury. Roughly 90% of those injured returned to participate within one week.\(^{26}\) These results suggest that rehabilitation programs in the early period of CAI and ankle sprain should be conducted for improved outcomes.

Considering the results of the present study, future research should assess whether combining the in-phase mode of the BASYS and conventional methods can enhance improvements in dynamic postural control, providing a new direction for balance training following ankle injury.

This study has some limitations. The interpretation of the exercises was solely based on the postural control variables. To assess the intervention in the in-phase mode of the BASYS, it would be interesting to observe the effect on the evoked muscle activation levels or functional outcome measures. A BD was used for the control group in this study. Further research is needed to exclude cognitive bias. There is ample room for evaluation of the optimal training programs using the BASYS device.

### Table 1. Anthropometric characteristics of the BASYS and Balance Disc groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>BASYS</th>
<th>Balance Disc</th>
<th>( p )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n )</td>
<td>10</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>Gender</td>
<td>4M 6F</td>
<td>5M 5F</td>
<td>-</td>
</tr>
<tr>
<td>Age (year)</td>
<td>21.0±0.9</td>
<td>20.7±1.2</td>
<td>0.55</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>164.9±8.2</td>
<td>165.6±5.9</td>
<td>0.85</td>
</tr>
<tr>
<td>Body Mass (kg)</td>
<td>61.1±5.5</td>
<td>63.5±5.4</td>
<td>0.36</td>
</tr>
</tbody>
</table>

BASYS, balance adjustment system

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### Table 2. Static postural control variables for the BASYS and Balance Disc groups

<table>
<thead>
<tr>
<th>COP</th>
<th>BASYS (n=10) mean±SD</th>
<th>Balance Disc (n=10) mean±SD</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post1</td>
<td>Post2</td>
</tr>
<tr>
<td>95% ellipse area (cm²)</td>
<td>42.0±23.6</td>
<td>30.1±9.8</td>
<td>25.4±8.2</td>
</tr>
<tr>
<td>Total trajectory (cm)</td>
<td>277.1±76.9</td>
<td>216.3±60.8</td>
<td>213.9±42.7</td>
</tr>
</tbody>
</table>

COP, center of pressure; BASYS, balance adjustment system; Post1, after the first training; Post2, after the last training; SD, standard deviation

### Table 3. Effect sizes calculated from the pre-post1, pre-post2, and post1-post2 for each static postural control variable and their 95% confidence intervals

<table>
<thead>
<tr>
<th>COP</th>
<th>BASYS (n=10) Effect size</th>
<th>Balance Disc (n=10) Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Post1</td>
<td>Pre-Post2</td>
</tr>
<tr>
<td>95% ellipse area</td>
<td>0.66</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>[-0.27,1.53]</td>
<td>[-0.02,1.82]</td>
</tr>
<tr>
<td>Total trajectory</td>
<td>0.88</td>
<td>1.02</td>
</tr>
<tr>
<td></td>
<td>[-0.08,1.75]</td>
<td>[0.05,1.90]</td>
</tr>
</tbody>
</table>

COP, center of pressure; BASYS, balance adjustment system; Post1, after the first training; Post2, after the last training

### Table 4. Dynamic postural control variables for the BASYS and Balance Disc groups

<table>
<thead>
<tr>
<th>Y-Balance Test</th>
<th>BASYS (n=10) mean±SD</th>
<th>Balance Disc (n=10) mean±SD</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post1</td>
<td>Post2</td>
</tr>
<tr>
<td>Anterior reach (cm)</td>
<td>65.9±6.1</td>
<td>64.6±5.9</td>
<td>64.6±5.2</td>
</tr>
<tr>
<td>PM reach (cm)</td>
<td>277.1±76.9</td>
<td>216.3±60.8</td>
<td>213.9±42.7</td>
</tr>
<tr>
<td>PL reach (cm)</td>
<td>103.8±8.2</td>
<td>104.9±7.9</td>
<td>107.6±6.6</td>
</tr>
</tbody>
</table>

BASYS, balance adjustment system; Post1, after the first training; Post2, after the last training; PM, posteromedial; PL, posterolateral; SD, standard deviation
Table 5. Effect sizes calculated from the pre-post1, pre-post2, and post1-post2 for each dynamic postural control variable and their 95% confidence intervals

<table>
<thead>
<tr>
<th>Y-Balance Test</th>
<th>Effect size [95%CI]</th>
<th>BASYS (n=10)</th>
<th>Balance Disc (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre-Post1</td>
<td>Pre-Post2</td>
</tr>
<tr>
<td>Anterior reach</td>
<td>0.21</td>
<td>0.22</td>
<td>-0.01</td>
</tr>
<tr>
<td></td>
<td>[-1.01,0.74]</td>
<td>[-0.67,1.09]</td>
<td>[-0.88,0.87]</td>
</tr>
<tr>
<td>PM reach</td>
<td>0.03</td>
<td>-0.25</td>
<td>-0.24</td>
</tr>
<tr>
<td></td>
<td>[-0.85,0.91]</td>
<td>[-1.12,0.64]</td>
<td>[-1.11,0.65]</td>
</tr>
<tr>
<td>PL reach</td>
<td>-0.14</td>
<td>-0.52</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>[-1.01,0.74]</td>
<td>[-1.38,0.40]</td>
<td>[-1.24,0.53]</td>
</tr>
</tbody>
</table>

BASYS, balance adjustment system; Post1, after the first training; Post2, after the last training; PM, posteromedial; PL, posterolateral

CONCLUSION

This is the first study to assess the efficacy of the BASYS used in the in-phase mode as an intervention tool to address post-CAI postural control deficits. The total trajectory for COP decreased from Pre to Post1 and Post2 in the BASYS group. Furthermore, large to moderate effect sizes in terms of static postural variables were evident in the BASYS group. However, both groups did not demonstrate improved dynamic postural control outcomes. Therefore, whether the BASYS or BD groups have the greatest effect on improving dynamic postural control remains unknown. Evaluating how postural control in patients with CAI is affected by the in-phase mode of the BASYS may provide additional insight into how to restore normal function. Future research should examine if combining the in-phase mode of the BASYS with conventional techniques will boost improvements in dynamic postural control, offering a new approach for balance training after an ankle injury.

CONFLICTS OF INTEREST

The authors have no competing interests to disclose.

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Original Research

Use of Patient-Reported Outcome Measures in Lower Extremity Research

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Keywords: Lower extremity, Patient reported outcome measures, PROMs, Umbrella Review

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Background

A large number of patient reported outcome measures (PROMs) have been developed for specific lower extremity orthopaedic pathologies. However, a consensus as to which PROMs are recommended for use in evaluating treatment outcomes for patients with hip, knee, ankle and/or foot pathology based on the strength of their psychometric properties is lacking.

Objective

To identify PROMs that are recommended in systematic reviews (SRs) for those with orthopaedic hip, knee, foot, and ankle pathologies or surgeries and identify if these PROMs are used in the literature.

Study design

Umbrella Review

Methods

PubMed, Embase, Medline, Cochrane, CINAHL, SPORTDisuCs and Scopus were searched for SRs through May 2022. A second search was done to count the use of PROMs in seven representative journals from January 2011 through May 2022. SRs that recommended the use of PROMs based on their psychometric properties were included in the first search. SRs or PROMs not available in the English were excluded. The second search included clinical research articles that utilized a PROM. Case reports, reviews, and basic science articles were excluded.

Results

Nineteen SRs recommended 20 PROMs for 15 lower extremity orthopaedic pathologies or surgeries. These results identified consistency between recommended PROMs and utilization in clinical research for only two of the 15 lower extremity pathologies or surgeries. This included the use of the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and the Copenhagen Hip and Groin Outcome Score to assess outcomes (HAGOS) for those with knee osteoarthritis and groin pain, respectively.

Conclusion

A discrepancy was found between the PROMs that were recommended by SRs and those used to assess clinical outcomes in published research. The results of this study will help to produce more uniformity with the use of PROMs that have the most appropriate psychometric properties when the reporting treatment outcomes for those with extremity pathologies.

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Level of evidence

3a

INTRODUCTION

Appropriately developed patient reported outcome measures (PROMs) with good psychometric properties can play an important role in assessing the effect of treatment in patient care. A large number of PROMs have been developed for specific lower extremity orthopaedic pathologies. However, a consensus as to which PROMs are recommended for use in evaluating treatment outcomes for patients with hip, knee, ankle and/or foot pathology based on the strength of their psychometric properties is lacking.1–4

Many PROMs have been used in research and clinical practice for those with lower extremity orthopaedic pathology or those who have undergone surgery. Haywood et al.5 identified that 28 different PROMs were developed for describing hip fracture outcomes. Similarly, Ramkumar et al.6 found 47 different PROMs for knee arthroplasty and 21 different PROMs for Achilles tendon rupture.7 Other systematic reviews also found that not only were a high number of PROMs used in published research, but many studies incorporated PROMs that lacked appropriate psychometric properties.1,8 This inconsistency in PROM use has led to difficulties in both clinical practice and research reporting.

When a number of different PROMs are used to report outcomes, it may be difficult to compare treatment outcomes in the same or similar populations.9 Additionally, clinicians and researchers may choose to use PROMs that do not have the most appropriate psychometric properties. This may negatively influence the interpretation of the obtained outcomes scores. Often multiple PROMs are used simultaneously to overcome the fact that there is little consensus regarding which instrument is most appropriate. The use of multiple PROMs causes problems with an increase in the time commitment for patients, clinicians, and researchers.

A review is needed to summarize which PROMs are recommended based upon their psychometric evidence for specific orthopaedic hip, knee, foot and ankle pathologies and surgeries. In addition, the actual utilization of recommended PROMs in published research in not known. The purpose of this study was to identify PROMs that are recommended in systematic reviews for those with orthopaedic hip, knee, foot, and ankle pathologies or surgeries and identify if these PROMs are used in the literature.

METHOD

An umbrella review was performed to identify published systematic reviews that made a recommendation regarding the use of PROMs for lower extremity pathologies or surgeries. Keywords in the search strategy were hip, knee, ankle, foot, index, measure, instrument, scale, questionnaire, reliability, validity, responsiveness, and psychometric properties. PubMed, Embase, Medline, Cochrane, CINAHL, SPORTDisucss and Scopus data bases were searched from the data base inception through March 2022. In order to be included in this review, articles needed to be a systematic review with an assessment of psychometric properties, including reliability, validity, and/or responsiveness of more than one lower extremity PROM. The systematic review also needed to include a recommendation for PROM use. Articles or PROMs not available in the English were excluded. Two authors independently evaluated the systematic reviews for inclusion, extracted data, and graded the included systematic reviews using the Joanna Briggs Institute checklist.9 Any conflicts were resolved by a third author.

A second search was done to determine the frequency that PROMs were used in published research articles in seven representative orthopedic journals from January 2011 through March 2022. The seven orthopedic journals included the following: 1) Journal of Orthopedic and Sports Physical Therapy, 2) International Journal of Sports Physical Therapy, 3) Foot & Ankle International, 4) American Journal of Bone and Joint Surgery, 5) American Journal of Sports Medicine, 6) Clinical Orthopedics and Related Research, and 7) Journal of Orthopedic Trauma. These seven journals were chosen because of their wide readership, impact factor, and frequent publications on orthopaedic clinical outcomes for the hip, knee, ankle and foot using PROMs. These methods were similar to those used by Hunt et al.8 and Hijji et al.9 The number of clinical research articles that utilized PROMs in each journal were manually counted by two separate authors. Case reports, review articles, and basic science articles were excluded in this second search. The specific PROM, name of the journal, publication date, and pathology or surgery were extracted independently by two authors.

RESULTS

The initial search identified 1584 articles to produce 19 systematic reviews that recommended a PROM for individuals with a hip, knee, ankle and/or foot pathology or surgery. (Figure 1) The 19 systematic reviews recommended 20 PROMs for 15 lower extremity pathologies or surgeries.7,10–27 (Table 1) The results of the Joanna Briggs Institute checklist appraisal for the included systematic reviews are shown in Table 2.

From the seven representative journals, 4879 studies were reviewed. The three most commonly used PROMs were matched to the 15 specific pathologies or surgeries and also reported in Table 1. These results identified consistency between recommended PROMs and utilization in clinical research for only two of the 15 lower extremity pathologies or surgeries. This included the use of the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and the Copenhagen Hip and Groin Outcome Score to assess outcomes (HAGOS) for those with knee osteoarthritis and groin pain, respectively.
DISCUSSION

The main finding of this umbrella review was that a total of 20 PROMs have been recommended for assessing the clinical outcomes for those with 15 specific hip, knee, ankle, and/or foot pathologies or surgeries. In addition, there was a discrepancy between PROMs that were recommended by systematic reviews and those used to assess clinical outcomes for the 15 specific lower extremity orthopedic pathologies or surgeries. To the authors’ knowledge, this is the first umbrella review that summarizes which PROMs are recommended by systematic reviews and compares these recommendations to what instruments have been used in clinical research articles in seven representative journals. The results of this study may help to improve uniformity of using PROMs and promote the use of PROMs that have the most appropriate psychometric properties when reporting treatment outcomes for those with lower extremity pathologies or surgeries.

There was an identified discrepancy between the recommended PROM and those utilized in published clinical research for 13 of the 15 pathologies. The most notable discrepancy occurred for those with non-arthritic intra-articular hip joint pain and anterior cruciate ligament injury. The modified Harris Hip Score (mHHS) and Knee Injury and Osteoarthritis Outcome Score (KOOS) were not recommended but were the most commonly used for those conditions, respectively. Considering the KOOS was recommended for use in total knee arthroplasty, clinicians should be cautious when using the KOOS in other conditions, such as non-arthritic intra-articular hip joint pain and anterior cruciate ligament injury. It should be noted that some of the recommendations of earlier systematic reviews of PROMs had been updated in later systematic reviews. This occurred for total hip arthroplasty, hip arthroscopy, non-arthritic joint pain, and total knee arthroplasty. The most updated recommendation included the use of following: the WOMAC for total hip arthroplasty, International Hip Outcome Tool-12 (iHOT-12), International Hip Outcome Tool-33 (iHOT-33), and HAGOS for hip arthroscopy and non-arthritic hip joint pain, and the KOOS and Work Osteoarthritis or Joint Replacement Questionnaire (WORQ) for total hip arthroplasty (WORQ).

The scores obtained from a PROM cannot be accurately interpreted if the PROM does not have established psychometric properties including evidence for validity, reliability, and responsiveness. Many of the most commonly used PROMs may be classified as legacy instruments and were not developed with contemporary methods. For example, the mHHS was the most common instrument used for those with non-arthritic intra-articular hip joint pain and contains items from the 1969 original Harris Hip Score. Alternatively, the Hip Outcome Score (HOS) was developed in 2005 using Item Response Theory (IRT) for item selection while the iHOT-12 and iHOT-33 were developed in 2012 using advanced item development from patient input. Clearly the standards behind developing, appraising, and

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Figure 1. PRISMA Search Diagram
guiding recommendations for PROM use has changed over the past 20 years. This includes the use of the Consensus-based Standard for the Selection of Health Measurement Instruments (COSMIN) checklist. PROMs that were developed before 2000 include the Knee Society scores (KSS), Victorian Institute of Sports Assessment-Achilles (VISA-A), WOMAC, KOOS, and Oxford Knee Score (OKS). Of these, only the WOMAC and KOOS were recommended for use in systematic reviews. Researchers continue to use legacy instruments so that recent clinical outcomes could be compared to previously published research. However, the scores obtained from PROMs that were not recommend

### Table 1. Recommended and Commonly used Patient Reported Outcome Measures

<table>
<thead>
<tr>
<th>Pathologies</th>
<th>Systematic review recommended</th>
<th>Most common instruments in seven journals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Most common</td>
</tr>
<tr>
<td>Total Hip Arthroplasty</td>
<td>WOMAC14, OHS14, HOOS11</td>
<td>WOMAC (28)</td>
</tr>
<tr>
<td>Hip Arthroscopy</td>
<td>HOS combined with NAHS17</td>
<td>mHHS (27)</td>
</tr>
<tr>
<td>Non-arthritic hip joint pain, femoroacetabular</td>
<td>mHHS (96)</td>
<td>HOS (69)</td>
</tr>
<tr>
<td>impingement, hip labral pathology</td>
<td>HAGOS18,24</td>
<td></td>
</tr>
<tr>
<td>Groin pain</td>
<td>HAGOS18,24</td>
<td>HAGOS (8)</td>
</tr>
<tr>
<td>Hip osteoarthritis undergoing non-surgical</td>
<td>HOOS11,16</td>
<td>mHHS (2)</td>
</tr>
<tr>
<td>treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior cruciate ligament injury</td>
<td>ACL-RSI25</td>
<td>KSS (45)</td>
</tr>
<tr>
<td>Total Knee Arthroplasty</td>
<td>KOOS19, WORQ26, OKS14</td>
<td>KSS (45)</td>
</tr>
<tr>
<td>Knee osteoarthritis undergoing non-surgical</td>
<td>WOMAC16</td>
<td>WOMAC (17)</td>
</tr>
<tr>
<td>treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patellofemoral pain syndrome</td>
<td>ADLS13, AKPS13</td>
<td>KOOS (8)</td>
</tr>
<tr>
<td>Recovery after Ankle Fractures</td>
<td>A-FORM22</td>
<td>OMAS (21)</td>
</tr>
<tr>
<td>Achilles’ tendon rupture</td>
<td>ATRS7</td>
<td>VISA-A (23)</td>
</tr>
<tr>
<td>Chronic Ankle instability</td>
<td>FAAM15, FADI15</td>
<td>KS (20)</td>
</tr>
<tr>
<td>Rheumatoid arthritis in the foot and ankle</td>
<td>SEFAS21</td>
<td>FAAM (2)</td>
</tr>
<tr>
<td>Hallux valgus surgery</td>
<td>MOXFQ20, SEFAS10</td>
<td>FAOS (9)</td>
</tr>
<tr>
<td>Foot or ankle diseases</td>
<td>MOXFQ23</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Patient reported outcome measures recommended by systematic reviews are shown with citations on superscript. Patient reported outcome measures commonly used in seven representative orthopedic journals are shown in most-first, second and third. The number of clinical research articles using patient reported outcome measures is shown parenthess.

A CL-RSI: ACL-Return to Sport after Injury Scale; ADLS: Activities of Daily Living Scale; A-FORM: Ankle-fracture outcome of rehabilitation measure; AKPS: Anterior Knee Pain Scale; ATRS: Achilles tendon Total Rupture Score; CAIT: Cumberland Ankle Instability Tool; FAAM: Functional Ankle Ability Measure; FADI: Foot and Ankle Disability Index; FAOS: Foot and Ankle Outcome Score; HAGOS: The Copenhagen Hip and Groin Outcome Score; HOOS: Hip Outcome Score; HSS: Hip dysfunction and Osteoarthritis Outcome Score; IKDC: International Knee Documentation Committee; IKDC: Knee Injury and Osteoarthritis Outcome Score; KSS: Knee Society scores; LEFS: Lower Extremity Functional Scale; LS: Lysholm knee scale; mHHS: Modified Harris Hip Score; MOXFQ: The Manchester-Oxford Foot Questionnaire; NAHS: Non-Arthritic Hip Score; OHS: Oxford hip score; OOS: Oxford Knee Score; OMAS: Olerud-Molander Ankle Score; SEFAS: Self-Reported Foot and Ankle Score; UCLA: University of California, Los Angeles (UCLA) activity scores; VISA-A: Victorian Institute of Sports Assessment-Achilles (VISA-A) score; WOMAC: The Western Ontario and McMaster Universities Osteoarthritis Index; WORQ: The Work Osteoarthritis or joint replacement questionnaire.
because of lacking psychometric evidence must be cautiously interpreted.

It is obvious that a large number of PROMs have been developed. The reason for so many PROMs is unclear. PROM use in clinical assessment became common in 1990s with many new and different PROMs rapidly becoming available. The science behind PROM development did not advance as quickly. This may be due to the fact that researchers had little objective means to evaluate and compare these new PROMs. Also, researchers and clinicians often had their own ideas of critical items that should be included and, therefore, would often create their own PROMs. Implementation of the COSMIN and similar tools allowed the methodological quality of PROMs properties to be reported. In this umbrella review, 11 of the 19 systematic reviews used the COSMIN and six of the remaining eight systematic reviews used a similar evaluation checklist to assess the PROM quality. These evaluation checklists use similar criteria to assess the psychometric properties of PROMs. PROMs which had poor psychometric properties were not recommended by systematic reviews. As the means to develop, evaluate, and compare PROMs becomes better understood, it is hopeful that clinicians and researcher will use PROMs that are recommended based on their psychometric properties.

LIMITATIONS

This umbrella review has some limitations that need to be acknowledged. This review assessed the most commonly used PROMs by looking at publications within the past 10 years from only seven journals. However, the seven journals were chosen to be representative because of their wide readership, impact factor, and frequent publications on orthopedic clinical outcomes for the hip, knee, ankle, and foot. These methods were similar to those utilized in previously published studies.1,8 Second, this study only covered instruments that were recommended in systematic reviews. There may be other PROMs that have not been included in these systematic reviews with adequate psychometric properties.

CONCLUSION

The results of this umbrella review indicate that a total of 20 PROMs have been recommended for assessing clinical outcomes for the hip, knee, ankle, and foot.
outcomes in those with 15 specific lower extremity orthopedic pathologies or surgeries. There is a discrepancy between PROMs that were recommended by systematic reviews and those used to assess clinical outcomes for the 15 specific lower extremity orthopedic pathologies. The results of this study may help to produce more uniformity in the use of PROMs that have the most appropriate psychometric properties when reporting treatment outcomes for those with lower extremity pathologies or surgeries. Further research is needed to identify the available language versions these recommend PROMs which may allow international researchers and clinicians to more consistently implement PROMs with the most appropriate psychometric evidence.

CONFLICTS OF INTEREST
The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article.

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Cross-Culturally Adapted Versions of Patient Reported Outcome Measures for the Lower Extremity

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Keywords: PROMs, cross-culturally adapted, lower extremity, language version

Background

A large number of patient reported outcome measures (PROMs) have been developed in the English language for various lower extremity orthopaedic pathologies. Twenty different PROMs were recommended for 15 specific musculoskeletal lower extremity pathologies or surgeries. However, the availability of cross-culturally adapted versions of these recommended PROMs is unknown.

Purpose

The purpose of this study was to identify the cross-culturally adapted versions of recommended PROMs for individuals experiencing orthopedic lower extremity pathologies or undergoing surgeries, and to identify the psychometric evidence that supports their utilization.

Study design

Literature Review

Methods

PubMed, Embase, Medline, Cochrane, CINAHL, SPORTDisics and Scopus were searched for cross-culturally adapted translated studies through May 2022. The search strategy included the names of the 20 recommended PROMs from previous umbrella review along with the following terms: reliability, validity, responsiveness, psychometric properties and cross-cultural adaptation. Studies that presented a non-English language version of the PROM with evidence in at least one psychometric property to support its use were included. Two authors independently evaluated the studies for inclusion and independently extracted data.

Results

Nineteen PROMs had cross-culturally adapted and translated language versions. The KOOS, WOMAC, ACL-RSL, FAAM, ATRS, HOOS, OHS, MOXFQ and OKS were available in over 10 different language versions. Turkish, Dutch, German, Chinese and French were the most common languages, with each language having more than 10 PROMs with psychometric properties supporting their use. The WOMAC and KOOS were both available in 10 languages and had all three psychometric properties of reliability, validity, and responsiveness supporting their use.

Conclusion

Nineteen of the 20 recommended instruments were available in multiple languages. The PROM most frequently cross-culturally adapted and translated were the KOOS and
WOMAC. PROMs were most frequently cross-culturally adapted and translated into Turkish. International researchers and clinicians may use this information to more consistently implement PROMs with the most appropriate psychometric evidence available to support their use.

**Level of evidence**

3a

**INTRODUCTION**

Patient reported outcome measures (PROMs) are widely used in orthopaedic settings. The decision regarding which PROM to use should be based on the available psychometric evidence. Although a large number of PROMs have been developed in the English language for various lower extremity orthopaedic pathologies, the psychometric evidence supporting their use is highly variable. An umbrella review by Zhang et al. assessed 19 systematic reviews and found that 20 different PROMs were recommended for 15 specific musculoskeletal lower extremity pathologies or surgeries. However, the availability of cross-culturally adapted versions of these recommended PROMs is unknown.

The usefulness of a PROM can be defined by the instrument’s psychometric properties, including evidence for reliability, validity, and responsiveness. Test-retest reliability defines the stability of a score over time for patients who have not changed. A useful value for clinicians related to test-retest reliability is minimal detectable change (MDC) which is the change in score outside of measurement error. This reflects a true change in the patient. Validity refers to the degree to which the instrument measures the construct it was intended to measure. PROMs commonly offer evidence for concurrent validity which is the degree to which the scores of a PROM relate to scores on other instruments that measure the same or similar construct. Responsiveness is the ability of an instrument to detect a meaningful change in patient status over time. It can be defined with a value for minimal clinically important difference (MCID). A PROM may be more useful to clinicians and researchers when there is evidence for the three psychometric properties of reliability, validity, and responsiveness.

Cross-cultural adaptation studies are needed to translate PROMs into a variety of languages that will allow for more international implementation. Cross-cultural adaptation studies ensure that the items and responses for the translated PROMs have the same meaning as the original language version. Clinicians and researchers need to not only be aware of recommended PROMs for specific lower extremity pathologies, but also be aware of which versions are cross-culturally adapted. The purpose of this study was to identify the cross-culturally adapted versions of recommended PROMs for individuals experiencing orthopedic lower extremity pathologies or undergoing surgeries, and to identify the psychometric evidence that supports their utilization.

**METHOD**

The current study utilized the results of a previous umbrella review to identify which of the 20 recommended PROMs have been translated and cross-culturally adapted. A literature review was conducted on PubMed, Embase, Medline, Cochrane, CINAHL, SPORTDiscus and Scopus Search from database inception to May 2022. The search strategy and terms are listed in Table 2. Studies were included if a non-English language version of one of the 20 recommended PROMs was cross-culturally adapted into another language while providing evidence of one psychometric property (reliability, validity and responsiveness) to support its use. Studies on individuals less than age 18 were excluded. Two authors independently evaluated the studies for inclusion and independently completed data extraction. Any conflicts were resolved by a third author. Cross-culturally adapted language versions for each of the 20 recommended PROMs were identified and recorded. The supporting psychometric properties for reliability, validity, and responsiveness for each version were extracted and recorded on a data collection spreadsheet for tabulation.

**RESULTS**

The search identified 9064 articles. 312 met the inclusion criteria. Of the 20 recommended PROMs, 19 were cross-culturally adapted into languages other than English (Table 3 and Figure 1). The Knee Injury and Osteoarthritis Outcome Score (KOOS), The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), ACL-Return to Sport after Injury Scale (ACL-RSL), Functional Ankle Ability Measure (FAAM), Achilles tendon Total Rupture Score (ATRS), Hip dysfunction and Osteoarthritis Outcome Score (HOOS), Oxford hip score (OHS), The Manchester-Oxford Foot Questionnaire (MOXFQ) and Oxford hip score (OKS) were available in over 10 different language versions. (Figure 2) A breakdown of the PROMs available in languages other than English are presented in Figure 3. Turkish, Dutch, German, Chinese, and French were the most common languages. Each of these versions had more than 10 PROMs with psychometric properties supporting their use.

The cross-culturally adapted translated PROMs with all three psychometric properties for reliability, validity and responsiveness are listed in Tables 4, 5, and 6. They correspond to the hip, knee, and foot and ankle, respectively. Cross-culturally adapted PROMs that do not have all three psychometric properties are listed in the Appendix. In addition, the number of research studies supporting each of the psychometric properties of reliability, validity, and re-

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Table 1. Recommended Patient Reported Outcome Measures

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<thead>
<tr>
<th>Systematic review recommended PROMs</th>
<th>Pathology/ Surgical Procedure</th>
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<tbody>
<tr>
<td>ACL-RSI</td>
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<td>A-FORM</td>
<td>Recovery after Ankle Fractures</td>
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<tr>
<td>ATRS</td>
<td>Achilles’ tendon rupture</td>
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<tr>
<td>FAAM</td>
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<tr>
<td>FADI</td>
<td>Chronic Ankle instability</td>
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<tr>
<td>HAGOS</td>
<td>Groin pain</td>
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<td></td>
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<td></td>
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<tr>
<td>HOS combined with NAHS</td>
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<tr>
<td>HOOS</td>
<td>Hip Arthroscopy</td>
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<td></td>
<td>Hip osteoarthritis</td>
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<td>Total Hip Arthroplasty for osteoarthritis</td>
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<tr>
<td>iHOT-12</td>
<td>Hip Arthroscopy for labral pathology</td>
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<tr>
<td></td>
<td>Non-arthritic hip joint pain, femoroacetabular impingement, Hip labral pathology</td>
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<tr>
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<td>Hip Arthroscopy for labral pathology</td>
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<tr>
<td>KOOS</td>
<td>Total Knee Arthroplasty for osteoarthritis</td>
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<tr>
<td>KOS-ADLS</td>
<td>Patellofemoral pain syndrome</td>
</tr>
<tr>
<td>MOXFQ</td>
<td>Foot or ankle diseases</td>
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<td></td>
<td>Surgery for hallux valgus</td>
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<tr>
<td>OHS</td>
<td>Total Hip Arthroplasty for osteoarthritis</td>
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<tr>
<td>OKS</td>
<td>Total Knee Arthroplasty for osteoarthritis</td>
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<tr>
<td>SEFAS</td>
<td>Surgery for hallux valgus</td>
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<tr>
<td></td>
<td>Rheumatoid arthritis in the foot and ankle</td>
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<tr>
<td>WOMAC</td>
<td>Knee osteoarthritis</td>
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<td></td>
<td>Total Hip Arthroplasty for osteoarthritis</td>
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<td>Total Knee Arthroplasty for osteoarthritis</td>
</tr>
<tr>
<td>WORQ</td>
<td>Total Knee Arthroplasty for osteoarthritis</td>
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</tbody>
</table>

Abbreviations: ACL-RSI, ACL-Return to Sport after Injury Scale; A-FORM, Ankle-fracture outcome of rehabilitation measure; AKPS, Anterior Knee Pain Scale; ATRS, Achilles tendon Total Rupture Score; FAAM, Functional Ankle Ability Measure; FADI, Foot and Ankle Disability Index; HAGOS, The Copenhagen Hip and Groin Outcome Score; HOS, Hip Outcome Score; HOOS, Hip dysfuction and Osteoarthritis Outcome Score; IHOT, International Hip Outcome Tool; KOOS, Knee Injury and Osteoarthritis Outcome Score; KOS-ADLS, Knee Outcome Survey of Daily Living Scale; MOXFQ, The Manchester-Oxford Foot Questionnaire; NAHS, Non-Arthritic Hip Score; OHS, Oxford hip score; OKS, Oxford Knee Score; SEFAS, Self-Reported Foot and Ankle Score; WOMAC, The Western Ontario and McMaster Universities Osteoarthritis Index; WORQ, The Work Osteoarthritis or joint replacement questionnaire

sponsiveness for the hip, knee, and foot and ankle are also shown in Tables 4, 5, and 6, respectively.

The WOMAC and the KOOS were both available in 10 languages and had all three psychometric properties of reliability, validity, and responsiveness supporting their use. The HOOS and OHS were both available in seven languages having all three psychometric elements of reliability, validity and responsiveness supporting their use. The most well studied PROMs were the German-WOMAC, Spanish-WOMAC, Swedish-KOOS and Swedish-SEFAS. (Tables 4-6) There were 124 cross-culturally adapted PROMs that had only studies providing evidence for reliability and/or validity. (Appendix)

DISCUSSION

Of the 20 PROMs with appropriate psychometric properties that were previously identified by Zhang et al.,11,19 have been cross-culturally adapted into language versions other than English. The KOOS and WOMAC were found to be available in 24 and 23 different languages, respectively. The most commonly culturally adapted language was Turkish, with 14 PROMs. There were 64 cross-culturally adapted translated PROMs with all three psychometric properties for reliability, validity, and responsiveness. To the authors’ knowledge, this is the first review that summarizes the availability of cross-culturally adapted PROMs for either
lower or upper extremity pathologies. The result of this study can be a useful resource for international clinicians and researchers when choosing a PROM to use based on the evidence available in their languages of interest.

While there are a variety of reasons PROMs may be cross-culturally adapted, pathology prevalence and length of time the PROM has been in use may be important factors. The authors’ identified nine PROMs that were cross-culturally adapted into 10 different languages, while 11 PROMs were cross-culturally adapted into less than 10. The most common cross-culturally adapted PROMs, the KOOS and WOMAC, were developed for use in knee osteoarthritis. Similarly, the HOOS and OHS, available in 13 different languages, were originally developed for use in hip osteoarthritis. Osteoarthritis in a prevalent pathology worldwide, which may explain the high frequency in which these PROMs were cross-culturally adapted into a language other than English.

The KOOS and the WOMAC, were developed in 1988 and 1998, respectively. These instruments may be cross-culturally adapted at a higher frequency because of the length of time these instruments have been available. However, PROMs developed more recently, such as the ACL-RSL, FAAM, and ATRS, have also been cross-culturally adapted into 14, 13, and 15 different languages, respectively. (Figure 2) Anterior cruciate ligament tears, Achilles tendon ruptures, and ankle instability are common pathologies. This may help to explain why a larger number of language versions for these instruments exist, despite being developed more recently.

In addition to the pathology prevalence and length of time the PROM has been in use, the frequency at which PROMs are cited in published research studies may also influence whether the instrument has been cross-culturally adapted into languages other than English. The umbrella review by Zhang et al. found the WOMAC, HOOS, KOOS, ATRS, and FAAM were the most commonly cited instruments. These PROMs were also found to be the most frequently cross-culturally adapted. When specifically looking at these PROMs, the WOMAC consists of 24 items divided into three subscales: pain (5 items), stiffness (2 items) and physical function (17 items). The HOOS consists of 40 items while the KOOS consists of 42 items, with each PROM being divided into five subscales: 1) pain, 2) symptoms, 5) activities of daily living, 4) sport and recreation function, and 5) knee-related quality of life. ATRS consists of 10 items and the FAAM consists of a 29-item questionnaire divided into two subscales: activities of daily living (21 item) and sports (8 times).

According to the results of this study, there are 64 cross-culturally adapted language PROMs supported by all three properties of reliability, validity, and responsiveness. (Tables 4-6) Studies that cross-culturally adapt PROMs commonly offer evidence for reliability and validity with evidence for responsiveness being infrequently studied. (Appendix) This may be due to the fact that responsiveness

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**Figure 1. PRISMA Search Diagram**

Records identified from:
- Databases (n = 9064)
- Pubmed, Scopus, Cochrane, Embase, Cinahl, Sportdiscus

Screening
- Full text read (n = 361)
- Not meet the inclusion criteria (n = 49)
- Ages of individuals less than 18 (n=8)
- Not cross-cultural adaptation study (n=12)
- Not patient-reported outcome scale (n=14)
- Electronic patient-reported outcome scale (n=4)
- Secondary data study (3) PROMs do not recommend (n=7)

Included
- Studies included in review (n = 312)
CONCLUSION

Of the 20 recommended PROMs identified in a previous review by Zhang et al., 11 19 were cross-culturally adapted into languages other than English. The PROMs most frequently cross-culturally adapted were the KOOS and WOMAC with 23 and 24 languages available, respectively. PROMs were most frequently cross-culturally adapted into Turkish. International researchers and clinicians may use this information to more consistently implement PROMs with the most appropriate psychometric evidence available to support their use.

LIMITATIONS

A limitation of this study is that this review does not include a comprehensive search of all PROMs. Only cross-culturally adapted PROMs that were recommended in other systematic reviews were included in this review. Additionally, this review focused solely on musculoskeletal lower extremity pathologies. Regional and global PROMs, as well as those that pertain to the spine and upper extremity were not included in this current review. The study did not present the details regarding specific values that define reliability, validity and responsiveness for each PROM.

CONFLICTS OF INTEREST

The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article.

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Abbreviations: ACL/RSI,ACL-Return to Sport after Injury Scale; ADLS, Activities of Daily Living Scale; A-FORM, Ankle fracture outcome of rehabilitation measure; AKPS, Anterior Knee Pain Scale; ATRS, Achilles tendon Total Rupture Score; FAAM, Functional Ankle Ability Measure; FADI, Foot and Ankle Disability Index; HAGOS, The Copenhagen Hip and Groin Outcome Score; HOOS, Hip Outcome Score; HOOS, Hip dysfuncion and Osteoarthritis Outcome Score; ILOT, International Hip Outcome Tool; KOOS, Knee Injury and Osteoarthritis Outcome Score; MDFXQ, The Manchester-Oxford Foot Questionnaire; NAHS, Non-Arthritic Hip Score; OHS, Oxford hip score; OKS, Oxford Knee Score; SEFAS, Self-Reported Foot and Ankle Score; WOMAC, The Western Ontario and McMaster Universities Osteoarthritis Index; WORQ, The Work Osteoarthritis or joint replacement questionnaire.

Figure 2. Number of Language Versions Available for Recommended Patient Reported Outcome Measures

Cross-culturally Adapted Versions of Patient Reported Outcome Measures for the Lower Extremity
Figure 3. Number of Language Versions Available for Recommended Cross-culturally Adapted Patient Reported Outcome Measures
### Table 2. Search Strategy

| (Reliability) OR (validity) OR (responsiveness) OR (“psychometric properties”) OR (“cross-cultural adaptation”) | ACL-Return to Sport after Injury Scale (ACL-RSI)  
Ankle-fracture outcome of Rehabilitation Measure (A-FORM)  
Anterior Knee Pain Scale (AKPS)  
Achilles tendon Total Rupture Score (ATRS)  
Functional Ankle Ability Measure (FAAM)  
Foot and Ankle Disability Index (FADI)  
The Copenhagen Hip and Groin Outcome Score (HAGOS)  
Hip Outcome Score (HOS)  
Hip dysfunction and Osteoarthritis Outcome Score (HOOS)  
International Hip Outcome Tool (IHOT)  
Knee Injury and Osteoarthritis Outcome Score (KOOS)  
Knee Outcome Survey-Activities of Daily Living Scale (KOS-ADLS)  
The Manchester-Oxford Foot Questionnaire (MOXFQ)  
Non-Arthritic Hip Score (NAHS)  
Oxford Hip Score (OHS)  
Oxford Knee Score (OKS)  
Self-Reported Foot and Ankle Score (SEFAS)  
The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)  
The Work Osteoarthritis or Joint Replacement Questionnaire (WORQ) |
|---|---|
Table 3. Available Language Versions for Recommended Patient Reported Outcome Measures

<table>
<thead>
<tr>
<th>PROMs Language versions</th>
<th>Arabic;16, Brazilian;17, Chinese;18,19, Dutch;20,21, French;22, German;23, Italian;24–26, Japanese;27, Korean;28, Lithuanian;29, Norwegian;30, Spanish;31, Swedish;32, Turkish;33</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACRS</td>
<td>Chinese;34, Danish;35, Dutch;36,37, French;38, Greek;39, Italian;40, Korean;41, Norwegian;42, Persian;43, Portuguese;44, Polish;45, Swedish;46, Turkish;47</td>
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<td>AKPS</td>
<td>Arabic;48, Brazilian;49, Dutch;50,51, French;52, Greek;53, Norwegian;54, Spanish;55</td>
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<tr>
<td>A-FORM</td>
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</tr>
<tr>
<td>FAAM</td>
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<tr>
<td>FADI</td>
<td>Italian;72</td>
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<tr>
<td>HAGOS</td>
<td>Brazilian;73, Chinese;74, Danish;75,76, Dutch;77–79, Italian;80, Norwegian;76, Swedish;81</td>
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<tr>
<td>HOOS</td>
<td>Chinese;82, Dutch;83, French;84, German;85,86, Italian;87, Japanese;88, Korean;89, Polish;90,91,92, Portuguese;93,94, Romanian;15, Thai;96, Turkish;97</td>
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<td>HOS</td>
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<td>Dutch;106, French;107, German;108, Greek;109, Japanese;110, Swedish;111, Turkish;112</td>
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<tr>
<td>IHOT-33</td>
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<tr>
<td>KOOS</td>
<td>Arabic;119–122, Chinese;123–127, Danish;128, Dutch;129–131, Finnish;132, French;133,134, Filipino;135, German;136, Greek;137, Hindi;138, Icelandic;139, India;140, Indonesian;141, Italian;142,143, Japanese;144–147, Malay;148, Norwegian;148, Persian;149–154, Polish;155,156, Portuguese;157–159, Spanish;160–162, Swedish;171–173, Turkish;163,164,165, Urdu;165</td>
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<td>KOS-ADLS</td>
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<tr>
<td>NHS</td>
<td>Portuguese;188, Turkish;189</td>
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<td>Chinese;190, Danish;191,192, Dutch;193, French;194, German;195,197, Indonesian;198, Italian;199, Japanese;200, Korean;201, Persian;202,203, Romanian;103, Spanish;204,205, Turkish;206</td>
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<tr>
<td>OKS</td>
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<td>SEFAS</td>
<td>Danish;235, German;236, Spanish; French;237, Swedish;238–242, Thai;243, Turkish;244</td>
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<td>WOMAC</td>
<td>Arabic;246,247, Bengali;248, Brazilian;249–251, Chinese;252–256, Dutch;257–259, Finnish;260–262, French;263, French-Canadian;264,265, German;266–272, Greek;273,274, Hebrew;275, Italian;276,277, Japanese;278,279, Korean;280,281, Malay;282, Marathi;283, Moroccan;284, Nepali;285, Persian;286,287, Spanish;288–295, Swedish;296–298, Thai;299,300, Turkish;301–303</td>
</tr>
</tbody>
</table>

Abbreviations: ACL-RSL, Return to Sport after Injury Scale; A- FORM, Ankle-fracture outcome of rehabilitation measure; AKPS, Anterior Knee Pain Scale; ATRS, Achilles tendon Total Rupture Score; FAAM, Functional Ankle Ability Measure; FADI, Foot and Ankle Disability Index; HAGOS, The Copenhagen Hip and Groin Outcome Score; HOOS, Hip Outcome Score; HOS, Hip dysfuncion and Osteoarthritis Outcome Score; IBOT, International Hip Outcome Tool; KOOS, Knee Injury and Osteoarthritis Outcome Score; KOS-ADLS, Knee Outcome Survey of Daily Living Scale; MOXFQ, The Manchester-Oxford Foot Questionnaire; NAHS, Non-Arthritic Hip Score; OHS, Oxford hip score; ORS, Oxford Knee Score; SEFAS, Self-Reported Foot and Ankle Score; WOMAC, The Western Ontario and McMaster Universities Osteoarthritis Index; WORQ, The Work Osteoarthritis or joint replacement questionnaire.
## Table 4. The Cross-culturally Adapted Translated Hip Patient Reported Outcome Measures with all three Psychometric Properties

<table>
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<tr>
<th>Hip PROM (Number of Language Versions)</th>
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<th>Validity</th>
<th>Responsiveness</th>
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</tbody>
</table>

Abbreviations: HAGOS, The Copenhagen Hip and Groin Outcome Score; HOOS, Hip Outcome Score; HOOS, Hip dysfunctions and Osteoarthritis Outcome Score; IHOT, International Hip Outcome Tool; OHS, Oxford hip score; WOMAC, The Western Ontario and McMaster Universities Osteoarthritis Index.
### Table 5. The Cross-culturally Adapted Translated Knee Patient Reported Outcome Measures with all three Psychometric Properties

<table>
<thead>
<tr>
<th>Knee (Number of Language Versions)</th>
<th>Language Version</th>
<th>Reliability</th>
<th>Validity</th>
<th>Responsiveness</th>
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</table>

Abbreviations: ACL-RSI, ACL-Return to Sport after Injury Scale; AKPS, Anterior Knee Pain Scale; KOOS, Knee Injury and Osteoarthritis Outcome Score; KOS-ADLS, Knee Outcome Survey of Daily Living Scale OKS, Oxford Knee Score

### Table 6. The Cross-culturally Adapted Translated Foot and Ankle Patient Reported Outcome Measures with all three Psychometric Properties

<table>
<thead>
<tr>
<th>Foot and Ankle (Number of Language Versions)</th>
<th>Language Version</th>
<th>Reliability</th>
<th>Validity</th>
<th>Responsiveness</th>
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</tbody>
</table>

Abbreviations: ATRS, Achilles tendon Total Rupture Score; MOXFQ, The Manchester-Oxford Foot Questionnaire; SEFAS, Self-Reported Foot and Ankle Score

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Appendix. Cross-culturally adapted PROMs psychometric properties. Number of the supporting psychometric properties for reliability, validity, and responsiveness for each PROMs language version are listed. PROMs language versions supported by evidence of reliability, validity, and responsiveness are highlighted in bold.

<table>
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<tr>
<th>PROMs</th>
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<th>Reliability</th>
<th>Validity</th>
<th>Responsiveness</th>
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</thead>
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Reliability of Upper Extremity Functional Performance Tests for Overhead Sports Activities

Bryan L Riemann\textsuperscript{a}, Kevin E Wilk, George J Davies

Keywords: Shoulder, Return to Sport, Limb Symmetry Index, Seated Single Arm Shot Put Test

Background

There is lack of consensus on which tests, particularly upper extremity functional performance tests (FPT) that should be used for clinical decision making to progress a patient through a rehabilitation program or criteria for return to sport (RTS). Consequently, there is a need for tests with good psychometric properties that can be administered with minimal equipment and time.

Purpose

(1) To establish the intersession reliability of several open kinetic chain FPT in healthy young adults with a history of overhead sport participation. (2) To examine the intersession reliability of the limb symmetry indices (LSI) from each test.

Study Design

Test-retest reliability, single cohort study.

Methods

Forty adults (20 males, 20 females) completed four upper extremity FPT during two data collection sessions three to seven days apart: 1) prone medicine ball drop test 90°shoulder abduction (PMBDT 90°), 2) prone medicine ball drop test 90°shoulder abduction/90° elbow flexion (PMBDT 90°-90°), 3) half-kneeling medicine ball rebound test (HKMBRT), 4) seated single arm shot put test (SSASPT). Measures of systematic bias, absolute reliability and relative reliability were computed between the sessions for both the original test scores and LSI.

Results

Except for the SSASPT, all tests demonstrated significant (p ≤ 0.030) improvements in performance during the second session. Generally, for the medicine ball drop/rebound tests, the absolute reliability was the highest (less random error) for the HKMBRT, next the PMBDT 90°followed by PMBDT 90°-90°. Excellent relative reliability existed for the PMBDT 90°, HKMBRT, and SSASPT, whereas fair to excellent relative reliability for the PMBDT 90°-90°. The SSASPT LSI revealed the highest relative and absolute reliability.

Conclusion

Two tests, HKMBRT and SSASPT demonstrated sufficient reliability; therefore, the authors’ recommend those tests can be used for serial assessments to advance a patient through a rehabilitation program as well as criteria for progression to RTS.

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Level of Evidence

INTRODUCTION

Despite comparable injury rates between the shoulder and knee, particularly in overhead sports, much less research attention has been paid to the return to sport (RTS) clinical decision-making process following shoulder injury and surgery. For example, there are over twice as many references indexed by PubMed.gov (searches conducted 11/26/22) concerning RTS for the knee ([return to sport] AND [knee]=1988 results) compared to the shoulder ([return to sport] AND [shoulder]=914 results). Based upon several recent systematic reviews and meta-analyses, the success of RTS and return to previous level of play following shoulder surgery is highly variable between investigations. While overall RTS ranges between 62.7% to 100%, those seeking to return to competitive overhead sports demonstrate less success at returning to the same or higher level of play. In addition to level of play, the specific injury and management (i.e., conservative versus surgical), age of athlete, and duration of follow up also likely contribute to the highly variable RTS estimates.

While it is certainly multi-factorial as to why and how an athlete returns to sport following shoulder injury or surgery, the complexity of RTS clinical decision-making is complicated by the lack of consensus or agreed upon metrics regarding the criteria that should be used. Systematic reviews and meta-analyses consistently report time following surgery as the most commonly used criteria for RTS. A few studies have used strength or range of motion, either in isolation, or in conjunction with time as RTS criteria. While time post-surgery would account for biological tissue healing with strength and range of motion being important markers of preliminary functional recovery, there appears to be a gap between the RTS criteria being used and whether a patient truly has the necessary recovery prerequisites to being ready for more rigorous sport specific activities and return to prior levels of performance.

The most recent consensus statement regarding RTS following shoulder injury recommends sport specific upper extremity tests be used with RTS decision making. Interestingly several of the tests suggested are bilateral tasks, while others do not replicate common movement patterns or demands imposed by many sport activities (e.g., the Y-Balance test) to provide insight about the readiness to RTS. In addition to many sports involving unilateral tasks, the use of bilateral tasks may permit compensation by the unaffected limb, thereby masking underlying performance deficiencies. Specific to overhead athletes is the function of both the anterior and posterior musculature with the shoulder in an abducted position. First suggested by Wilk et al. for assessments with overhead athletes, and included in the Bern Consensus, are the prone medicine ball drop test (PMBDT) and wall throws test. Despite the apparent ecological validity of these assessments to the overhead athlete, reliability metrics remain unknown.

The seated single arm shot put test (SSASPT) is an additional unilateral upper extremity functional performance test that has been studied in both healthy individuals and patients with shoulder pain or injury. Similar to other unilateral functional performance tests, in circumstances of unilateral pathology, a limb symmetry index (LSI) can be computed to provide a unitless metric to interpret a patient’s performance thereby avoiding many of the confounding issues with normative data comparisons. Previous literature has reported SSASPT LSI in healthy persons ranges between 103 to 111%, favoring the dominant limb. Additionally, a previous investigation demonstrated that, except for greater release velocities for the dominant limb, which were attributable to underlying strength and power differences, healthy persons perform the SSASPT with similar underlying projection mechanics between the dominant and nondominant limbs. Most recently, the SSASPT LSI was demonstrated to have minimal association with a patient reported outcome measure (QuickDASH) in patients being discharged from physical therapy following shoulder injury or surgery. This finding suggests that both subjective and objective measures are needed to attain a complete assessment of a patient’s functional and perceived status. Furthermore, patients with nondominant shoulder involvement being discharged from rehabilitation exhibited lower SSASPT LSI than patients with dominant shoulder involvement. Surprisingly, despite all the attention the SSASPT LSI has received in the literature, to date, there have been no investigations regarding the reliability of the LSI metric.

The purpose of this investigation was to establish the intersession reliability of several open kinetic chain (OKC) functional performance tests (FPT) in healthy young adults with a history of overhead sport participation. Specifically studied were two variations of the PMBDT (shoulder abducted 90°, shoulder abducted 90°/elbow flexed 90°) and a variation of the wall throws test (half-kneeling medicine ball rebound test [HKMVRT]). To provide context for the reliability results of the three assessments, the SSASPT was also included. A secondary purpose was to examine the intersession reliability of the LSI computed from the SSASPT, HKMVRT and two PMBDT. The hypotheses were that all tests would demonstrate moderate to good reliability, with the reliability of LSI expected to be slightly less than the original scores.

METHODS

PARTICIPANTS

Forty healthy young adults (20 males, 20 females) with a history of overhead sport participation were recruited for the study. Prior to study participation, participants completed a demographic, injury and physical activity history form and the 2019 Physical Activity Readiness-Questionnaire. All forms were reviewed by a member of the inves-
tigative team to verify that each participant was appropriate for study participation. Inclusion criteria included being between 18 and 35 yrs old, meeting the American College of Sports Medicine criteria for being physically active, and participation in an overhead recreational or competitive sport for a minimum of one year. Participants were excluded if they had a previous history of cervical spine or upper extremity injury or surgery within a year prior of data collection, were deficient in the range of motion needed to adopt the upper extremity testing positions required to perform the tests or were unable to complete the tests as prescribed. This investigation was approved by a university institutional review board and all participants read and signed an approved informed consent form.

RESEARCH DESIGN

This study utilized a randomized repeated measures research design. Study participation required two testing sessions three to seven days apart. Testing sessions were scheduled at near identical times each day and participants were asked to avoid vigorous physical activity (e.g., upper extremity resistance or exercise training), 24 hours prior to each session. At each session, participants completed identical protocols. Each participant was randomly allocated a test and limb (dominant, nondominant) order; the order used for the first session was replicated for the participant’s second session. At the beginning of each session, all participants completed a warm-up which consisted of arm circles forwards, backwards, and arm crosses. Each warm-up activity was completed for thirty seconds, for a total of three sets. After completion of the warm-up, participants were shown a pre-recorded demonstration video illustrating the four tests to be performed. Prior to the two PMBDT and HKMBRT tests, participants were given time to practice each task and demonstrate proficiency. Proficiency was defined as being able to repetitively and continuous perform the two PMBDT and HKMBRT tasks without hesitation between catches. Familiarization to the SSASPT procedures was a component of the four-trial gradient warm up described below. Additional time and cuing were provided to participants as needed. Between each test, participants completed two-minute rest periods.

TEST PROCEDURES

PRONE MEDICINE BALL DROP TEST AT 90° SHOULDER ABDUCTION (PMBDT 90°)

The PMBDT 90° (Figure 1) was performed with the participants lying prone on a treatment plinth with their testing shoulder abducted to 90°, elbow straight, and the forearm supinated (palm to floor). The non-testing arm was supported over the opposite side of the table. Participants were instructed to not grasp the table during testing. Participants dropped and caught a .91 kg medicine ball as many times as possible for thirty seconds. A mobile stool was placed under the hand to catch the medicine ball in circumstances in which the participants missed a catch. During the test participants were verbally instructed to maintain the 90° shoulder abducted position. One trial was performed on each arm, with a 30s rest between each testing trial. The total number of catches recorded during the 30s trial served as the performance outcome metric.

PRONE MEDICINE BALL DROP TEST AT 90° SHOULDER ABDUCTION/90° ELBOW FLEXION (PMBDT 90°-90°)

The PMBDT 90°-90° (Figure 2) was performed with the participants lying prone on a treatment plinth with their testing shoulder abducted to 90°, the elbow flexed to 90°, and forearm supinated (palm to floor). The non-testing arm was supported over the opposite side of the table. Participants were instructed to not grasp the table during testing. Participants dropped and caught a .91 kg medicine ball as many times as possible for thirty seconds. A mobile stool was placed under the hand to catch the medicine ball in circumstances in which the participants missed a catch. During testing, participants were verbally instructed to maintain the 90° shoulder abducted position and 90° elbow flexed position. One trial was performed on each arm, with a 30s rest between each testing trial. The total number of catches recorded during the 30s trial served as the performance outcome metric.

HALF-KNEELING MEDICINE BALL REBOUND TEST (HKMBRT)

The HKMBRT was slightly modified from the original description. Instead of being performed in a standing position, the participants assumed a half-kneeling position in a doorway to eliminate contributions from the legs (Figure 3). The testing shoulder was abducted to 90°, the elbow flexed to 90°, and forearm supinated (palm toward wall). The non-testing hand was placed on the ipsilateral knee.
Figure 2. Positioning for the performance of the Prone Medicine Ball Drop Test at 90° shoulder abduction/90° Elbow Flexion.

Figure 3. Positioning for the performance of the Half-Kneeling Medicine Ball Rebound Test.

Figure 4. Starting position for the seated single arm shot put test.

SEATED SINGLE ARM SHOT PUT TEST (SSASPT)

Like previous studies, the SSASPT began with the participants assuming a long sitting position on the floor against a wall with the non-testing hand in their lap. The test began with the participant holding a 2.0kg medicine ball in the palm of their hand while keeping their elbow adjacent to their torso. Participants were instructed to "put or press the medicine ball as hard as they could for greatest distance" while maintaining their back against the wall and avoid the test limb crossing torso midline. Furthermore, participants were cued to perform the movement with a pure concentric action without any preloading (stretch-shortening). Prior to performing three maximal effort trials, participants performed four gradient sub-maximal to maximal warm-up practice trials at 25%, 50%, 75% and 100% effort. The distance from the wall to the first location of medicine ball ground contact was measured and averaged across the three test trials.

STATISTICAL ANALYSIS

All statistical procedures were conducted using IBM SPSS Statistics for Windows, version 27 (IBM Corp., Armonk, NY, USA) and Microsoft Excel, version 16 (Microsoft Corporation, Redmond, WA, USA). Separate statistical analyses were conducted for the males and females. Exploratory analyses were conducted on the data from each session to identify potential erroneous data entry errors. Normality of the between session difference scores was examined using Q-Q plots and Shapiro-Wilks tests. Heteroscedasticity between sessions was examined by using the Bland-Altman method. Systematic bias between testing sessions were
Table 1. Participant demographics and overhead sport participation.

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<th>Males</th>
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<td>Height (m)</td>
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<td>1.81 ± 0.7</td>
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<tr>
<td>Mass (kg)</td>
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<td>85.0 ± 13.9</td>
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PMBDT 90°-90° LSI. Relative reliability for the SSASPT LSI ranged from good to excellent whereas the other three tests ranged from poor to fair.

DISCUSSION

This study sought to primarily examine the intersession reliability of four OKC FPT which could be used as criteria for rehabilitation program progression and RTS clinical decision making. The PMBDT 90° and PMBDT 90°-90° largely focused on the posterior glenohumeral musculature whereas HKMBRT and SSASPT were more anterior musculature focused. The results support the incorporation of the SSASPT and HKMBRT as potential tools into clinical decision making because of their excellent reliability. While the relative reliability of the PMBDT 90° was excellent, the absolute reliability bordered just beyond acceptability thresholds. The reliability of PMBDT 90°-90° was below acceptable thresholds. Thus, this investigation provides greater support for the two anterior musculature focused tests and less support for the current versions of the two posterior musculature centered tests. The secondary purpose of the investigation, examination of the intersession LSI reliability of the four OKC FPT, supports the SSASPT LSI as being a reliable metric. Compared to the SSASPT, larger changes in HKMBRT and PMBDT 90° LSI scores would be needed to be confident the changes are beyond measurement error.

Table 2. Descriptive statistics for each of the functional performance tests. The units associated with PMBDT 90°-90°, PMBDT 90°, and HKMBRT are medicine ball catches, whereas the units for the SSASPT are meters.

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<th>Test</th>
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<th>Sex</th>
<th>Session 1 Mean ± SD</th>
<th>Session 2 Mean ± SD</th>
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<td>55.7 ± 13.5</td>
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<tr>
<td></td>
<td></td>
<td>M</td>
<td>61.5 ± 9.9</td>
<td>68.3 ± 12.8</td>
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<td>ND</td>
<td>F</td>
<td>44.4 ± 12.8</td>
<td>51.0 ± 11.1</td>
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<td></td>
<td></td>
<td>M</td>
<td>58.1 ± 10.1</td>
<td>66.5 ± 10.4</td>
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<tr>
<td>PMBDT 90°</td>
<td>D</td>
<td>F</td>
<td>64.7 ± 13.4</td>
<td>71.6 ± 13.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>74.7 ± 9.9</td>
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<td>ND</td>
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<td>58.9 ± 13.4</td>
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<td>M</td>
<td>70.4 ± 9.9</td>
<td>76.7 ± 9.3</td>
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<tr>
<td>HKMBRT</td>
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<td>69.0 ± 16.5</td>
<td>76.9 ± 14.4</td>
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<td>74.9 ± 12.6</td>
<td>82.7 ± 13.5</td>
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<td>64.0 ± 12.9</td>
<td>71.0 ± 13.6</td>
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<td>70.1 ± 11.9</td>
<td>77.4 ± 13.0</td>
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<td>4.91 ± 0.67</td>
<td>4.83 ± 0.66</td>
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<td>M</td>
<td>4.63 ± 0.69</td>
<td>4.60 ± 0.61</td>
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</table>

PMBDT 90°-90°: prone medicine ball drop test in 90°-90° position; PMBDT 90°: prone medicine ball drop test in 90° position; HKMBRT: half-kneeling medicine ball rebound test; SSASPT: seated single arm shot put test; SD: standard deviation; D: dominant; ND: nondominant; F: female; M: male
Table 3. Results of the systematic bias, absolute reliability, and relative reliability analysis conducted on the functional performance tests. The units associated with PMBDT 90°-90°, PMBDT 90°, and HKMBRT are medicine ball catches, whereas the units for the SSASPT are meters.

<table>
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<tr>
<th>Test</th>
<th>Limb</th>
<th>Sex</th>
<th>Mean ± SD</th>
<th>P</th>
<th>SEM</th>
<th>CV%</th>
<th>MDD90%</th>
<th>Relative Reliability ICC (95% CI)</th>
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<td>PMBDT 90°-90°</td>
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<td>F</td>
<td>5.3 ± 10.1</td>
<td>.030</td>
<td>7.1</td>
<td>17.6</td>
<td>16.7</td>
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<td>M</td>
<td></td>
<td>7.0 ± 8.7</td>
<td>.002</td>
<td>6.1</td>
<td>10.3</td>
<td>14.3</td>
<td>.713 (0.405-.876)</td>
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<tr>
<td>ND</td>
<td>F</td>
<td></td>
<td>6.6±7.4</td>
<td>&lt;.001</td>
<td>5.2</td>
<td>14.3</td>
<td>12.2</td>
<td>.809 (0.580-.920)</td>
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<td></td>
<td>8.4±11.0</td>
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<td>7.8</td>
<td>13.0</td>
<td>18.2</td>
<td>.424 (.011-.724)</td>
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<td>PMBDT 90°</td>
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<td>7.1±9.1</td>
<td>.003</td>
<td>6.5</td>
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<td></td>
<td>7.8±6.4</td>
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<td>4.5</td>
<td>6.1</td>
<td>10.5</td>
<td>.881 (0.724-.951)</td>
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<td>3.8</td>
<td>5.5</td>
<td>8.9</td>
<td>.917 (0.803-.966)</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td></td>
<td>7.3±6.5</td>
<td>&lt;.001</td>
<td>4.6</td>
<td>6.5</td>
<td>10.7</td>
<td>.865 (0.691-.944)</td>
</tr>
<tr>
<td>SSASPT</td>
<td>D</td>
<td>F</td>
<td>-.026±.238</td>
<td>.637</td>
<td>.170</td>
<td>5.3</td>
<td>.397</td>
<td>.848 (0.657-.937)</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td></td>
<td>-.089±.199</td>
<td>.060</td>
<td>.141</td>
<td>3.0</td>
<td>.330</td>
<td>.956 (0.892-.982)</td>
</tr>
<tr>
<td>ND</td>
<td>F</td>
<td></td>
<td>-.034±.187</td>
<td>.423</td>
<td>.130</td>
<td>4.2</td>
<td>.304</td>
<td>.934 (0.841-.973)</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td></td>
<td>-.037±.202</td>
<td>.426</td>
<td>.141</td>
<td>3.2</td>
<td>.330</td>
<td>.952 (0.883-.981)</td>
</tr>
</tbody>
</table>

PMBDT 90°-90°: prone medicine ball drop test in 90°-90° position; PMBDT 90°: prone medicine ball drop test in 90° position; HKMBRT: half-kneeling medicine ball rebound test; SSASPT: seated single arm shot put test; SD: standard deviation; SEM: standard error of the measurement; CV: coefficient of variation; MDD90%: 90% minimal detectable difference; ICC: intraclass correlation coefficient; CI: confidence interval; D: dominant; ND: nondominant; F: female; M: male

Table 4. Descriptive statistics for each of the limb symmetry indices (%) from the functional performance tests.

<table>
<thead>
<tr>
<th>Test</th>
<th>Sex</th>
<th>Session 1 Mean ± SD</th>
<th>Session 2 Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMBDT 90°-90°</td>
<td>F</td>
<td>119.2 ± 32.0</td>
<td>110.2 ± 16.0</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>106.2 ± 11.0</td>
<td>102.8 ± 12.4</td>
</tr>
<tr>
<td>PMBDT 90°</td>
<td>F</td>
<td>111.5 ± 14.2</td>
<td>115.5 ± 18.0</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>106.4 ± 6.3</td>
<td>104.1 ± 10.6</td>
</tr>
<tr>
<td>HKMBRT</td>
<td>F</td>
<td>107.3 ± 12.1</td>
<td>108.6 ± 9.7</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>107.3 ± 9.5</td>
<td>107.4 ± 11.2</td>
</tr>
<tr>
<td>SSASPT</td>
<td>F</td>
<td>104.7 ± 6.9</td>
<td>105.0 ± 7.6</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>106.4 ± 8.0</td>
<td>105.3 ± 9.4</td>
</tr>
</tbody>
</table>

PMBDT 90°-90°: prone medicine ball drop test in 90°-90° position; PMBDT 90°: prone medicine ball drop test in 90° position; HKMBRT: half-kneeling medicine ball rebound test; SSASPT: seated single arm shot put test; SD: standard deviation; F: female; M: male

Intraclass correlation coefficients are the most frequently reported reliability statistics reported in the literature and reflect the stability of the rank or position of an individual relative to the group across a repeated assessment. Using the arbitrary threshold of .75 as having clinical meaningfulness, all tests across both sexes and limbs except for the PMBDT 90°-90° met the criteria. Also critical to fully interpreting ICC is consideration of the confidence interval precision and range, particularly the lower bound, around each ICC point estimate. Consistent with previous literature,15,20,28,29 the ICC for the SSASPT were all >.85. Additionally, except for the dominant limb for females, the confidence interval lower bounds were above .75, further supporting the relative reliability of the SSASPT. The ICC values for the HKMBRT and PMBDT 90° also met the clinical meaningfulness threshold, although many of the lower confidence interval bounds reside in the fair to good range. Except for nondominant limb for females, the PMBDT 90°-90° ICC values were below clinical meaningfulness threshold, and the confidence intervals were very wide. Thus, likely because of the larger random error that was reflected by the absolute reliability statistics, the relative reliability for PMBDT 90°-90° was reduced.

Of the previous studies15,28,29 that considered relative and absolute reliability of the SSASPT, none appear to have considered systematic bias. Remarkably, the SSASPT was the only assessment in the current investigation void of significant repeated exposure changes. For the two PMBDT, practitioners can expect an average improvement between five to seven catches and for the HKMBRT between seven to eight catches that are attributable to completion of the test a second time.

Absolute reliability has the most pertinence to clinicians by providing an estimate of the expected random error associated with a test.30 For example, when conducting serial assessments during rehabilitation to monitor patient progress, a patient’s performance change must exceed the mean systematic bias plus an absolute reliability estimate (e.g., SEM, MDD) to definitively declare improvement. With the two PMBDT and the HKMBRT, patients must attain
Table 5. Results of the systematic bias, absolute reliability, and relative reliability analysis conducted on the limb symmetry indices (%) for each functional performance test.

<table>
<thead>
<tr>
<th>Test</th>
<th>Sex</th>
<th>Systematic Bias Mean ± SD</th>
<th>Absolute Reliability SEM</th>
<th>CV %</th>
<th>MDD90%</th>
<th>Relative Reliability ICC (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMBDT 90°-90°</td>
<td>F</td>
<td>-9.0±30.5</td>
<td>.202</td>
<td>21.6</td>
<td>19.7</td>
<td>50.4</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>-3.4±14.6</td>
<td>.312</td>
<td>10.4</td>
<td>11.0</td>
<td>24.1</td>
</tr>
<tr>
<td>PMBDT 90°</td>
<td>F</td>
<td>4.0±17.1</td>
<td>.307</td>
<td>12.1</td>
<td>10.6</td>
<td>28.2</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>-2.4±11.7</td>
<td>.375</td>
<td>8.3</td>
<td>8.3</td>
<td>19.3</td>
</tr>
<tr>
<td>HKMBRT</td>
<td>F</td>
<td>1.3±11.4</td>
<td>.619</td>
<td>8.1</td>
<td>7.8</td>
<td>18.8</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>0.1±7.9</td>
<td>.960</td>
<td>6.9</td>
<td>6.0</td>
<td>16.1</td>
</tr>
<tr>
<td>SSASPT</td>
<td>F</td>
<td>0.3±5.7</td>
<td>.233</td>
<td>4.0</td>
<td>3.7</td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>-1.2±5.1</td>
<td>.323</td>
<td>3.6</td>
<td>3.3</td>
<td>8.3</td>
</tr>
</tbody>
</table>

PMBDT 90°-90°: prone medicine ball drop test in 90°-90° position; PMBDT 90°: prone medicine ball drop test in 90° position; HKMBRT: half-kneeling medicine ball rebound test; SSASPT: seated single arm shot put test; SD: standard deviation; SEM: standard error of the measurement; CV: coefficient of variation; MDD90%: 90% minimal detectable difference; ICC: intraclass correlation coefficient; CI: confidence interval; F: female; M: male

~seven additional catches (systematic bias) plus ~five catches (SEM) on a subsequent assessment to have some confidence that their improvement is not attributable to learning effects or measurement error. In contrast, for the SSASPT, because there was no significant systematic bias, patients would just need to exhibit ~.15m (SEM) improvement. The MDD is a more conservative estimate of measurement error and when changes exceed the magnitude of the MDD, clinicians can be extremely confident that the patient has experienced improvement. The MDD for the two PMBDT and HKMBRT are rather large, ranging between nine and 17 catches. As a result, it is likely that patients may experience clinically meaningful changes that may not be reflected in test performance exceeding the MDD.

Coefficient of variation as an index of variability is particularly useful when data demonstrate heteroscedasticity. It is noteworthy that none of the tests assessed, for either limb or sex, in the current investigation demonstrated heteroscedasticity. An additional advantage of the CV is that because it is unitless, comparisons can be made between various instruments. It is important that such CV comparisons be made between CV derived from similar populations. For example, in the current study, for both the dominant and nondominant limbs, the males demonstrated higher SSASPT values than the females. If the variability between sessions was the same for both sexes, the CV would be higher for the females compared to the males because the two sessions mean (denominator) would be lower. Thus, it is most prudent to compare the CV between tests within each sex. Coefficient of variation value comparisons within each sex reveal similar results, with SSASPT having the lowest CV, followed by the HKMBRT. With regards to the 10% CV acceptability threshold, only the PMBDT 90°-90° (both sexes and limbs) largely exceeded. The CV results, in conjunction with the large MDD, further challenges to the clinical utility of the current version of the PMBDT 90°-90° as a reliable test of functional performance.

Currently, there is a void of FPT focusing upon the posterior glenohumeral musculature to use during clinical decision making. Unfortunately, in the current investigation, the two tests emphasizing glenohumeral posterior musculature revealed the lowest reliability, with the PMBDT 90°-90° demonstrating slightly worse reliability than the PMBDT 90°. Both tests involved a 30s effort of catching a medicine ball while maintaining a prone position. The movement pattern differences between the two tests likely explains the slight difference in reliability. The PMBDT 90° involved a horizontal abduction movement whereas the PMBDT 90°-90° was slightly more complex and required maintaining 90° abduction while performing external rotation movements to repeatedly catch and drop the medicine ball. Based on the current results, both tests could benefit from some revision aimed towards improving their reliability. Based on the authors’ experience with the tests during the investigation, as well as qualitative comments made by some of the participants, exploring the use of two 15s trials rather than a single 30s trial is recommended. Some participants reported fatigue of their hand muscles occurring during the last ~10s affected their ability to catch and maintain the transitory grip of the medicine ball required for each repetition. As the goal of the two PMBDT is to concentrate on the posterior shoulder musculature, it is important that grip fatigue as a potential performance limitation be reduced. The authors expect that modifying the two PMBDT to be based upon the average number of catches across two 15s trials will greatly improve both relative and absolute reliability metrics.

Because LSI incorporates performance of the dominant and nondominant limbs simultaneously, it was expected that the LSI reliability metrics would be weaker than the individual dominant and nondominant limb metrics. Statistically, there were no LSI differences (i.e., systematic bias) between the two testing sessions across the four assessments for either the males or females; however, except for the SSASPT, there appeared to be a lot of between participant variability based on the standard deviations. Additionally, aside from the SSASPT, attaining LSI changes that exceed the MDD would likely be very difficult, particularly for the PMBDT 90° and PMBDT 90°-90°. Given the expectation for lower LSI reliability as described earlier, using the LSI
SEM as a threshold for identifying change exceeding measurement error in a patient’s performance may be more appropriate. Based on this suggestion, achieving LSI changes in patients that exceed the LSI SEM for the HKMBRT and PMBDT 90° (males) seems reasonable. Like the individual limb reliability metrics, the authors expect the PMBDT 90° and PMBDT 90°-90° LSI reliability metrics to improve with the modification of the tests to include two 15s trials.

The LSI for the SSASPT were the smallest (i.e., closest to 100%) of the four tests indicating more similar performance between the dominant and nondominant limbs. Furthermore, the SSASPT LSI scores in the current study were within, albeit towards the lower end, of the SSASPT LSI range (103 to 111% favoring dominant limb) previously reported in healthy persons.14–18,20 The LSI reliability metrics provided by the current investigation, coupled with six separate investigations14–18,20 reporting healthy persons demonstrate SSASPT LSI within the above range, supports clinicians using the SSASPT LSI for rehabilitation program progression evaluation and RTS clinical decision making. When using the SSASPT LSI to assess RTS readiness in a patient with UE pathology, there may be a need to consider which limb is the involved based upon a recent investigation reporting SSASPT LSI differences between patients with dominant versus nondominant limb involvement at the time of discharge from rehabilitation following shoulder injury or surgery.21 Specifically, the odds of a patient with a nondominant involved limb being below the normative LSI range (i.e., <89%) were two times higher than the odds of a patient with a dominant involved limb being below the normative range (i.e., <103%). With only one report examining SSASPT LSI differences between dominant/nondominant involved limbs at time of rehabilitation discharge, further research is clearly needed.

There are a few limitations to the current study that should be recognized. First, although the overall sample size is justifiable for a reliability study, preliminary analyses revealed sex differences to be present in some of the reliability metrics. As a result, all analyses were conducted separately for the males and females, thereby effectively lowering sample sizes within each sex to 20. With all else remaining constant (e.g., within subject variability across sessions), sample size directly influences confidence interval previson. Subsequently, this may explain some of the large ICC confidence interval widths. Furthermore, part of the inclusion criteria required participants to have been participating in an overhead recreational or competitive sport for a minimum of one year. The resulting sample was overwhelmingly (95%) involved with unilateral sports. Surprisingly, there were not large differences in the reliability metrics between the dominant and nondominant limbs within each sex, nor did the LSI for the SSASPT or HKMBRT reveal large average bilateral asymmetry. Unfortunately, there is no data regarding the level of play (recreational versus competitive), nor is there data regarding participation history. While collecting current level of play is straightforward, simultaneously trying to quantify history of participation and level of play simultaneously would be difficult. Additionally, it is likely the participants have histories of participating in non-overhead athletic activities (e.g., resistance training). As a result, the variability of participation history, level of play, and other sporting activities may be responsible for the average SSASPT and HKMBRT LSI scores being <10% with the associated standard deviations ranging between 6.9 to 12.1%. Finally, with regard to the participant characteristics, it is worth noting that 80% of the women participants were involved with either softball or volleyball, whereas the men had more dispersion among participation in four sports. Although overall there were not large sex differences in the reliability metrics, the sport participation differences may help explain the trend for the men to have better dominant limb absolute reliability compared to the women, whereas the women demonstrated better nondominant limb absolute reliability compared to the men. Lastly, it is important to note that the current investigation used a three-to-seven-day test-retest interval. This interval is likely shorter than the typical serial testing intervals used for monitoring rehabilitation progression in patients. Critical to test-retest research design is the assumption that the underlying characteristic is not changing.20 Using a longer than seven day interval to estimate random measurement error in physically active participants could be confounded by actual changes in functional performance. Hence, the rationale for using a three-to-seven-day test-retest interval in the current study. Using shorter test-retest intervals has the benefit that improvements associated with learning during novel test performance (e.g., systematic bias) are likely to be greater when shorter time intervals are used compared to longer intervals. Thus, we speculate the performance improvements revealed in the current study for the PMBDT and HKMBRT are liberal estimates compared to typical longer test-retest intervals used in monitoring rehabilitation progression.

CONCLUSION

There is a lack of consensus on which battery of tests, particularly UEPFT that should be used for clinical decision making to progress a patient through a rehabilitation program or criteria for RTS. Based on the results of this study, the authors recommend using the SSASPT and HKMBRT tests because they demonstrated moderate to good reliability, and interestingly, focus on the anterior musculature which is commonly used in overhead throwing sports. However, the posterior musculature, which is obviously critical in the throwing motion as part of the eccentric deceleration phase, still requires additional research to determine an ecologically valid test with good psychometric properties.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.
ACKNOWLEDGEMENTS

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Performance, Test-retest Reliability, and Measurement Error of the Upper Limb Seated Shot Put Test According to Different Positions of Execution

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Keywords: functional performance testing, outcome assessment, overhead athletes, upper extremity

BACKGROUND
The unilateral Seated Shot-Put Test (USSPT) is an easy to apply, inexpensive tool that can be used to assess shoulder performance unilaterally. Two different positions of execution have been described in previous studies, however, differences regarding reference values and psychometric properties were not assessed.

PURPOSE
To investigate the performance, test-retest reliability and measurement error of the USSPT according to different positions of execution (floor versus chair) in overhead athletes. The hypothesis was that both positions would present similar values, good to excellent test-retest reliability and clinically acceptable measures.

STUDY DESIGN
Test-retest reliability.

METHODS
Forty-four overhead athletes performed the USSPT on the floor (USSPT-F) and on a chair (USSPT-C). Normative values were established according to gender, age, and dominance. Test-retest reliability was determined using Intraclass Correlation Coefficient and measurement error through Standard Error of Measurement, Smallest Detectable Change, as well as Bland and Altman plots.

RESULTS
Reference values for both positions were provided. Women performed better on the USSPT-C than USSPT-F. Excellent test-retest reliability 0.97 (0.89 – 0.99) for dominant side and 0.95 (0.80 – 0.98) for non-dominant side was found for the USSPT-F. Moderate to excellent reliability 0.91 (0.67 – 0.98) for dominant side and 0.74 (0.01 – 0.93) for non-dominant side was found for the USSPT-C. Presence of systematic error (14.76 cm) was found only for USSPT-C dominant (p=0.011).

CONCLUSION
Differences were found only for women with better performance on the USSPT-C. The USSPT-F presented higher reliability values. Both tests presented clinically acceptable measures. Presence of systematic error was found only in the USSPT-C.

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INTRODUCTION

Overhead sports involve the repetitive use of the shoulder with the hand above the head.1 Baseball, lacrosse, volleyball, handball, and tennis can be highlighted as the most overhead sports studied. The overall incidence of injuries ranges from 2.6/1000 hours in volleyball athletes to 6.5/1000 hours in handball athletes. Overuse injuries should be highlighted, as the incidence ranges from 20% to 37%,1 and the shoulder is one of the most injured joints with an incidence of 9-32%.2 This high incidence is related to movements performed at high velocity and in extreme ranges of motion3; unfortunately, athletes who sustained a shoulder injury had a mean absence of participation of 6.2 weeks in overhead sports as handball or volleyball.1

Several extrinsic and intrinsic risk factors are connected to shoulder injuries in overhead sports.1 Extrinsic factors include external loads sustained during match and training while intrinsic factors include gender, history of injury, level of play, shoulder range of motion, flexibility, and muscle strength.1,3 An interaction between extrinsic (external load), and intrinsic (reduced external rotation or scapular dyskinesia) factors has been associated with higher shoulder injury rates in handball players.4

Among risk factors, muscle strength is one of the most studied and important. The isometric strength of the internal rotators (IR) and external rotators (ER) was described as a protective factor in the development of rotator cuff tendinopathy in overhead athletes.5 Isokinetic or isometric dynamometry can be used to assess athletes; however, they are not widely available measurement tools.6 On the other hand, Physical Performance Tests (PPTs) are reliable, easy to apply, and inexpensive tools that can be used to assess shoulder performance, and previous studies have reported a strong relationship between the Closed Kinetic Chain Upper Extremity Stability Test (CKUEST) and the Upper Seated Shot Put Test (USSPT-T) with IR and ER isokinetic strength.7,8 Therefore, performance tests may be used in pre-season assessments as an alternative to a dynamometer.

The CKUEST is a closed kinetic chain test with normative values for different populations9 and that is capable of predicting shoulder injury,10 however, is not possible to evaluate performance unilaterally. One alternative is the USSPT that can be performed on a chair (USSPT-Ch)11 and on the floor (USSPT-F).12 Normative values and psychometric properties for the USSPT have been reported for athletes from different sports,11,13,14 healthy active adults,11,15,16 and overhead athletes.14 However, the differences in results for both positions have not been described in the literature in terms of measurement comparisons and reliability. So, these comparison values would make it easier for clinicians to choose one of the tests to utilize.

Therefore, the primary objective of this study was to investigate the performance, test-retest reliability and measurement error of the USSPT according to different positions of execution (chair versus floor) in overhead athletes. The secondary objective was to investigate the relationship between results from both test positions. The hypothesis was that both positions would present similar values, good to excellent test-retest reliability and clinically acceptable measures. Also, we expected that both positions would be highly correlated.

METHODS

TYPE OF STUDY

A test-retest design was carried out according to the recommendations of STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) and COSMIN (Consensus-based Standards for the selection of health Measurement Instruments). The order of the tests were randomized for all participants. Before testing, all participants signed an informed consent form and the rights of the subjects were protected. The study was approved by the Ethical Committee of the University of State of São Paulo (UNESP – Campus Botucatu) under protocol number 44561421.7.0000.5411. Informed consent was obtained in accordance with the Helsinki Declaration and local resolution.

PARTICIPANTS

A convenience sample of healthy male and female overhead athletes was recruited for the study. They were later divided according to sex and age category for analyses. The mean age was used to dichotomize participants. The inclusion criteria were: (I) age between 18 and 40 years; (II) overhead athletes with a frequency of three times per week during one hour / day. The exclusion criteria were: (I) history of shoulder pain or surgeries in the trunk, upper or lower limbs in the prior year; (II) presence of shoulder pain during arm elevation in the frontal plane. Any subject that trained for competitive purposes, that was affiliated with an gym, club or sports institution, and that competed in the prior year was considered as an athlete.17

OUTCOME MEASURES

The comparison of the average distance in the USSPT-F and USSPT-C according to gender and age category was the primary outcome of the study. The test-retest reliability, measurement error, and correlation between the USSPT-F and USSPT-C were the secondary outcomes of the study. Normative data and the relationship between both tests were described considering the total sample (n=44), while the test-retest reliability and measurement error were calculated with part of the sample (n=10).
STUDY PROTOCOL

Data collection began with subjects completing an adapted questionnaire\(^{18}\) to obtain identification data and general information such as age, height, body mass, body mass index, limb dominance, training characteristics, and injury history. Limb dominance was determined as the arm used to throw a ball. Next, the tests were performed. Before the tests were executed, the participants received information about how they were to be performed. The participants performed both versions of the USSPT with one examiner who was previously trained to apply the tests. After seven days, both tests were performed in the same conditions to assess test-retest reliability.

For the USSPT-F, participants were seated on the floor with their backs supported against a wall. The knees remained flexed and the feet flat on the floor. The non-tested arm was positioned close to the trunk with medial rotation of the shoulder and ninety degree of elbow flexion. A measuring tape was placed on the floor and extended at a distance of 10 meters. A 3 kg medicine ball was then delivered to the participants, and they were instructed to hold it with the throwing hand at shoulder height, and then push the ball as far as possible in relation to the tape measure placed on the floor. (Figure 1) Three attempts throwing with an interval of one minute between them. The average of three repetitions was considered for analyses. If the participant moved their back off the wall or launched the ball in a non-horizontal trajectory, the repetition was not valid and a new one was performed. The mean (to account for variability) distance (centimeters) covered by the ball was marked with the same measuring tape.\(^{12}\) (Figure 1)

For the USSPT-C, participants were seated on a standard 45 cm chair without armrests. The subjects were seated in the chair with their feet and lower legs placed on another 45 cm chair, positioned just in front of their chair. The non-tested arm was positioned across the chest. A measuring tape was placed in front of the chair and extended at a distance of 10m. A 3 kg medicine ball was then delivered to the participants and they were instructed to hold it with the throwing hand at shoulder height, and then push the ball as far as possible in relation to the tape measure placed on the floor. Also, they were instructed to keep their head, scapula on the non-tested side, and back in contact with the wall. Three attempts throwing with an interval of one minute between them. The average of three repetitions was considered for analyses. Similarly, if the participant moved their back off the chair or launched the ball in a non-horizontal trajectory, the repetition was not valid and a new one was performed. The mean (to account for variability) distance (centimeters) covered by the ball was marked with the same measuring tape.\(^{11}\) (Figure 1)

DATA ANALYSIS

Data were analyzed using SPSS software (version 23.0; SPSS, Chicago, IL, USA). Data normality and homogeneity of variance were tested using the Shapiro Wilk and Levene's tests, respectively. Mean and standard deviation were calculated for the anthropometric data, and for the results of the USSPT-F and USSPT-C. For the anthropometric data, a linear regression model was applied considering "sex" (male or female), and "age category" (18-25 or 26-40) as fixed factors in order to determine significant differences between these aspects. Additionally, side (dominant or non-dominant), and position differences (floor x chair) were also examined for the USSPT using a linear mixed model by adding the fixed factors "side" and "position". The anthropometric data that were different across the subgroups were included in the model as covariates. For all variables, only the highest significant interaction-effect (or mean effect in absence of an interaction effect) was used in the model for interpreting the results.\(^{19}\) Sidak's post hoc test was used to make pairwise comparisons. Effect sizes were determined using partial eta-squared (\(\eta^2_p\)). Values of \(\eta^2_p > 0.01\) were defined as small, \(\eta^2_p > 0.06\) as medium, and \(\eta^2_p > 0.14\) as large. The test-retest reliability of the USSPT performed on the floor and on a chair was assessed using the Intraclass Correlation Coefficient (ICC) with a random two-way model, evaluation using the same examiner at different times (k = 2), and absolute agreement. ICC values below 0.50 were considered as poor reliability, between 0.51 and 0.75 moderate reliability, 0.76 and 0.90 good reliability, and above 0.91 excellent reliability.\(^{20}\) Standard error of measurement was calculated using the following formula: SEM = SD x \(\sqrt{1 - ICC}\) where SEM = Standard Error of Measurement; SD = Pooled Standard deviation of the variable; ICC = Intraclass Correlation Coefficient. Smallest Detectable Change was calculated as follows: SDC = SEM x \(1.96 \times \sqrt{2}\) where SDC = Smallest Detectable Change; SEM = Standard Error of Measurement. In addition, Bland-Altman Plots (BAPs) were used to verify the absolute agreement between assessments from the scatter plot between the difference of the two assessments and the average of the two evaluations. Bias and 95% limits of agreement were used to determine the accuracy of these measures. Also, a linear regression analysis was conducted to test the null hypothesis. Correlations between the USSPT performed on the floor and on a chair were assessed across the subgroups of the study using Pearson's Correlation Coefficient (r). Associations were classified as negligible (0.0 - 0.5), low (0.51 - 0.5), moderate (0.51 - 0.7), good (0.71 - 0.9), or excellent (0.91 - 1.0).\(^{21}\) A significance level of p < 0.05 was used.

RESULTS

The 44 participants (24=male versus 20=female) had a mean age of 25 (6.33) years, a body mass of 75.72 (16.51) kg, a height of 1.73 (0.07) m, and a Body Mass Index of 25.31 (4.78) kg/m². Based upon mean age, subjects were divided into two groups, 26 in the 18–25 year group and 18 in the 26–40 year old group. No significant effect of the interaction between sex and age was found for the anthropometric characteristics, however, an effect of sex was found for body mass (F = 6.59; p = 0.016), and height (F = 18.56; p < 0.001), with men presenting greater values. These comparisons presented medium to large effect sizes respectively (\(\eta^2_p = 0.158\); \(\eta^2_p = 0.315\)).
Figure 1. Upper Limb Seated Shot-Put Test.
A. Floor version, B. Chair version.

PERFORMANCE OF THE USSPT ON THE FLOOR AND ON A CHAIR

Due to the influence of body mass and height on the scores of the USSPT, these variables were considered in the final statistical models as covariates. An effect of the interaction between sex and position was found for the USSPT [F = 6.39; p = 0.012]. Post hoc testing showed that only female participants had a difference in the performance between the two positions with greater scores obtained when the test was performed on the chair (p<0.001). This comparison presented a medium effect size (η²p = 0.084). Also, males had a better performance than females on the USSPT-F (p<0.001) and USSPT-C (p<0.001). These comparisons presented large effect sizes respectively (η²p = 0.474; η²p = 0.326). Reference values for both positions according to gender, age, and dominance are provided (Table 1).

RELIABILITY AND MEASUREMENT ERROR OF THE USSPT PERFORMED ON THE FLOOR AND ON A CHAIR

Excellent test-retest reliability was found for the USSPT when performed on the floor for both limbs (ICC = 0.95 – 0.97), while excellent test-retest reliability was found for the test performed on the chair with the dominant limb (ICC = 0.97), and moderate reliability with the non-dominant limb (ICC = 0.74). In the USSPT-F, the SEM values ranged from 8 to 11 cm, and the SDC ranged from 23 to 30 cm, while in the USSPT-C, the SEM values ranged from 8 – 19 cm, and the SDC ranged from 22.53 to 52.49 cm (Table 2). In addition, according to the Bland-Altman Plots and the regression analysis performed, it is possible to observe the absence of systematic error between assessments (p > 0.05) for the USSPT-F (dominant – p = 0.731; non-dominant – p = 0.250), and for the USSPT-C (non-dominant – p = 0.443). Presence of systematic error was found for the USSPT-C for the dominant arm (p = 0.011) (Figure 2).
Correlation between the USSPT performed on the floor and on a chair.

Significant, positive good to excellent correlations were found between the USSPT performed on the floor and on a chair for both upper limbs according to gender and age categories pre-specified (all, $r > 0.70$; $p < 0.05$), except for the dominant limb in women 26 to 40 years old, where a positive, moderate, and non-significant relationship was found ($r = 0.614$; $p = 0.059$) (Table 3).

Discussion

Differences between the positions of execution of the USSPT were found only for the female participants, where a greater distance of throwing was found for the USSPT-C. One hypothesis for this difference could be the stabilization provided by the non-throwing limb positioned in the glenohumeral joint during the execution of the USSPT-C.

Excellent test-retest reliability was found for the USSPT-F with SEM and SDC values for the whole sample ranging from 8 - 11 cm and 23 - 30 cm respectively. Moderate to excellent test-retest reliability was found for the USSPT-C with SEM and SDC values ranging from 15 - 19 cm and 41 - 52 cm respectively. Presence of systematic error was found only for the USSPT-C dominant. The authors are unsure why this was the only test in which systematic error was detected.

Good to excellent correlations were found between USSPT-F and USSPT-C for both upper limbs. This correlation is expected due to the standard position of movement between the two versions of the test, testing the same movement construct. The non-dominant limb presented a lower reliability coefficient, which may be explained by the...
Figure 2. Bland-Altman Plot for the USSPT performed on the floor, and on a chair.

A. USSPT-C non-dominant limb; B. USSPT-F dominant limb; C. USSPT-C dominant limb; D. USSPT-F non-dominant limb. Straight line represents bias and dotted lines 95% limits of agreement. USSPT-F = Upper Seated Shot Put Test performed on the Floor; USSPT-C = Upper Seated Shot Put Test performed on the Chair; D = Dominant; ND = Non-Dominant.
fact that this limb would not the extremity of choice for the athlete to perform the shotput movement. Further, athletes may have less strength, coordination and control in the non-dominant limb explaining the higher variability during testing.

In relation to the performance in the USSPT-F, the current results were similar with those reported in studies that assessed healthy/physically active participants,\textsuperscript{15,16} and athletes from different sports.\textsuperscript{13,22} Lower scores were found compared to Division I collegiate athletes.\textsuperscript{10,12} In relation to the performance in the USSPT-C, in general, the current scores were greater (577.88 cm for USSPT-F) and (395.26 cm for USSPT-C) than those from a study performed with healthy active adults (92 inches = 223.00cm).\textsuperscript{11} Previous studies found correlations between strength tests and the performance tests such as the USSPT,\textsuperscript{16} which can be explained due to the overlap of some of the variables examined in the two forms of evaluations, including strength, power and speed. Thus, because of the current reliability findings, clinicians may have an option of an accessible and cheaper test than instrumented strength testing.\textsuperscript{15} It is expected that the performance in the USSPT is influenced by the population assessed, therefore, clinicians must be aware that the current study was performed with handball players.

Excellent test-retest reliability was found for the USSPT-F, while moderate to excellent test-retest reliability was found for the USSPT-C. These results corroborate with previous data that found good to excellent test-retest reliability 0.94 (0.88–0.97) for the USSPT-F,\textsuperscript{13} and excellent test-retest reliability 0.98 (0.97–0.99) for the USSPT-C\textsuperscript{11} in active/physically adults. In relation to SEM and MDC, Pinheiro et al.\textsuperscript{13} reported values of 16.27 cm and 45.11 cm for the USSPT-F, while Negrete et al.\textsuperscript{11} reported 17.78 – 20.32 cm and 43.18 – 45.72 cm for the USSPT-C. The current results were similar for both positions. It is recommended that clinicians use the mean of three repetitions with the rest time of one minute between them to get the most stable and accurate measure in the USSPT.\textsuperscript{15,22}

The current results showed good to excellent correlations between the USSPT-F and USSPT-C. In previous studies, performance in the USSPT-F presented strong correlation with shoulder flexor and elbow extensor strength,\textsuperscript{14–16} strong correlations with IR and ER isokinetic strength,\textsuperscript{8} and moderate to strong correlations with pushing force assessed through isokinetic dynamometry\textsuperscript{15} in active/physically adults. Also, the isometric strength of the serratus anterior was correlated with USSPT-F performance.\textsuperscript{14} Because shoulder muscle weakness may be a risk factor for overuse shoulder injuries\textsuperscript{5} and rotator cuff tendinopathy\textsuperscript{43} in overhead athletes, it is suggested that clinicians might consider the use of the USSPT-F and USSPT-C as an indirect measure of shoulder and elbow strength in this population. Future studies need to assess the direct correlation between the USSPT-C with isokinetic shoulder and elbow strength.

This is the first study to assess performance of the USSPT in different positions. Normative values according to sex, age and limb dominance, as well as test-retest reliability and measurement error for both positions in handball players are presented. Studies that present normative values and psychometric properties of the upper extremity physical performance tests in different populations are necessary.\textsuperscript{24} In this context, the current adds to the literature. The USSPT is a reliable tool to assess strength and power unilaterally in the absence of an isokinetic dynamometer\textsuperscript{15}; and because this test reproduces a similar position of the arm during sports movements, the authors recommend its implementation in the assessment of overhead athletes. The USSPT-F may be preferred considering the reliability values and the absence of systematic error found in both limbs. Further, the SEM and MDC values provided can be used to guide the rehabilitation programs.

The limitations of this study should be noted. All assessments were performed during the season, so, the results might be influenced by training. The sample consisted of healthy handball athletes; therefore, interpretation of the results regarding participants with shoulder pain or that practice other overhead sport (i.e. baseball, tennis, volleyball, badminton, basketball, and swimming) must be performed with caution. In the same way, interpretation of the results in relation to participants older than 40 years old is not recommended due to the mean age of the sample. Finally, the current sample size prevented some comparisons with other sports from being powered adequately. Future studies that present normative values of the USSPT in other overhead sports and those that investigate the ability of the test to predict shoulder injuries are necessary.

CONCLUSION

The results of the current study highlight differences in the performance of the USSPT according to the position of execution in women where greater scores were obtained in the USSPT-C. Excellent test-retest reliability was found for the USSPT-F, and moderate to excellent test-retest reliability was found for the USSPT-C. SEM and MDC were established. Presence of systematic error was found only in the USSPT-C for the dominant extremity. Good to excellent correlations were found between both positions.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

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Measuring the Average Peak Timing of Kinematic Variables in Youth and Adolescent Baseball Pitchers

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Keywords: pitcher, motion analysis, shoulder, elbow, adolescent, youth

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Background

Previous studies have examined the timing of peak kinematic variables during the pitching cycle in high school, collegiate, and professional pitchers. These same variables have been studied less in younger populations.

Purpose

To determine whether youth and adolescent baseball pitchers will experience peaks in certain kinematic variables at different times throughout the pitching cycle compared to professional/collegiate pitchers.

Study Design

Cross-sectional, descriptive study

Methods

Twenty-four participants were recruited for testing consisting of five recorded pitches using 3-Dimensional VICON® motion analysis system. The maximum values and timing of the peak kinematic variables were averaged across all trials using VICON Polygon® data analysis software. These values were recorded as percentages of the pitching cycle, defined from foot contact (0%) to ball release (100%). The following variables were examined: shoulder external rotation range of motion, shoulder internal rotation velocity, trunk rotation range of motion, trunk rotation velocity, pelvic rotation velocity, and stride length. Descriptive outcomes were calculated and results were compared to previous studies examining the same variables in collegiate and professional pitchers.

Results

Twenty-four male participants (mean age 12.75 years, SD ± 2.02) were included in the study. Mean and standard deviations were identified for peak kinematic variables of shoulder external rotation ROM (158.71°, ±9.32), shoulder internal rotation velocity (92.26 rad/sec, ±19.29), trunk rotation velocity (15.94 rad/sec, ±1.68), trunk rotation ROM (23.57°, ±8.14), and average stride length (81.97% height ±6.45). Additionally, mean and standard deviations of peak kinematic variables were expressed as percentages to reflect when they occurred in the pitching cycle and included trunk rotation ROM (8.45%, ±12.72), pelvic rotation velocity (33.26%, ±16.42), trunk rotation velocity (41.59%, ±9.27), shoulder external rotation ROM (71.54%, ±6.61), and shoulder internal rotation velocity (86.95%, ±6.45).
Conclusion

The sequential order of each variable was similar in youth and adolescents in comparison to collegiate and professional pitchers. However, the timing of each variable within the pitching cycle occurred approximately 10% earlier in the younger pitchers. The findings suggest differences in pitching mechanics exist between younger and more experienced populations.

Level of Evidence

Level 3

INTRODUCTION

Youth and high school sports have become increasingly competitive over recent years. Children are beginning to specialize in a specific sport at a younger age and often play year-round or even on concurrent teams. The repetitive nature of the motion of a baseball pitch in combination with the stress that the pitching motion places on the musculoskeletal system of a developing body put youth and adolescent baseball pitchers at risk for shoulder and elbow injury.\(^1,2\) Sports-related injuries in young baseball pitchers is a topic that is currently receiving significant attention in the sports medicine world due to the high prevalence of injuries.

The act of throwing an overhand baseball pitch is one of the fastest known motions a human being can produce.\(^3\) This complex movement pattern puts an incredible amount of stress on the human body and often leads to injury. Little League Baseball is the world’s largest organized youth sports program with three million children playing baseball in the USA.\(^4\) Due to the growing popularity of youth sports, like baseball, and the opportunity to participate in multiple leagues year-round, throwing related injuries continue to rise. Fleisig et al. identified that up to five percent of youth pitchers suffer a serious non-contact elbow or shoulder injury requiring surgery or retirement from baseball within ten years following the injury.\(^5\) Furthermore, up to 74% of youth baseball players between the ages of 8-18 report some degree of arm pain while throwing.\(^6\) Evidence has also demonstrated that the volume of pitches and amount of rest taken by athletes elevates the risk of injury. According to a study by Fortenbaugh et al., a pitcher who continues through fatigue was 56 times more likely to undergo surgery.\(^6\) To prevent a further increase in injuries to baseball pitchers, it is crucial to identify risk factors for injury.

An abundant amount of literature has examined the risk factors that predispose a high school, college, or professional baseball pitcher to injury. These risk factors include anthropometric measurements, biomechanical flaws seen during the pitching motion, or general overuse. For example, glenohumeral rotational range of motion (ROM) deficits, strength deficits, and height have all been identified as risk factors for injury.\(^2,5,7–10\) Biomechanics of pitching such as stride length, pelvic tilt, and arm slot influence the amount of force experienced by the upper extremity and can be predictive risk factors for injury.\(^11,12\) With more youth specializing in one sport and participating in multiple leagues year-round, overuse has also become a growing concern for injury risk. Previous authors have found that number of pitches thrown, throwing on consecutive days, playing in multiple leagues, and other positions played can put a youth pitcher at an increased risk for injury.\(^5,10,13–16\) For instance, an average of more than 80 pitches per game almost quadrupled the chance of surgery.\(^5\) In addition, pitching competitively for more than eight months per year increased the odds of surgery fivefold.\(^5\) The lack of recognition of an injury was identified as a risk factor for further injury as the initial injury may not have been managed appropriately.\(^17\) While pitching is a heavily researched topic, there is little to no research that has examined the link between each of these risk factors in the youth and adolescent populations.

While pitching mechanics are highly variable between youth and high school pitchers, variability of kinematic parameters decreases with an increase in the level of development.\(^6\) Aguinaldo et al. examined the segmental flow of energy during the pitching cycle in collegiate and professional pitchers.\(^18\) This study broke down the pitching cycle from initial lead foot contacting the ground (foot contact) to the moment the ball left the subject’s hand (ball release) and examined when peaks in certain kinematic variables occurred. The peak kinematic variables included trunk rotation velocity, trunk rotation ROM, pelvic rotational velocity, shoulder external rotation ROM, and shoulder internal rotation velocity. While studies have examined these values in high school, collegiate, and professional pitchers, no study has looked at these variables in a younger population.\(^18,19\) The purpose of the current study was to examine the average timing of peak kinematic variables in youth and adolescent baseball pitchers. The results were compared to previous studies examining the same variables in collegiate and professional pitchers.

It was hypothesized adolescent baseball pitchers would experience peaks in kinematic variables at different times throughout the pitching cycle as compared to professional/collegiate pitchers.

METHODS

This study was reviewed by Saint Francis University’s Institutional Review Board and was approved. Subject recruitment occurred through the researcher’s making appearances at local baseball practices and contacting local little leagues. Players were informed of the details of the study through a PowerPoint designed by the research team. Based on a statistical power analysis (GPower 3.1), 25 participants were needed as the minimum sample size for detecting a significant relationship between independent and
dependent variables at a power of 0.95 and an effect size of 0.80. After the recruitment of each subject, informed consent was obtained by the participant and their parent/guardian. Participants initially completed a questionnaire and if the subject was a minor the questionnaire was completed with a parent/guardian present. The questionnaire consisted of questions aimed to identify previously identified risk factors for injury in overhead athletes including pitching volume, pain or discomfort before or after pitching, playing in multiple leagues, positions played, history of previous injury, and types of pitches thrown. Demographic measurements were collected including height, weight, and hand dominance. Anthropometric measurements were taken before motion analysis testing.

The subjects completed approximately 10 minutes of a stretching routine of their choice to prepare for pitching. Reflective markers were placed on the bony landmarks of the subject for motion analysis (Figure 1) using a full body monitoring marker set. Upper extremity markers were placed on both arms on the acromion process, lateral epicondyle, upper arm between the elbow and shoulder, forearm between the elbow and wrist, radial styloid, ulnar styloid, and third metacarpal. Lower extremity markers included: anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), iliac crest, lateral aspect of the thigh between the iliac crest and lateral femoral condyles, lateral femoral condyles, lateral aspect of the tibia between the lateral femoral condyle and lateral malleolus, lateral malleolus, dorsum of foot at second metatarsal, and posterior aspect of the heel. Markers on the torso included C7 and T10 spinous process, sternoclavicular (SC) joint, xiphoid process, and the right scapula.

Once markers were in place, the subject’s anthropometric data was entered into the motion capture system. Next, the subject was allowed 20 pitches from a pitching mound to further their warm-up and allow them to adjust to the mound. Subjects wore their own sneakers and threw to a net with a strike zone target located 40 feet from the pitching rubber. After the player completed 20 pitches, the following five pitches were recorded using a VICON® motion capture system. The VICON® motion capture system used eight high-speed (120 Hz) cameras. Motion analysis is the reference standard for assessing joint angles during complex movements such as the baseball pitch and has been proven to be highly reliable and valid.20 The system captured the motion and angular velocities of various joints, including those of the pelvis, trunk, and upper extremity during the pitching motion. The subject’s arm slot position (shoulder abduction angle), shoulder maximal external rotation, and stride length were analyzed.9,21 Data were processed and the average of the five trials for each subject was calculated for each variable independently using VICON Polygon® data analysis software. Previous authors have suggested that ideal stride length is slightly less than body height, and this measurement was recorded as a percentage of the athlete’s body height.22,23

Following data collection, mean values and standard deviations were calculated across all tests and measures of the

Figure 1. Reflective marker placement for 3-dimensional motion analysis during pitching trials.

study to determine the prevalence of the risk factors among the participants.

RESULTS

Twenty-four participants participated in the study, average age being 12.75 years old (SD ± 2.02). Of the 24 total participants, 23 subjects were right-hand dominant, and one subject was left-hand dominant.

Table 1 displays the average maximum values and standard deviation for kinematic variables of the pitching cycle measured across the 24 subjects. Table 2 displays the mean and standard deviation of the peak kinematic variables related to the pitching cycle. These values are recorded as percentages of the pitching cycle, defined from foot contact (0%) to ball release (100%). The timing of each peak kinematic variable, as outlined in Table 2, were found to occur at distinct points in the pitching cycle. Figure 2 illustrates the timing of the mean of the maximum kinematic values as they occurred throughout the pitching cycle.

DISCUSSION

The proper segmental flow of energy throughout the body is vital during the baseball pitch. When energy is not being transferred through the body appropriately, it decreases the mechanical efficiency of the pitch and increases the risk of
injury. Previous investigators have examined the segmental flow of energy and its relation to elbow torque during the baseball pitch in collegiate and professional baseball pitchers. One study to date has analyzed this in high school baseball pitchers. There were significant differences between the professional and high school groups in the timing of the following variables in relationship to the pitching cycle: maximum pelvis rotation velocity (42.9% vs. 27.9%, respectively), maximum trunk rotation (33% vs. 2%, respectively), and maximum shoulder internal rotation velocity (102.4% vs. 95.0%, respectively).

Compared to the data referenced in the previous paragraph, the results of this study indicate that youth pitchers experienced peaks in certain kinematic variables approximately 10% earlier in the pitching cycle compared to collegiate and professional pitchers. While it cannot be confirmed why this difference in peak variables occurred earlier in the subjects in the current study, the findings also demonstrated a shorter stride length as a percentage of height as compared to collegiate/professional pitchers. The decrease in stride length may account for the difference in timing. The shorter stride length would cause the stride foot to contact the mound earlier in the pitching delivery, likely initiating the transfer of energy through the pelvis, trunk, and throwing shoulder earlier in the pitching cycle and potentially influencing the efficiency of energy transfer during pitch delivery.

In the current study the average stride length was 81.9% of the participant’s height. According to previous studies, normative data for stride length in youth pitchers is variable. Fry et al. examined ninety-two 9-14 year-old pitchers and found the average stride length 66% of height. However, another study by van Trigt et al. examined 52 pitchers ages 10-18 had an average stride length of 79.8%. Although not defined by age, the American Sports Medicine Institute also reported that a pitcher’s stride length should be slightly less than the height of the pitcher. Montgomery and Knudson found that the optimal average stride length of six professional pitchers was 85-90% of their height in order to increase pitching speed. The norms of stride length in youth baseball pitchers have not been well established, therefore, normative values for professional pitchers, as reported by Montgomery and Knudson, were used for comparison to the current subjects.

Maximum pelvis rotation velocity occurred slightly before maximal trunk rotation velocity, followed by maximal shoulder internal rotational velocity. The results confirm that energy is being transferred from the ground through the arm through a specific kinematic sequence. These results closely resemble the results found in the collegiate and professional baseball pitchers researched by Aguinaldo and Escamilla. While these events closely resemble the collegiate and professional pitcher, the timing of these events occurred consistently earlier throughout the pitching cycle in youth and adolescent subjects. Additionally, previous studies have demonstrated that lower body mechanics have an influence on the forces experienced by the upper body. The notion that professionals can throw harder while minimizing the amount of valgus torque they experienced at the elbow suggests that the younger pitchers have some form of biomechanical flaw in their mechanics. The alteration in biomechanics could potentially be explained by a shortened stride length, decreased strength, skeletal immaturity, or limited pitching experience.

There are some limitations of this study. One limitation is the rural location where data collection occurred leading to a small sample size. The small sample size limits the generalizability of the study as these results may not represent the overall population of youth pitchers. A second limitation is that the study took place in a laboratory environ-
Figure 2. Timing of specific events expressed as a percentage of the pitching cycle, 0% and 100% corresponding to front foot contact (FC) and ball release (BR), respectively.
ment. Since the VICON® motion analysis system has fixed cameras, the data collection for this study was restricted to the confines of the Human Performance Lab which could not accommodate the standard pitching distance for youth and adolescent pitchers. The final limitation of this study would be the inability of the motion analysis system to assess torque throughout the pitching motion. While this study could measure the average peak timing of kinematic variables, torque was not measured due to the capability of the motion analysis system. There is evidence that the elbow generates more torque when the proper segmental flow of energy is interrupted or due to poor body sequential motion.\(^\text{19}\) Elbow valgus loading and torque are variables that could be used in future studies to correctly identify risk factors throughout the pitching motion in this population.

One significant strength of the current research was the age range that was targeted; 9-16-year-old baseball pitchers. The mean age of participants in the current study was 12.75 years old (SD = 2.02) while the mean ages of pitchers previously studied by Aguinaldo and Escamilla were 21.9 years old (SD = 3.6) for professional pitchers and 15.5 years old (SD = 1.1) for high school pitchers.\(^\text{19}\) According to the literature review, this younger age range is a heavily under-investigated group. Yet, this is the age range where most injuries occur.\(^\text{2,20,27,28}\) There is certainly more opportunity for future research to be conducted on this topic. Future research should attempt to recruit a larger sample size with subjects from a larger geographic region. Also, future research is needed to definitively identify why the timing in peak kinematic variables occurred earlier in youth pitchers. This study obtained when the peaks occurred but could not conclude, with certainty, why the peaks happened earlier in the pitching cycle for youth subjects.

**CONCLUSION**

The results of this study identified that youth pitchers experienced peaks in certain kinematic variables approximately 10% earlier in the pitching cycle compared to data from prior research on collegiate and professional pitchers. Future studies are needed to identify the link between stride length and its effect on the kinematic sequence of the baseball pitch. Because the baseball pitch is a very complex motion that requires a combination of flexibility, strength, and motor control, future studies are needed to identify variables that may be linked to the observed differences between youth and collegiate/professional pitchers. This could give direction to future training protocol development for youth pitchers to minimize injury risk and maximize performance during key developmental years.

**CONFLICTS OF INTEREST**

The authors of this study declare no conflicts of interest.

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Original Research

Effect of Scapular Retraction on Lower Trapezius, Infraspinatus, and Deltoid Muscle Electromyographic Activity During the Side-Lying Abduction Exercise

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Keywords: electromyography, lower trapezius, side-lying abduction exercise, scapular retraction

Background
The lower trapezius (LT) muscle, which stabilizes the scapula posteriorly during arm elevation, has been interesting to both clinicians and researchers for its importance in throwing-related shoulder rehabilitation and injury prevention.

Purpose
The purpose of this study was to investigate the electromyographic activity of the LT and other relevant muscles during scapular and shoulder activities in the side-lying position.

Methods
Twenty collegiate baseball players volunteered to participate in this study. Electromyographic (EMG) output of the lower trapezius, infraspinatus, posterior deltoid, middle deltoid, serratus anterior, and upper trapezius muscles were collected. All the subjects performed isometric resistance exercises in four arm positions: 0° horizontal abduction from the coronal plane (NEUT) with protraction (NEUT-PRO), 15° horizontal adduction from the coronal plane (HADD) with protraction (HADD-PRO), and NEUT with retraction (NEUT-RET), and HADD-RET in a side-lying isometric abduction exercise with two external loads: a 9.1 kg dumbbell and 40% of the manual muscle test (MMT). The subjects also performed two more isometric resistance exercises: supine protraction and side-lying external rotation (ER) of the glenohumeral (GH) joint in GH adduction at 90° of GH ER or with as much ER as possible. All raw EMG data were normalized to maximal voluntary isometric contraction (% MVIC) of the corresponding muscle.

Results
LT activity was significantly greater in HADD-RET with 9.1 kg than that of HADD-PRO (p < 0.001) (55 vs 21% MVIC) while middle deltoid muscle activity was significantly decreased in both NEUT and HADD-RET compared to that of NEUT and HADD-PRO (p < 0.001). In contrast, IS muscle activity was significantly increased in HADD-RET with 9.1 kg compared with that 40% MMT (p < 0.001) (41 vs 22% MVIC).

Conclusion
LT activity was modulated by changes in scapulothoracic and glenohumeral joint positioning during a side-lying isometric abduction exercise. These findings may help clinicians to select exercises to improve scapular muscle balance ratios during rehabilitation of the shoulder complex.

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INTRODUCTION

The lower trapezius (LT) muscle plays a critical role in stabilizing the scapula while it assists in the upward rotation of the scapula as part of a force couple. Of particular importance is the activity of the LT muscle which serves to maintain the width of the subacromial space during arm elevation through posterior tilting of the scapula.\(^1,2\) Conversely, altered activity ratio of the upper trapezius (UT) and LT muscle, such as hyperactivity of the UT muscle, can lead to scapular dyskinesis, which may be associated with symptomatic shoulders.\(^1,2\) For instance, patients with subacromial pain syndrome showed significantly higher ratios of UT to LT muscle activity in both the ascending and descending phase of arm elevation in the scapular plane, compared with asymptomatic individuals.\(^3\) A college baseball pitcher with shoulder symptoms after arthroscopic labral surgery abruptly increased the ratio of UT to LT muscle activity on the throwing arm during the weighted scapular dyskinesis test, compared with the non-throwing arm side.\(^4\)

For healthy college and professional pitchers, the highest LT muscle activity has been reported during the acceleration and deceleration phases of the throwing motion.\(^5\) These findings can be associated with one of thrower’s adaptations where LT muscle activity was significantly greater on their dominant side than their nondominant side in both elevation and descent movements, and UT muscle activity was significantly less on their dominant side than their nondominant side.\(^6\) Consequently, the ratio of UT to LT muscle activity can be monitored not only for identification of a factor contributing to symptomatic shoulders, but also to provide objective guidance for shoulder exercise progression especially for overhead athletes.\(^7,8\)

Several previous studies have investigated UT and LT muscle electromyography (EMG) activities in a variety of exercises and postural positions.\(^9\)–\(^15\) Cools et al\(^11\) found of the 12 common shoulder rehabilitation exercises, prone shoulder abduction, side-lying forward flexion, and prone horizontal abduction with external rotation (ER), activated the LT muscle up to 80% maximal voluntary isometric contraction (MVIC) while minimizing UT muscle activity to less than 50% MVIC. The UT/LT ratio in the prone horizontal abduction (HABD) with ER exercise was also confirmed by a recent study, which was less than 0.4.\(^9\) Additional studies suggest that the prone horizontal abduction exercise at 120° of shoulder abduction effectively activates the LT muscle due to the alignment of the LT muscle fibers.\(^16,17\)

However, clinicians need to be aware of prone horizontal abduction exercises with the shoulder abducted to 120° or even 90° may increase UT muscle activity to more than 70% MVIC when the scapula is retracted,\(^18\) which is not desired to improve scapular force coupling. In contrast, the prone horizontal abduction exercise can minimize UT muscle activity in the scapular plane without scapular retraction, leading to the UT/LT ratio less than 0.9.\(^13\) Thus, scapular position needs to be considered during prone abduction exercises to minimize UT muscle activity while emphasizing LT muscle activity.

Exercise intensity is another important consideration during shoulder exercises because it may affect glenohumeral external rotator muscle activity.\(^19,20\) LT activity has been correlated with external rotator muscle activity during both shoulder and scapular exercises while UT muscle activity has been correlated with middle deltoid (MD) muscle activity in the coronal plane.\(^15,21,22\) Furthermore, the hyperactivity of the MD can cause superior migration of the humeral head, leading to a decrease in subacromial space width especially during shoulder abduction.\(^19,23\) Therefore, exercise intensity must be controlled during the performance of shoulder rehabilitation exercise from the perspective of deltoid muscle activity especially for overhead athletes who need to improve scapular muscle balance ratios.\(^5,13–15,17\)

Few studies have investigated LT muscle activity with respect to scapular protraction and retraction during side-lying shoulder abduction exercise, in which the patient is required to stabilize glenohumeral joint (GHJ) and the straight arm against gravity. Therefore, the purpose of this study was to investigate the electromyographic activity of the LT and other relevant muscles during scapular and shoulder activities in the side-lying position.

The authors of this study hypothesized that the side-lying position with the shoulder abducted to 90° with the scapula retracted would minimize MD activity, whereas the same arm position with scapular protraction would increase MD activity.

METHODS

PARTICIPANTS

Collegiate baseball players were recruited for the purpose of this study. This study obtained institutional review board approval prior to the start of study. All participants read and signed the informed consent confirming their voluntary participation. All subjects were asymptomatic, competitive baseball players without neurologic or physiologic deficits in the upper body according to the completion of a preliminary screening questionnaire. All tests were conducted in the Kinesiology Laboratory at San Jose State University.

PROCEDURES

EMG outputs of the lower trapezius (LT), upper trapezius (UT), infraspinatus (IS), posterior deltoid (PD), anterior deltoid (AD), and serratus anterior (SA) on the dominant side were collected. Bipolar surface silver (Ag) EMG electrodes with a bar length of 10mm, width of 1mm, and a distance of 1cm between active recording sites (Delsys Bagnoli-8, Delsys inc, Natick, MA) were used. Electrodes were placed on the center of the muscle belly in line with the muscle fibers for the specific manual muscle test (MMT). The elec-
trode for the LT was placed obliquely between the intersection of the scapular spine and the scapular inferior angle outside the medial border at the level of seventh thoracic spine.\textsuperscript{24,25} For the IS muscle, the electrode was placed 4 cm inferior and parallel to the scapular spine over the infrascapular fossa.\textsuperscript{19} For the PD muscle, the electrode was placed in an oblique direction parallel to the muscle fibers of the deltoid muscles at the lateral border of the scapular spine\textsuperscript{19,24}; while the electrode was placed halfway between the tip of acromion and the deltoid tubercle for the MD muscle.\textsuperscript{19} For the SA muscle, the electrode was placed below the axilla between the latissimus dorsi and pectoralis major at the level of the scapular inferior angle,\textsuperscript{24,25} while the electrode was placed halfway between the C7 spinal process and the acromion process for the UT muscle.\textsuperscript{24,25}

Once the electrodes were secured, all the subjects performed a 4-second maximum voluntary isometric contraction (MVIC) after ramp-up contraction for each muscle using the MMT procedures for normalization of EMG data. The manual pressure was applied by the same examiner for all testing positions to determine each of the MVICs. For the MVICs of UT and MD muscles, the subjects resisted downward pressure applied on the arm with the shoulder abducted to 90° with the elbow flexed in the standing position.\textsuperscript{24,25} For the MVICs of LT and PD muscles, the subjects abducted their arm to 90° with the shoulder horizontally abducted in the prone position.\textsuperscript{24} The subjects resisted downward pressure applied on the distal portion of the forearm in the coronal plane while they lifted the arm barely off the table. For the MVIC of the IS muscle, the subjects resisted manual pressure applied toward internal rotation of the shoulder with the elbow flexed to 90° and the shoulder adducted with a towel held under the arm in the seated position.\textsuperscript{19} For the MVIC of the SA muscle the subjects protracted the scapula with the shoulder flexed to 90° and the elbow straight in the supine position while resisting manual pressure applied toward retraction of the scapula or down the arm, known as the "supine serratus punch." The amount of maximum force (N) was determined with a handheld dynamometer (MicroFET, Hoggan Scientific, LLC, Salt Lake City, UT) for each subject prior to performance of the intervention exercises simultaneously when the examiner measured the MVICs of LT and IS muscle activity during the MMT.

All the subjects performed isometric contraction exercises at 90° of shoulder abduction with the elbow straight in a side-lying position for EMG data collection with two different scapula positions: protraction (PRO) and retraction (RET), and two different HADD positions: 0° horizontally adducted from the coronal plane (NEUT) and 15° horizontally adducted from the coronal plane (HADD). The subjects were asked to extend the arm as much as possible for the PRO testing condition while for the RET testing condition the subjects were asked to pull their scapula down toward their spine. The subjects were asked to minimize any sway of the arm against gravity in the NEUT position, while for the HADD position, the subjects were asked to hold the arm 15° inward from the NEUT position (Figure 1). Finally, all subjects performed the supine serratus punch and side-lying external rotation (ER) of the GHJ in shoulder adduction with a towel under the arm at 90° of shoulder ER or with as much ER as possible (Figure 2).

All of the subjects were asked to perform the isometric exercises under two kinds of external loads: a 9.1 kg (20 lb) dumbbell and 40% of the corresponding MVIC discerned during the MMT. The amount of external weight (9.1 kg) was determined from clinical practices in which overhead athletes were often instructed to specifically activate the SA muscle in supine as if performing scapular punch exercise. The amount of external load (40% MMT) was selected based on the protocol of the previous studies.\textsuperscript{19–22} For 40% MMT, the subjects were asked to match the external load pressure given just above the posterior distal portion of the forearm as a manual isometric resistance. The direction of resistance application with the handheld dynamometer was in the direction of HADD. Each subject performed the isometric resistance exercises in random order for three trials in each of the four positions (NEUT-PRO, NEUT-RET, HADD-PRO, and HADD-RET). The subjects held each of the arm positions for 10 seconds in each of the two different external loads. Additionally, the subjects performed the supine serratus punch with the 9.1 kg dumbbell and side-lying ER exercise with 40% MMT for 10 seconds for three trials each. The subjects had a10-second rest period after each of the trials while a 30-second rest period was given between different arm positions to minimize the effect of fatigue. The thumb on the tested side was pointing toward the head for all the procedures.

**DATA ANALYSIS**

The EMG electrodes were pre-amplified (X 10) and routed through the EMG mainframe, which further amplified (X 100), and band-pass filtered (20–450 Hz) the signals. The EMG activities were then collected using a data collection program (MP 150 Data Acquisition System; Biopac System, Inc, Goleta, CA) with a sample rate of 1000 Hz; all data were recorded and stored in a computer for off-line analysis. The mean EMG activity of the middle two seconds of each four-second MVIC testing was calculated to determine the individual’s MVIC. For the exercises, the mean EMG activity of the middle five seconds of each 10-second intervention exercise was calculated. All data were calculated in root-mean-square (RMS) values, normalized to MVIC of the corresponding muscle, and presented as a percentage of MVIC (% MVIC). UT/LT ratios were calculated for each of the individual three trials in each of the eight exercise conditions.

A 2 x 2 x 2 (external loads x scapular positions x shoulder positions) repeated-measures analysis of variance (ANOVA) was used to identify any difference in the mean values of normalized EMG muscle activity. This three-way counterbalanced repeated-measures ANOVA analysis was also used to identify a difference in the mean ratios of UT to LT normalized EMG muscle activity. In addition, a one-way repeated measures ANOVA was used to identify a difference in the mean values of IS normalized EMG muscle activity across two different GHJ positions (NEUT, HADD) in the scapular retraction position (RET), and ER in response to isometric contraction with 40% MMT as well as the mean.

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values of SA normalized EMG muscle activity between the supine and side-lying position with the 9.1 kg dumbbell in NEUT and HADD in the scapular protraction position (PRO). Where appropriate, a post hoc test with Tukey’s honestly significant difference (HSD) was used to measure any significant difference between the three different arm positions. The significance level was set at $\alpha = 0.05$. Additionally, the effect size of omega square ($\omega^2$) was calculated to estimate the amount of variance.
RESULTS

Twenty collegiate baseball players, including 10 pitchers, belonging to the National Collegiate Athletic Association Division I conference (height: 185.3 ± 5.1 cm, mass: 90.7 ± 12.6 kg, age: 20.1 ± 1.8 years) participated in this study. The mean force values produced in the prone HADD at 90° ABD arm position and the seated ER at 0° ABD arm position were 119.8 (+/- 16.0) N or 12.2 (+/- 1.6) kg and 69.8 (+/- 11.2) N or 7.1 (+/- 1.1) kg, respectively. Subsequently, the mean value used for 40% MMT load that the subjects were asked to match was 47.9 N or 4.9 kg for the HADD resistance exercise regardless of the shoulder and scapular positions and 27.9 N or 2.8 kg for the IR resistance exercise.

Mean values, 95% confidence intervals, and intraclass correlation coefficients (ICCs) (3, 1) for each of the six EMG activities (% MVIC) are presented in Table 1. The mean of the ICCs (3, 1) in the four different arm positions with the two different weight loads was 0.86.

LOWER TRAPEZIUS

COMPARISON BETWEEN 9.1 KG AND 40% MMT

A significant 3-way interaction in the mean values of IS EMG activity was found between the two different external load exercises by the two scapular positions and two shoulder positions was found [F (1, 19) = 5.60, p = 0.029, $\omega^2 = 0.18$. Specifically, the mean value was significantly greater with 40% MMT in PRO for NEUT than that of 9.1 kg (p < 0.001) (16 vs 5% MVIC, respectively), whereas no significant difference was observed between the two different external load exercises in PRO for HADD (p = 0.328). Likewise, the mean LT value was significantly greater with 40% MMT in RET for NEUT than that of 9.1 kg (p < 0.001) (38 vs 24% MVIC, respectively). Conversely, the mean value was significantly greater with 9.1 kg in RET for HADD than that of 40% MMT (p < 0.001) (55 vs 45% MVIC, respectively). (Figure 3)

COMPARISON BETWEEN RETRACTION AND PROTRACTION

The mean values of LT EMG activity were significantly greater in RET with 9.1 kg than those of PRO for both NEUT and HADD (p < 0.001) (24 vs 5% MVIC for NEUT); (p < 0.001) (55 vs 21% MVIC for HADD). Likewise, the mean values were significantly greater in RET with 40% MMT than those of PRO for both NEUT and HADD (p < 0.001) (38 vs 16% MVIC for NEUT) (p < 0.001) (45 vs 18% MVIC for HADD). (Figure 3)

COMPARISON BETWEEN NEUT AND HADD POSITIONS

The mean values were significantly greater for HADD with 9.1 kg than those of NEUT in both PRO and RET (p < 0.001) (21 vs 5% MVIC for PRO) (p < 0.001) (55 vs 24% MVIC for RET). In contrast, no significant difference was observed between NEUT and HADD with 40% MMT in both PRO and RET (p = 0.532 and 0.063, respectively). (Figure 3)

INFRASPINATUS

COMPARISON BETWEEN 9.1 KG AND 40% MMT

A significant 3-way interaction in the mean values of IS EMG activity was found between the two different external load exercises by the two scapular positions and two shoulder positions [F (1, 19) = 9.57, p = 0.006, $\omega^2 = 0.29$. Specifically, the mean values were significantly greater with 9.1 kg for HADD than those of 40% MMT in both PRO and RET (p < 0.001) (33 vs 23% MVIC, respectively); (p < 0.001) (41 vs 22% MVIC, respectively), whereas no significant difference was observed between the two different external load exercises for NEUT in both PRO and RET (p = 0.07 and 0.10, respectively). (Figure 4)

COMPARISON BETWEEN RETRACTION AND PROTRACTION

The mean value of IS EMG activity was significantly greater in RET with 9.1 kg for HADD than that of PRO (p < 0.001) (41 vs 33% MVIC, respectively), whereas no significant difference was observed between RET and PRO with 9.1 kg for NEUT (p = 0.22). No significant difference was observed between RET and PRO with 40% MMT for both NEUT and HADD (p = 0.64 and 0.16, respectively). (Figure 4)
Table 1. Mean Raw EMG Values and Intraclass Correlation Coefficients during the Side-lying Abduction Exercise.

Normalized EMG values are reported as Mean (SD).

<table>
<thead>
<tr>
<th></th>
<th>9.1 KG</th>
<th></th>
<th>40% MMT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PRO</td>
<td>RET</td>
<td>PRO</td>
</tr>
<tr>
<td></td>
<td>NEUT</td>
<td>HADD</td>
<td>NEUT</td>
</tr>
<tr>
<td>LOWER TRAPEZIUS</td>
<td>5 (3.7)</td>
<td>21 (15.27)</td>
<td>24 (20.29)</td>
</tr>
<tr>
<td>ICC (3, 1)</td>
<td>0.91</td>
<td>0.94</td>
<td>0.89</td>
</tr>
<tr>
<td>INFRASPINATUS</td>
<td>16 (12.19)</td>
<td>33 (26.40)</td>
<td>13 (11.15)</td>
</tr>
<tr>
<td>ICC (3, 1)</td>
<td>0.72</td>
<td>0.86</td>
<td>0.75</td>
</tr>
<tr>
<td>POSTERIOR DELTOID</td>
<td>17 (14.20)</td>
<td>50 (42.58)</td>
<td>8 (6.11)</td>
</tr>
<tr>
<td>ICC (3, 1)</td>
<td>0.68</td>
<td>0.76</td>
<td>0.82</td>
</tr>
<tr>
<td>MIDDLE DELTOID</td>
<td>26 (21.31)</td>
<td>49 (42.56)</td>
<td>14 (11.17)</td>
</tr>
<tr>
<td>ICC (3, 1)</td>
<td>0.86</td>
<td>0.83</td>
<td>0.74</td>
</tr>
<tr>
<td>UPPER TRAPEZIUS</td>
<td>3 (2.4)</td>
<td>6 (3.8)</td>
<td>11 (5.16)</td>
</tr>
<tr>
<td>ICC (3, 1)</td>
<td>0.95</td>
<td>0.95</td>
<td>0.88</td>
</tr>
<tr>
<td>SERRATUS ANTERIOR</td>
<td>10 (6.14)</td>
<td>7 (5.9)</td>
<td>9 (7.11)</td>
</tr>
<tr>
<td>ICC (3, 1)</td>
<td>0.90</td>
<td>0.84</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Figure 3. Mean Values of Lower Trapezius Muscle Activity expressed as % of maximum voluntary isometric contraction (% MVIC)

Figure 4. Mean Values of Infraspinatus Muscle Activity, expressed as percentage of the maximum voluntary isometric contraction (% MVIC).

COMPARISON BETWEEN NEUT AND HADD POSITIONS

The mean values were significantly greater for HADD with 9.1 kg than those of NEUT in both PRO and RET (p < 0.001) (33 vs 16% MVIC for PRO) (p < 0.001) (41 vs 13% MVIC for RET). Likewise, the mean value was significantly greater for HADD in RET with 40% MMT than that of NEUT (p = 0.035) (22 vs 17% MVIC), whereas no significant difference was observed between NEUT and HADD in PRO with 40% MMT (p = 0.243). (Figure 4)

POSTERIOR DELTOID

COMPARISON BETWEEN 9.1 KG AND 40% MMT

A significant 3-way interaction was found in the mean values of PD EMG activity between the two different external load exercises by the two scapular positions and two shoulder positions [F (1, 19) = 4.86, p = 0.006, $\omega^2 = 0.16$. Specifically, the mean values were significantly greater with 40% MMT for NEUT than those of 9.1 kg in both PRO and RET (p < 0.001) (38 vs 17% MVIC for PRO, respectively) (p = 0.035) (20 vs 8% MVIC for RET, respectively). In contrast, the mean values were significantly greater with 9.1 kg for HADD than those of 40% MMT in both PRO and RET (p < 0.001) (50 vs 44% MVIC for PRO, respectively); (p = 0.019) (28 vs 21% MVI for RET, respectively). (Figure 5)
Figure 5. Mean Values of Posterior Deltoid Muscle Activity, reported as percentage of maximum voluntary isometric contraction (% MVIC)

PRO= protraction, RET= retraction, 40% MMT-PRO= 40% of manual muscle test load, shoulder retracted, 40% MMT-RET= 40% of manual muscle test load, shoulder retracted, NEUT= neutral position, HADD= horizontal adduction position

**COMPARISON BETWEEN RETRACTION AND PROTRACTION**

The mean values of PD EMG activity were significantly greater in PRO with 9.1 kg than those of RET for both NEUT and HADD (p = 0.010) (17 vs 8% MVIC for NEUT, respectively); (p < 0.001) (50 vs 28% MVIC for HADD, respectively). Likewise, the mean values were significantly greater in PRO with 40% MMT than those of RET for both NEUT and HADD (P < 0.001) (58 vs 20% MVIC for NEUT, respectively) (p < 0.001) (44 vs 21% MVIC for HADD, respectively). (Figure 5)

**COMPARISON BETWEEN NEUT AND HADD POSITIONS**

The mean values were significantly greater for HADD with 9.1 kg than those of NEUT for both PRO and RET (p < 0.001) (50 vs 17% MVIC for PRO); (p < 0.001) (28 vs 8% MVIC for RET). In contrast, no significant difference was observed between NEUT and HADD in 40% MMT for both PRO and RET (p = 0.068 and 0.822, respectively). (Figure 5)

**MIDDLE DELTOID**

**COMPARISON BETWEEN 9.1 KG AND 40% MMT**

No significant interaction in the mean values of MD EMG activity between the two different external load exercises by the two scapular positions and two shoulder positions was found (p = 0.378). However, there was a 2-way interaction in the mean values between the two different external load exercises by two shoulder positions [F (1, 19) = 62.8, p < 0.001, η² = 0.75]. Specifically, the marginal mean value was significantly greater with 40% MTT for NEUT than that of 9.1 kg regardless of the scapular positions (p < 0.001) (33 vs 20% MVIC for NEUT, respectively) whereas the marginal mean value was significantly greater with 9.1 kg for HADD than that of 40% MTT (p = 0.015) (38 vs 34% MVIC for HADD, respectively). The marginal mean value was significantly greater for HADD with 9.1 kg than that of NEUT regardless of the scapular positions (p < 0.001) (38 vs 20% MVIC, respectively) whereas no significant difference between the two exercises for HADD with 40% MMT (p = 0.069). (Figure 6a)

**Figure 6a. Marginal Mean Values of Middle Deltoid Muscle Activity with Comparison between 9.1 kg and 40% MMT, expressed as percentage of the maximum voluntary isometric contraction (% MVIC)**

NEUT= neutral position, HADD= horizontal adduction position

The glenohumeral joint was no (0°) horizontally adducted from the coronal plane (NEUT) and 15° horizontally abducted from the coronal plane (HADD) during side-lying isometric contraction while the scapula was protracted (PRO) and retracted (RET). Each of the electromyographic (EMG) activities was normalized to maximum voluntary isometric contraction (MVIC) of the corresponding muscle and presented as a percentage of MVIC (% MVIC) in the vertical axis.

**SIDE- LYING EXTERNAL ROTATION**

Mean values, standard deviations, and the ICCs (3, 1) of each of the six muscle activities are presented during side-lying ER with the elbow flexed to 90° in Table 2. Specifi-
cally, the mean value of the IS muscle activity was significantly greater in side-lying ER with the elbow flexed to 90° with 40% MMT than that of both NEUT and HADD in the RET (Tukey’s HSD (DTukey) = 5.5%, p < 0.05) (44, 17, and 22% MVC, respectively).

SUPINE PROTRATION

Mean values, standard deviations, and the ICCs (3, 1) of each of the six muscle activities are presented during supine PRO in Table 2. Specifically, the mean value of the SA muscle activity was significantly greater in supine PRO with 9.1 kg than that of both NEUT and HADD in the PRO (DTukey = 4.2%, p < 0.05) (59, 10, and 7% MVC, respectively).

Mean values, standard deviations, and the ICCs (3, 1) of each of the six muscle activities are presented during supine PRO in Table 2. Specifically, the mean value of the SA muscle activity was significantly greater in supine PRO with 9.1 kg than that of both NEUT and HADD in the PRO (DTukey = 4.2%, p < 0.05) (59, 10, and 7% MVC, respectively).

RATIO OF UPPER TO LOWER TRAPEZIUS

A significant 3-way interaction was found in the mean values of the UT/LT ratio between the two different external load exercises by the two scapular positions and two shoulder positions [F (1, 19) = 5.94, p = 0.025, η² = 0.14]. Specifically, the mean UT/LT ratio was significantly greater with 9.1 kg for NEUT than that of 40% MMT in PRO (p = 0.015) (1.01 vs 0.50, respectively) (p = 0.015). Also, the mean ratio was significantly greater in PRO with 9.1 kg for NEUT than that of RET (p < 0.001) (1.01 vs 0.50, respectively). Likewise, the mean UT/LT ratios were significantly greater for NEUT in 9.1 kg than those of HADD for both PRO and RET (p < 0.001) (1.01 vs 0.32 for PRO, respectively) (p < 0.04) (0.50 vs 0.25 for RET, respectively). (Figure 7)

DISCUSSION

The results of this study supported the primary hypothesis in which the side-lying position with the shoulder abducted to 90° with the scapula retracted significantly minimized deltoid muscle activity (up to 27% MVC), which in turn significantly increased LT activity with the shoulder horizontally abducted 15° from the coronal plane (55% MVC with the 9.1 kg dumbbell). This side-lying arm position exercise minimized MD activity by almost half of the amount of MD activity performed in standing horizontal abduction exercise at 120° ABD with an elastic resistive band while it activated the LT more than that of the standing exercise.14 The LT plays a critical role in maintaining the posterior tilt and external rotation of the scapula during the late cocking phase of the throwing or serving motion. Conversely, excessive activity of the MD decreases the subacromial space width as a result of superiorly directed humeral head translation relative to the glenoid fossa.19,23 In summary, side-lying isometric shoulder abduction exercise with scapular retraction can substantially activate the LT muscle in the position of shoulder horizontal adduction while compensatory activity of the MD muscle can be minimized.

The UT/LT ratios calculated in this study were significantly lower in the side-lying scapular retraction position with the dumbbell weight of 9.1 kg, compared to the scapular protraction position. These UT/LT ratios were similar to the ratios seen during performance of prone ER in 90° of shoulder abduction and side-lying ER with a weight of 1 kg in hand during isotonic exercise without the instruction for active scapular retraction.27 It was presumed that for the side-lying position the gravitational force assisted with the placement of the scapula toward the spine. The scapular position in turn minimized the activity of the rhomboid muscles, which could be co-contrasted with the UT muscle when the scapula was retracted.10 Subsequently, the findings of this study show the side-lying abduction exercise

Table 2. Mean Values, 95% Confidence Intervals in Parentheses ( ), and Intraclass Correlation Coefficients (ICCs) (3, 1) during Supine Protraction

<table>
<thead>
<tr>
<th>% MVC</th>
<th>UT</th>
<th>LT</th>
<th>SA</th>
<th>MD</th>
<th>PD</th>
<th>IS</th>
</tr>
</thead>
<tbody>
<tr>
<td>90° Elbow Flexion ER</td>
<td>5 (5)</td>
<td>34 (16)</td>
<td>5 (4)</td>
<td>7 (4)</td>
<td>12 (8)</td>
<td>44 (11)</td>
</tr>
<tr>
<td>ICC (3, 1)</td>
<td>0.93</td>
<td>0.88</td>
<td>0.95</td>
<td>0.85</td>
<td>0.93</td>
<td>0.88</td>
</tr>
<tr>
<td>Supine Protraction</td>
<td>4 (3)</td>
<td>3 (3)</td>
<td>39 (10)</td>
<td>20 (9)</td>
<td>8 (5)</td>
<td>25 (11)</td>
</tr>
<tr>
<td>ICC (3, 1)</td>
<td>0.97</td>
<td>0.84</td>
<td>0.93</td>
<td>0.85</td>
<td>0.72</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Figure 7. Ratio of Upper Trapezius (UT) to Lower Trapezius (LT) Muscle Activity

PRO= protraction, RET= retraction, UT/LT ratio= ratio of UT to LT EMG activity, 40% MMT-PRO= 40% of manual muscle test load, shoulder protracted, 40% MMT-RET= 40% of manual muscle test load, shoulder retracted. The error bars denote the standard error of the mean.
can effectively minimize UT activity, regardless of shoulder positions (NEUT and HADD). Therefore, this exercise might help those who need to improve the optimal UT/LT ratio, such as patients with subacromial impingement syndrome.5,7

The amount of IS activity generated in the side-lying horizontal abduction exercise was less than half of the IS muscle activity generated in the side-lying ER exercise. The findings of this study were consistent with previous studies in which the IS was hardly activated during isolated horizontal abduction exercise in the position of shoulder abduction.15,21,22 Previous studies also have revealed that resistance of horizontal adduction at 90° of shoulder abduction significantly augmented IS activity when the subjects generated shoulder ER force.15,22 Taken together, IS activity decreases in horizontal abduction exercise without ER force generation.21

The amount of activity of the IS has been demonstrated to vary with the amount of MD activity during ER exercise of the GHJ at 0° ABD. MD activity can be further decreased in the scapular plane, compared with the coronal plane during ER exercises.15,21,22 The side-lying abduction with the elbow straight position with the scapula retracted placed the humeral head in the GHJ steadily enough to minimize both MD and IS activities in the NEUT position. The horizontal adduction position at 15° from the sagittal plane with the dumbbell weight produced only a mild amount of MD activity. Consequently, the findings of this study indicate that such small degrees of horizontal adduction position may involve the IS in an attempt to stabilize the humeral head in the GHJ, leading to an increase in the muscle activity as much as side-lying ER exercise at 0° ABD.

The PD has been reported to contribute to ER force in shoulder abduction along with the external rotators of the GHJ.28 In addition, the PD can be positively associated with the LT in quadruped shoulder flexion,25 arm elevation in the scapular plane, (known as scaption),25 prone horizontal abduction,21 Shoulder ER at 90° of abduction with the elbow flexed to 90°, (known as 90/90 ER),14,15,21,29 and dynamic motion exercises, such as the lawn mower and robbery exercise.25,30 This study revealed that the amount of PD activity was reduced in the scapula retracted condition during the side-lying abduction exercises regardless of the different external loads, compared with the scapular protraction condition. Likewise, the PD barely contributed to ER force in the side-lying ER exercise, which may be accounted for by the muscle length-tension relationship.31 Therefore, both LT and IS activities can be independent of PD muscle activity in the side-lying abduction exercise with scapular retraction.

**LIMITATIONS**

This study determined the amount of exercise intensity based on MD activity ranging between low and moderate activity as indicated by DiGiove et al. Although a significant difference was found in the marginal mean value of MD activity between the two exercise intensities: the external weight of 9.1 kg dumbbell and external force generated by 40% MMT (38% vs 34% MVIC), the exercise interventions demonstrated in this study were comparably controlled to identify LT activity modulations. This study solely included collegiate baseball players with asymptomatic shoulders and all analyses were performed only on the dominant side. Thus, the implication of the findings to individuals with differing age, levels of performance, presence of shoulder symptoms, non-dominant side, and the dumbbell weight used in this study may have limitations.

**CONCLUSION**

This study investigated the amount of scapular, deltoid, and rotator cuff muscle activity during two isometric exercise positions with altered scapular positions and differing external loads. The findings of this study suggest that the amount of LT activity can be modulated by changes in scapulothoracic and glenohumeral positioning. This study also revealed that IS activity was augmented with the scapula retracted in the side-lying abduction exercise by the external load of a dumbbell, compared with resistance of HADD. Changes in the UT/LT ratio based on scapular position and exercise characteristics were observed. Further studies are warranted to investigate the effect of scapular positions on the activity of the LT, IS, UT, and deltoid muscles in side-lying exercises for use in injury prevention programs, especially for those overhead athletes who need to improve scapular muscle balance ratios.

**CONFLICTS OF INTEREST**

The authors have no conflicts of interest to declare that are relevant to the content of this study.

**ACKNOWLEDGEMENT**

The authors thank Wesley Clawson and Karter Lang, MA, ATC for their assistance with data collection during this study.

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REFERENCES


Original Research

Trunk, Mass Grasp, Knee, and Hip Muscle Performance in CrossFit Participants: Reference Values According to Participants’ Sex and Limb Dominance

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Keywords: CrossFit, hand grip, isokinetic, muscular strength, normative data.

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Background
CrossFit is characterized by a diverse range of exercises recruiting different muscles and requiring different muscle functions. A characterization of muscular performance parameters in this population is needed.

Purpose
To determine reference values for various aspects of muscular performance of muscles of the trunk, thigh, hip, and mass grasp in CrossFit participants. Also, this investigation aimed to compare the strength measures between male and female CrossFit participants, as well as between dominant and non-dominant limbs.

Design
Descriptive, Cross-sectional.

Setting
Laboratory.

Methods
Isometric strength of trunk extensors (TE) and mass grasp was measured with handheld and Jamar dynamometer respectively. An isokinetic dynamometer was used to assess the muscle performance of the knee flexors (KF) and extensors (KE) (at 60º/s and 500º/s), and hip flexors (HF), extensors (HE), and abductors (HA) (60º/s and 240º/s ). Reference values for torque, work, power, fatigue, flexor:extensor ratio for the knee (hamstring:quadriceps - H:Q) and hip (HF:HE) joints were calculated. The torque and work values were normalized by the body mass. Mixed multivariate and univariate analyses of variance and independent t-tests were used for statistical analyses to compare between sexes and limbs.

Results
Participants included 111 individuals (58 males and 53 females) with at least one year of experience in CrossFit. Normative data are provided for the outcome variables. Males had greater values of muscular performance parameters than females in most variables (p<0.05). Also, the dominant limb had greater mass grasp strength (p<0.002), greater KE
power at 60°/s (p=0.015), lower H:Q ratio at 60°/s (p=0.021) and 300°/s (p=0.008), and lower KE fatigue (p=0.002).

Conclusion
This study provides reference values for the trunk extensors, mass grasp, knee, and hip muscle performance in male and female CrossFit practitioners. Their muscle performance profile was characterized by few inter-limb asymmetries, and males demonstrated greater muscular performance outcomes than females, even after normalization by body mass. These reference values can be used for comparisons in research and clinical settings.

Level of Evidence
3b

INTRODUCTION
CrossFit imposes physical demands on different body segments through multiple exercises. For example, during the squat, participants’ lower limb muscles must generate movement primarily in the sagittal plane while stabilizing the motion in the frontal and transverse planes to maintain proper dynamic knee alignment. Moreover, exercises involving weightlifting (e.g., Olympic lifts and power lifts) and gymnastic-like movements (e.g., push-ups and ring exercises) require trunk strength to be performed correctly. The demand for trunk strength may explain the high injury rate in the lumbar spine in CrossFit practitioners. CrossFit exercises are performed at high velocity, with a high number of repetitions and short or no recovery time between sets, thus requiring muscular endurance and power. Therefore, CrossFit requires more than only muscle strength to perform workouts.

Several authors have assessed muscular performance in CrossFit participants. To the authors knowledge, these investigations were limited to measurements of isokinetic peak of torque (PT) and the agonist:antagonist ratios of knee flexors and extensors (known as the hamstring to quadriceps ratio [H:Q] and shoulder internal and external rotators). Reference values considering other muscle groups and parameters are needed since CrossFit is characterized by exercises involving multiple body segments and muscle functions (e.g., power, work, and strength endurance). In addition, few studies have investigated inter-limb differences in CrossFit participants. Considering the symmetric characteristics of the exercises, it is possible that CrossFit does not impose asymmetrical demand on the dominant (DOM) and non-dominant (NDOM) limbs. If reference values confirm absence of limb-differences, asymmetry findings in clinical assessments may be related to weakness or muscular imbalance in CrossFit participants. Therefore, the comprehensive characterization of multiple muscular performance parameters in CrossFit practitioners will help to understand the muscular profile of CrossFit athletes and the influence of limb dominance. Furthermore, reference values can be used to identify practitioners that lack proper levels of muscular performance and inform preventive programs and rehabilitation of injured athletes.

The purpose of this study was to determine reference values for various aspects of muscular performance of muscles of the trunk, thigh, hip, and mass grasp in CrossFit participants. Also, this investigation aimed to compare the muscular strength measures between male and female CrossFit participants, as well as between dominant and non-dominant limbs. The authors hypothesized that males would present greater muscular strength, work and power, and lower fatigue than females, and there would be no difference between limbs.

METHODS
STUDY DESIGN
This cross-sectional study assessed the isometric strength of the trunk extensors and mass grasp, and isokinetic torque production (as a measure of "strength"), power, work and fatigue of the knee flexors and extensors and hip flexors, extensors, and abductors in CrossFit participants. These muscle groups were chosen to comprehensively assess common muscles used during CrossFit exercises, such as isometric trunk extensors to perform weightlifting, proper mass grasp strength to grasp different equipment, and knee and hip muscles to manage weight-bearing exercises (e.g., squat).

PARTICIPANTS
Participants were recruited from multiple CrossFit gyms. The inclusion criteria were 18 to 45 years of age, a minimum of one year of CrossFit practice, absence of musculoskeletal injury in the prior six months, and no surgery in the prior year. An injury was defined as withdrawing from training for at least seven days or reducing the ability to train for at least 14 days. The exclusion criteria were incapacity to perform the investigated tests or experiencing pain during any procedure. None of the participants met the exclusion criteria. The participants provided a written informed consent form, and the University’s Ethics Committee approved this study (Protocol number: CAAE-95670418.9.0000.5149).

PROCEDURES
Initially, the participants performed jumping jacks for one minute to warm up. All tests were performed during the same visit by the same trained examiner (physical therapist with experience with CrossFit athletes and isokinetic eval-
position, following the recommendations of the American Society of Hand Therapy (Figure 1). The isometric contraction was held for five seconds, bilaterally. Isometric strength data were converted into Newtons (N) and normalized by each participant’s body mass to allow comparison between individuals. Three trials were performed for each isometric test, with 30 seconds of rest time between them. The mean was considered for analysis.

The test-retest reliability of the isometric tests was assessed in a prior pilot study performed with 10 participants and an interval of seven days between measurements. All measures had excellent test-retest reliability. The trunk extensor MVIC showed an intraclass correlation coefficient (ICC) of 0.910, confidence interval (95%CI) of 0.680–0.977, and a standard error of measurement (SEM) of 1.49 N/kg. The DOM mass grasp MVIC showed ICC=0.884, 95%CI=0.601–0.970, and SEM=0.92 N/kg. The NDOM mass grasp MVIC showed ICC=0.86, 95%CI=0.541–0.974, and SEM=0.87 N/kg.

ISOKINETIC PERFORMANCE OF THE KNEE AND HIP MUSCLES

The knee and hip muscles were assessed using an isokinetic dynamometer (Biodex System® 4 Pro, Shirley, NY, USA) in the concentric mode. The isokinetic dynamometer has documented excellent mechanical reliability (ICC=0.99–1.00).\textsuperscript{15} The knee flexors and extensors were assessed with the participants seated with the trunk inclined at 70° anteriorly, and the trunk and tested thigh stabilized using the chair belts. The rotational axis of the dynamometer was aligned to the lateral epicondyle of the femur, and the distal lever was attached 2 cm above the lateral malleolus (Figure 2). The range of motion was 95° (100° to 5° of flexion; 0° = full knee extension). Concentric strength of the knee flexors and extensors was assessed during five repetitions at 60°/s and 30 at 300°/s.

The hip flexors and extensors were assessed with the participant positioned supine over the dynamometer chair. The rotational axis was aligned anteriorly and superiorly to the greater trochanter of the femur. The distal lever was attached to the distal third of the thigh, and the range of motion was 110° (10° to 120° of flexion) (Figure 2). The hip flexors and extensors were assessed concentrically during five repetitions at 60°/s and 30 repetitions at 240°/s.

The hip abductors were assessed with the participant positioned side-lying, with the assessed limb positioned parallel to the ground in a neutral position. The contralateral hip and knee were flexed and fixed with straps. The trunk was stabilized using a belt proximal to the iliac crest. The axis of rotation of the dynamometer was aligned with the greater trochanter of the femur, and the distal lever was attached to the distal third of the thigh (Figure 2). The range of hip motion was 45° (0° [neutral position] to 45° of hip abduction). The hip abductors were assessed five repetitions at 60°/s and 30 repetitions at 240°/s.

The participants had one minute of rest between assessments at different angular velocities. The variables that were examined included the peak of torque (PT) and maximum repetition of total work (MW) normalized by body

Figure 1. Maximal Voluntary Isometric Contraction (MVIC) of the trunk extensors (frontal (A) and sagittal (B) plane views) and mass grasp strength (frontal (C) and sagittal (D) plane views)
mass and multiplied by 100; and power. In addition, we analyzed the flexors:extensors ratio for the knee (H:Q) and hip (HF:HE) joints. The fatigue (ratio of the difference between the work in the first third to the work in the last third of the test, expressed as a percentage) was obtained only at 300°/s and 240°/s for the knee and hip joint respectively.16

STATISTICAL ANALYSIS

Descriptive analyses were used to characterize the sample and the study variables. Data normality was verified and confirmed with the Kolmogorov-Smirnov test. Independent t-test was used to compare sexes in the trunk extensor strength, and mixed analysis of variance (ANOVA) was used to compare sexes and limbs in the mass grasp strength. Finally, mixed multivariate analyses of variance (MANOVA) were used to compare the hip and knee isokinetic variables between sexes and lower limbs. ANOVA was performed to locate differences identified by MANOVA. All analyses were performed using SPSS 19 (SPSS Inc, Chicago, USA), considering an alpha level of 0.05.

RESULTS

The study assessed 111 participants (58 males and 53 females). The descriptive characteristics of the participants are presented in Table 1. The reference values for trunk extensors, mass grasp, knee flexors and extensors, and hip flexors, extensors, and abductors are presented according to the participant’s sex and limb dominance in Tables 2 to 5, respectively.

PARTICIPANT’S SEX AND LIMB DIFFERENCES

Males demonstrated greater isometric strength of the trunk extensors (d = 1.565; p < 0.001) and mass grasp ($\eta_p^2 = 0.151$; $p = 0.001$) than females. The DOM hand had greater mass grasp strength than the NDOM hand ($\eta_p^2 = 0.145$; $p < 0.002$). No sex vs limb dominance interaction effect was observed for the mass grasp ($\eta_p^2 = 0.002; p = 0.674$) (Table 2).

For the knee flexors and extensors, males presented greater values of torque, work, power than females ($p < 0.05$), except for fatigue ($p > 0.05$) (Table 3). The DOM limb had a smaller H:Q ratio at 60°/s ($\eta_p^2 = 0.048$; $p = 0.021$) and 300°/s ($\eta_p^2 = 0.062$; $p = 0.008$), higher knee extensors power 60°/s ($\eta_p^2 = 0.059$; $p = 0.015$) and lower fatigue ($\eta_p^2 = 0.094$; $p = 0.002$) than the NDOM limb. No sex vs limb dominance interaction effect was observed for the muscular performance variables of the knee joint ($p > 0.05$) (Table 3).

For the hip extensors, males showed greater values of torque, work, and power than females ($p < 0.001$), except for fatigue ($p > 0.05$) (Table 4). For the hip flexors muscles, males had greater values than females for PT at 60°/s ($\eta_p^2 = 0.087$; $p = 0.040$) and 240°/s ($\eta_p^2 = 0.214$; $p = 0.001$), MW at 240°/s ($\eta_p^2 = 0.130$; $p = 0.011$) and power at 60°/s ($\eta_p^2 = 0.085$; $p = 0.001$), lower fatigue ($\eta_p^2 = 0.094$; $p = 0.002$) than the NDOM limb. No sex vs limb dominance interaction effect was observed for the muscular performance variables of the hip joint ($p > 0.05$) (Table 4).
Table 1. Characterization of the sample, presented as mean and standard deviation (SD).

<table>
<thead>
<tr>
<th></th>
<th>FEMALE (n = 53)</th>
<th>MALE (n = 58)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>29.15 (5.26)</td>
<td>29.41 (5.80)</td>
<td>0.80</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>64.01 (8.67)</td>
<td>81.38 (8.10)</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.63 (0.05)</td>
<td>1.75 (0.06)</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.02 (2.71)</td>
<td>26.6 (2.71)</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>Time of CrossFit participation (months)</td>
<td>26.09 (12.82)</td>
<td>29.31 (17.92)</td>
<td>0.283</td>
</tr>
<tr>
<td>Hours of training/week</td>
<td>6.15 (3.28)</td>
<td>7.44 (4.03)</td>
<td>0.07</td>
</tr>
</tbody>
</table>

BMI = body mass index; kg = kilogram; kg/m² = kilogram/square meter.

* Independent t-test p-value less than 0.05

Table 2. Maximal isometric outputs of the dominant (DOM) and non-dominant (NDOM) mass grasp and trunk extensors according to the participant’s sex. Presented as mean, standard deviation (SD), and 95% confidence interval (CI).

<table>
<thead>
<tr>
<th></th>
<th>FEMALE</th>
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<th>MALE</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Mean  (SD)</td>
<td>95% CI</td>
<td>Mean (SD)</td>
<td>95% CI</td>
</tr>
<tr>
<td>Mass grasp (N/kg)*</td>
<td>DOM</td>
<td>4.41 (0.8)</td>
<td>4.21 – 4.70</td>
<td>5.10 (0.9)</td>
</tr>
<tr>
<td></td>
<td>NDOM</td>
<td>4.21 (0.9)</td>
<td>4.02 – 4.51</td>
<td>5.00 (0.9)</td>
</tr>
<tr>
<td>Trunk (N/kg)**</td>
<td></td>
<td>13.15 (3.16)</td>
<td>12.28 – 14.02</td>
<td>17.84 (2.85)</td>
</tr>
</tbody>
</table>

N/kg: Newton/kilogram; * difference between sexes and lower limb in mixed ANOVA (p<0.05); ** difference between sexes in the independent t-test (p<0.001).

DISCUSSION

The present study provides reference values for trunk extensors and mass grasp isometric strength and for isokinetic parameters for the knee and hip joints according to the participant’s sex and limb dominance. Males exhibited greater torque, work, and power than females in almost all tested muscles, as hypothesized. Finally, a difference between DOM and NDOM limbs was only observed in a few variables.

The isometric strength of the trunk extensors was assessed in a standing position, with the trunk bending forward, a posture similar to the one adopted during powerlifting exercises performed during CrossFit sessions. This proposed protocol could be used to compare CrossFit practitioners to other athletes aiming to understand the trunk strength profile in CrossFit participants. For example, the CrossFit male practitioners assessed in the current study demonstrated similar performance to the findings reported to judokas submitted to the same protocol (15.69 N/kg). Furthermore, the mass grasp was assessed since the CrossFit involves multiple exercises to grasp the equipment, such as the bar during weightlifting. CrossFit practitioners of the present study also showed mass grasp strength similar to what was reported for judokas, but lower than climbing athletes, who produced 7.39 N/kg (average of the DOM and NDOM hand). It is noteworthy that the trunk extensors and mass grasp were assessed since these muscles are recruited in several CrossFit exercises, such as deadlift and gymnastic-like movements. To the authors knowledge, this is the first study to investigate reference values for the performance of these muscles.

The present study provides reference values for multiple knee and hip muscular performance parameters. Few studies have assessed the isokinetic muscular performance in CrossFit participants. Kramer et al. reported isokinetic knee PT to determine the effect of chronic dietary nitrate supplementation on muscular strength. However, these authors did not normalize the torque values by body mass, which limits the comparison to the current findings. Furthermore, Motta et al. described slightly greater values of concentric PT of knee flexors and H/Q ratio in both sexes compared to reported in the present study. As Motta’s sample presented a sample of CrossFit athletes who had participated for 2.9 years (males) and 2.5 years (females), and the sample of the present study had been trained for approximately 2.4 years (males) and 2.1 years (females), the difference in muscular performance between studies cannot be explained solely by the different experience-level in CrossFit, however the specifics of workouts may, in part, explain this difference. However, the effect of experience-level was not assessed in the present study.
Male CrossFit athletes had lower knee muscular performance than those reported in football players\textsuperscript{23} and long-distance runners\textsuperscript{24} and higher performance compared to non-athletes.\textsuperscript{25} Therefore, it appears that the muscle strength profile depends on the specifics of the sport practiced by an individual. The present study expands the muscular performance data for CrossFit participants since previous studies focused only on assessment of the knee or shoulder joints and PT or agonist:antagonist ratio variables. Thus, the current findings provide valuable and comprehensive information about muscular performance in CrossFit participants.

Reference values for maximum work, power, and fatigue were considered important to evaluate since CrossFit workouts involve high-intensity exercises performed quickly with little or no recovery time.\textsuperscript{1} These variables are essential since they inform about the capability of the muscle to develop torque during the range of motion (work), to sustain torque across the repetitions (fatigue), and about how fast a muscle can produce work (power).\textsuperscript{16} Therefore, these muscular performance parameters investigated in the current study can contribute to understanding the impact of CrossFit on these physical attributes. Also, the data obtained in the present study may be used as a reference in sports settings (training and rehabilitation) and allow comparisons to future studies.

CrossFit female participants presented a mean knee H:Q ratio varying from 46.25\% to 54.46\%, whereas male participants presented 46.58\% to 54.52\% at both isokinetic velocities. These H:Q ratio values below 60\% suggest that the CrossFit participants have a strength imbalance between the hamstrings and quadriceps (i.e. lower hamstring

| Table 3. Peak torque to body weight (PT%) values for knee extensors and flexors, maximum repetition of total work to body weight (MW%), average power (Watts), fatigue (WF%) and H:Q ratio (%) of dominant (DOM) and non-dominant (NDOM) limbs for each sex. Presented as mean, standard deviation (SD), and 95\% confidence interval (CI). |
|---------------------------------|------------------|------------------|------------------|------------------|
|                                | **FEMALE**       | **MALE**         | **FEMALE**       | **MALE**         |
|                                | **Mean (SD)**    | **95\% CI**      | **Mean (SD)**    | **95\% CI**      |
| **PT flexors**                 | **DOM**          |                  | **NDOM**         |                  |
|                                | 219.10          | (42.57)          | 268.88          | (38.17)          |
|                                | 275.94          | (22.57)          | 297.81          | (23.46)          |
|                                | 127.57          | (15.77)          | 123.62          | (10.40)          |
|                                | 121.35          | (15.77)          | 129.28          | (23.24)          |
| **PT flexors**                 | **DOM**          |                  | **NDOM**         |                  |
|                                | 107.00          | (32.73)          | 132.25          | (25.93)          |
|                                | 126.14          | (15.77)          | 138.36          | (21.24)          |
|                                | 64.46           | (13.84)          | 68.81           | (16.40)          |
|                                | 60.11           | (13.84)          | 80.31           | (16.40)          |
| **MW extensors**               | **DOM**          |                  | **NDOM**         |                  |
|                                | 224.36          | (46.80)          | 281.48          | (42.35)          |
|                                | 271.44          | (23.46)          | 291.51          | (20.24)          |
|                                | 116.45          | (15.77)          | 115.64          | (17.48)          |
|                                | 109.98          | (15.77)          | 110.06          | (17.48)          |
| **MW flexors**                 | **DOM**          |                  | **NDOM**         |                  |
|                                | 123.97          | (53.15)          | 155.59          | (28.15)          |
|                                | 148.18          | (15.49)          | 162.99          | (18.87)          |
|                                | 57.90           | (13.82)          | 62.17           | (18.87)          |
|                                | 53.63           | (13.82)          | 75.79           | (18.87)          |
| **Power extensors**            | **DOM**          |                  | **NDOM**         |                  |
|                                | 88.69           | (23.86)          | 145.02          | (28.72)          |
|                                | 137.47          | (32.87)          | 152.58          | (32.87)          |
|                                | 128.49          | (38.72)          | 157.55          | (38.72)          |
|                                | 119.42          | (38.72)          | 161.33          | (38.72)          |
| **Power flexors**              | **DOM**          |                  | **NDOM**         |                  |
|                                | 47.83           | (15.16)          | 76.62           | (16.35)          |
|                                | 72.32           | (20.05)          | 80.16           | (15.68)          |
|                                | 58.17           | (20.05)          | 61.24           | (26.60)          |
|                                | 52.64           | (20.05)          | 56.92           | (26.60)          |
| **WF extensors**               | **DOM**          |                  | **NDOM**         |                  |
|                                | -               | -                | -               | -                |
|                                | 40.86           | (10.55)          | 37.61           | (9.67)           |
|                                | 34.05           | (10.14)          | 39.93           | (9.97)           |
| **WF flexors**                 | **DOM**          |                  | **NDOM**         |                  |
|                                | -               | -                | -               | -                |
|                                | 41.44           | (13.88)          | 37.17           | (11.54)          |
|                                | 42.63           | (11.54)          | 45.72           | (16.41)          |
| **H:Q ratio**                  | **DOM**          |                  | **NDOM**         |                  |
|                                | 46.25           | (10.43)          | 46.58           | (7.43)           |
|                                | 44.62           | (9.83)           | 48.53           | (9.83)           |
|                                | 50.64           | (9.83)           | 53.85           | (9.83)           |
|                                | 47.92           | (9.83)           | 54.03           | (9.70)           |
|                                | 54.03           | (9.70)           | 54.52           | (9.70)           |

\*significant main effect sex in MANOVA and ANOVA (p<0.05); **significant main effect dominance in MANOVA and ANOVA (p<0.05)
Table 4. Peak torque to body weight (PT%) values for hip extensors and flexors, maximum repetition of total work to body weight (MW%), average power (Watts), fatigue (WF%) and hip flexors:extensors (HF:HE%) ratio of dominant (DOM) and non-dominant (NDOM) limbs for each sex. Presented as mean, standard deviation (SD), and 95% confidence interval (CI).

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<td>60%</td>
<td>240%</td>
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<tr>
<td></td>
<td>Mean</td>
<td>CI 95% Lower - Upper</td>
<td>Mean</td>
<td>CI 95% Lower - Upper</td>
<td>Mean</td>
<td>CI 95% Lower - Upper</td>
</tr>
<tr>
<td>PT extensors*</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>DOM</td>
<td>112.19</td>
<td>(21.54)</td>
<td>106.25 - 118.13</td>
<td>139.96</td>
<td>(22.74)</td>
<td>133.98 - 145.94</td>
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<tr>
<td>NDOM</td>
<td>111.43</td>
<td>(22.52)</td>
<td>105.22 - 117.64</td>
<td>137.48</td>
<td>(20.82)</td>
<td>132.00 - 142.95</td>
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<tr>
<td>DOM</td>
<td>187.83</td>
<td>(48.56)</td>
<td>174.44 - 201.21</td>
<td>202.90</td>
<td>(50.02)</td>
<td>189.75 - 216.06</td>
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<tr>
<td>NDOM</td>
<td>189.40</td>
<td>(41.45)</td>
<td>177.97 - 200.82</td>
<td>209.22</td>
<td>(43.10)</td>
<td>197.89 - 220.56</td>
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<tr>
<td>DOM</td>
<td>157.78</td>
<td>(24.89)</td>
<td>150.92 - 164.65</td>
<td>189.15</td>
<td>(29.76)</td>
<td>181.33 - 196.98</td>
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<tr>
<td>NDOM</td>
<td>155.06</td>
<td>(25.58)</td>
<td>148.01 - 162.11</td>
<td>184.77</td>
<td>(30.33)</td>
<td>176.79 - 192.74</td>
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<td>MW flexors*</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>DOM</td>
<td>290.38</td>
<td>(78.17)</td>
<td>268.83 - 311.93</td>
<td>294.44</td>
<td>(77.37)</td>
<td>274.09 - 314.78</td>
</tr>
<tr>
<td>NDOM</td>
<td>284.45</td>
<td>(67.70)</td>
<td>265.79 - 303.11</td>
<td>293.64</td>
<td>(74.19)</td>
<td>274.13 - 313.15</td>
</tr>
<tr>
<td>Power extensors*</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>DOM</td>
<td>46.61</td>
<td>(9.48)</td>
<td>44.00 - 49.22</td>
<td>80.23</td>
<td>(25.57)</td>
<td>73.51 - 86.96</td>
</tr>
<tr>
<td>NDOM</td>
<td>46.00</td>
<td>(8.99)</td>
<td>43.52 - 48.48</td>
<td>75.76</td>
<td>(12.93)</td>
<td>72.36 - 79.16</td>
</tr>
<tr>
<td>Power flexors*</td>
<td></td>
<td></td>
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<tr>
<td>DOM</td>
<td>84.08</td>
<td>(18.37)</td>
<td>79.01 - 89.14</td>
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<td>(28.82)</td>
<td>108.50 - 123.66</td>
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<tr>
<td>NDOM</td>
<td>84.57</td>
<td>(18.32)</td>
<td>79.52 - 89.62</td>
<td>118.37</td>
<td>(28.92)</td>
<td>110.76 - 125.97</td>
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<tr>
<td>DOM</td>
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<td>-</td>
<td>-</td>
<td>36.40</td>
<td>(9.44)</td>
<td>32.32 - 40.49</td>
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<tr>
<td>NDOM</td>
<td>-</td>
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<td>-</td>
<td>37.43</td>
<td>(10.47)</td>
<td>32.90 - 41.96</td>
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<td></td>
</tr>
<tr>
<td>DOM</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>25.94</td>
<td>(9.49)</td>
<td>21.83 - 30.04</td>
</tr>
<tr>
<td>NDOM</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>24.40</td>
<td>(10.95)</td>
<td>19.67 - 29.14</td>
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<td>HF:HE Ratio*</td>
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<tr>
<td>DOM</td>
<td>62.50</td>
<td>(17.93)</td>
<td>57.56 - 67.45</td>
<td>68.84</td>
<td>(12.39)</td>
<td>65.58 - 72.10</td>
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<td>NDOM</td>
<td>62.39</td>
<td>(18.80)</td>
<td>57.21 - 67.58</td>
<td>67.24</td>
<td>(10.39)</td>
<td>64.50 - 69.97</td>
</tr>
</tbody>
</table>

Notes: *significant main effect sex in MANOVA and ANOVA (p<0.05).

strength). The ratios seen in this study were similar to those reported among CrossFit athletes by Motta et al (mean, 52.12%).10 In both studies, the observed values of H:Q are lower than 60%, value indicated in the literatures as expected ratio.26 Therefore, the results of the present study reinforce the Motta et al.10 findings and suggest that CrossFit practice may favor a lower H:Q ratio (muscle imbalance). More studies are necessary to investigate which specific exercises during CrossFit may favor this lower H:Q ratio. Nevertheless, muscular imbalances are a risk factor for injury in athletes,26 suggesting that CrossFit strengthening programs should consider minimizing the imbalance between hamstring and quadriceps strength. Furthermore, there are no data in the literature about the hip F:E ratio in CrossFit participants. The current findings of the hip F:E ratio (males, 68%; females, 62%) were similar to those reported in healthy individuals (males, 75%; females, 65%).27

Considering the isokinetic fatigue assessment of 30 repetitions, CrossFit practitioners showed fatigue of approximately 40% for knee extensors, 42% for knee flexors, 37.5% for hip extensors, 24.5% for hip flexors, and 26.5% for hip adductors. CrossFit involves high power throughout the training with little or no recovery time, which can produce muscle fatigue.28 Indeed, Maté-Munoz et al.28 reported that the exercises performed in one CrossFit training session resulted in muscle fatigue, decreased jump height, and maximum strength and power in athletes. The present study’s findings demonstrated that the knee muscles showed greater fatigue than the hip muscles, for both sexes. This difference may be due the type and characteristics of exercises performed during workout. However, as train-
Table 5. Peak torque to body weight (PT%) values for hip abductors, maximum repetition of total work to body weight (MW%), average power (Watts), and fatigue (WF%) of dominant (DOM) and non-dominant (NDOM) limbs for each sex. Presented as mean, standard deviation (SD), and 95% confidence interval (CI).

<table>
<thead>
<tr>
<th></th>
<th>FEMALE</th>
<th></th>
<th>Male</th>
<th></th>
<th>FEMALE</th>
<th></th>
<th>Male</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>CI 95% Lower -</td>
<td>Mean (SD)</td>
<td>CI 95% Lower -</td>
<td>Mean (SD)</td>
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<tr>
<td><strong>60%</strong></td>
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<td>Upper</td>
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<tr>
<td>PT abductors</td>
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</tr>
<tr>
<td>DOM</td>
<td>122.19 (23.16)</td>
<td>116.33 - 129.10</td>
<td>134.48 (27.89)</td>
<td>127.15 - 141.82</td>
<td>67.49</td>
<td>62.46 - 72.28</td>
<td>72.88</td>
</tr>
<tr>
<td>NDOM</td>
<td>125.61 (27.93)</td>
<td>117.91 - 133.31</td>
<td>137.54 (26.46)</td>
<td>140.58 - 149.49</td>
<td>67.43</td>
<td>62.26 - 70.03</td>
<td>65.80</td>
</tr>
<tr>
<td><strong>240%</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DOM</td>
<td>61.38 (14.41)</td>
<td>57.41 - 65.36</td>
<td>61.62 (14.46)</td>
<td>57.82 - 65.43</td>
<td>29.71</td>
<td>24.77 - 34.65</td>
<td>29.81</td>
</tr>
<tr>
<td>NDOM</td>
<td>61.05 (12.44)</td>
<td>57.62 - 64.48</td>
<td>61.81 (13.64)</td>
<td>58.23 - 65.40</td>
<td>29.24</td>
<td>24.96 - 33.50</td>
<td>28.81</td>
</tr>
<tr>
<td>Power abductors*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DOM</td>
<td>39.86 (7.94)</td>
<td>37.67 - 42.05</td>
<td>55.77 (12.11)</td>
<td>52.59 - 58.96</td>
<td>36.72</td>
<td>32.18 - 41.26</td>
<td>58.06</td>
</tr>
<tr>
<td>NDOM</td>
<td>40.35 (8.89)</td>
<td>37.90 - 42.80</td>
<td>56.09 (10.30)</td>
<td>53.38 - 58.80</td>
<td>35.37</td>
<td>30.66 - 40.07</td>
<td>52.70</td>
</tr>
<tr>
<td>WF abductors</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DOM</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td>27.75 (16.16)</td>
<td>20.93 - 34.58</td>
<td>24.96</td>
</tr>
<tr>
<td>NDOM</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td>27.85 (16.15)</td>
<td>21.03 - 34.68</td>
<td>29.97</td>
</tr>
</tbody>
</table>

Notes: *significant main effect sex in MANOVA and ANOVA (p<0.05)

ing aspects were not evaluated, it is not possible to establish the reason for the greater fatigue in the knee muscles. Therefore, more studies are necessary to identify whether greater knee fatigue is a tendency in CrossFit practitioners, specifically, whether training characteristics could be associated with less fatigue resistance in this joint.

The assessment of sex-based differences revealed that males exhibited greater muscular performance parameters than females, even after normalizing the variables by body mass, corroborating a previous study.10 Considering that muscle strength is influenced by body size, normalization of these variables by body mass has traditionally been performed to remove body size dependence and allow comparison between different populations and studies.29 However, strength normalization by body mass minimized, but did not eliminate, sex differences. The fact that males have a higher percentage of lean mass (80.15%) relative to total body mass than females (70.8%),10 lower body fat percentage, and a greater muscle fiber cross-sectional area30 likely explains this finding. Although both males and females adapt similarly to resistance training for lower-body strength,30 the differences between sexes observed in the present study demonstrated the importance of reporting strength outcomes according to participants’ sex.

The bilateral comparisons were performed to investigate the presence of inter-limb asymmetries. The DOM limb demonstrated significantly better performance than the NDOM only for knee extensor power at 60°/s and fatigue and mass grip strength and lower H:Q ratio than the NDOM limb during both angular speeds. The clinical relevance of these differences must be addressed since they represent only small mean differences between limbs. Despite the statistical significance reached due to the large sample size, the magnitude of the differences suggests that these asymmetries are not clinically relevant since the differences were lower than 10% for all variables. Values above 10% or 15% of inter-limb difference have been associated with an increased risk of sports injuries.31 The current results suggest that CrossFit does not impose an asymmetrical demand between lower limbs, which may be consistent with the movement and types of bilateral exercises performed in this training. Evidence that CrossFit participants presented higher symmetry between sides in Functional Movement Screen scores (such as hurdle step, line lunge, rotatory stability, and shoulder mobility)12 reinforces this argument.

A limitation of the present study was the investigation of only one type of contraction in each muscle group (either isometric or concentric isokinetic). Future studies should consider the assessment of eccentric contractions to enhance the knowledge of the muscular profile since this type of contraction is also required during CrossFit exercises. The current study is an initial comprehensive analysis needed to characterize this population using gold-standard instruments. The present study described multiple muscular performance parameters for knee and hip muscles and assessed trunk and mass grasp strength as these segments deal commonly involved in the demands of CrossFit and show a high prevalence of injuries.6,52 These data may help to establish pre-injury values to be considered in rehabilitation or preventive programs for this population. Future studies may focus on a comprehensive evaluation of upper limb muscles in this population.

CONCLUSION

The results of this study provide reference values for muscular performance in CrossFit participants, including parameters related to work, power, and fatigue. The reference
values were reported according to the participant’s sex and limb dominance. Males had greater values of muscular performance parameters than females, even after normalizing the variables by body mass, revealing the importance of reporting muscular performance separately for each sex. As lower H:Q ratio was observed, future studies could assess the agonist:antagonist ratio in other joints and verify the workout specificities that could contribute to possible imbalances. Finally, the results suggest that CrossFit does not impose an asymmetrical demand on the assessed muscles as inter-limb differences were not observed. The muscular performance information provided can be used in future investigations and clinical and sports settings.

DECLARATIONS OF INTEREST
None.

ACKNOWLEDGMENT
Coordination for the Improvement of Higher Education Personnel (CAPES - Finance Code 001), State of Minas Gerais Funding Agency (FAPEMIG), and National Council for Scientific and Technological Development (CNPq-Process: 305285/2021-1)

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REFERENCES


The Functional Movement Screen: Exploring Interrater Reliability between Raters in the Updated Version

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Keywords: functional movement screen, interrater, physical therapy, reliability, wellness

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Background
The Functional Movement Screen™ (FMS™) was updated by adding the ankle clearing test and modifying the rotary stability movement pattern and scoring criteria. This updated FMS™ may be used to support clinical decisions for the well-being of athletes and active adults.

Purpose
The purpose of this study was to determine if the updated FMS™ has acceptable interrater reliability, so that various practitioners can utilize it with their patients.

Study Design
Observational Laboratory Study

Methods
Two licensed Physical Therapists (PTs) conducted the testing for the study. No warmup was allowed for the participants. Each participant underwent one FMS™ session while being recorded on video lasting approximately 15 minutes. Participants were allowed three attempts to complete each movement pattern with the best score recorded. The participants, 45 healthy active PT students, were taken through the FMS™ by a licensed PT and videotaped. The raters were four second-year PT students that observed and scored the FMS independently after videotaping was completed. SPSS was used for the interrater reliability analysis. ICC was calculated using a 2-way mixed model looking for absolute agreement.

Results
The interrater reliability was highest for the rotary stability test (ICC 0.96) while the deep squat was the least reliable (ICC 0.78). The total scores showed excellent reliability among the four student raters with an ICC of 0.95. The updated FMS™ produced good to excellent interrater reliability.

Conclusion
The updated FMS™ has acceptable interrater reliability between minimally, but adequately trained individuals. The updated FMS™ may be reliably used to assess risk for future injury.

Level of Evidence
3
INTRODUCTION

Movement is essential to human life. It is a vital aspect to the overall health and well-being of every human. Good movement quality has been defined as the performance of fundamental movements in a properly balanced and well-coordinated manner. On the contrary, poor movement quality has been defined as the inability to complete fundamental movements in accordance with accepted theoretical norms. These theoretical norms for movement have been developed by screening and scoring humans.

The original Functional Movement Screen™ (FMS™) has primarily been completed on the athletic population. If athletes or active adults want to potentially reduce a risk factor for injury and potentially improve their performance, then they need to be aware of how they are fundamentally moving. The FMS™ allows athletes, coaches, and clinicians to be aware of the movement strategies, and discern if alterations are needed before providing or progressing an appropriate exercise prescription. This awareness allows the athlete, coach, or clinician to modify exercise prescriptions based on the athlete’s needs. The recommended goal of the FMS™ is to obtain a score of 3 indicating movement competency; however, high level athletes can still score a 1 (indicating inability to perform) or a 2 (alteration/compensation during completion of movement) or demonstrate asymmetrical movements and remain successful. The FMS™ was developed as a screening tool to see if an athlete or active adult has pain or asymmetrical movement patterns. The screen was meant to help decide if the athlete should be protected, corrected, or developed.

The FMS™ has been utilized by movement professionals to screen an individual’s functional and fundamental movement patterns to produce a quantifiable measure of their movement quality (0, 1, 2, or 3). The FMS has helped identify movement quality dysfunction in athletes or active adults that may be at risk of, but not currently experiencing, signs or symptoms of a musculoskeletal injury. Although the FMS™ is not intended to make a diagnosis, it has been used to identify and improve movement quality in individuals that are screened. The FMS™ has seven separate movement patterns that were specifically designed to place an individual in positions where movement deficits are noticeable if appropriate stability and mobility are not used. The seven movement patterns include: the deep squat, the hurdle step, the inline lunge, shoulder mobility, active straight-leg raise, the trunk stability pushup, and rotary stability. A scale from 0–3 has been used to score the seven movement patterns. A 0 indicates the individual has pain during any part of the movement, a 1 indicates the individual cannot perform the movement pattern even with compensations, a 2 indicates the individual can perform the movement but utilizes poor mechanics and compensatory patterns to accomplish the movement, and a 3 indicates that the individual can perform the movement without any compensations according to the established criteria.

The FMS™ is clinically relevant to athletes and active adults because the scoring allows clinicians to progress the individual appropriately and safely with exercise prescription. If the athlete or active adult scores a 0 on a movement pattern, then they are to be referred to a qualified health-care provider for further assessment due to the presence of pain. If the athlete or active adult scores a 1 on a movement pattern, then they are to be coached or provided with corrective exercises to improve the movement quality, which may potentially reduce a risk factor for future injury. If the athlete or active adult scores a 2 or 3, then their movement patterns may be considered acceptable and there is no need for corrective exercises to be administered.

Past studies on the original FMS™ have found that there was good to excellent interrater and intrarater reliability between the raters. Gribble et al. found evidence that was moderate to strong supporting intrarater reliability. Gulgin and Hoogenboom found acceptable reliability among four raters (three novices and one expert) that were all certified in FMS™. Leeder et al. found good to excellent reliability of the FMS™ when the raters were untrained and were only given instructions on how to score the recorded individuals via a DVD. Tehyen et al. had novice examiners go through 20 hours of training regarding the FMS who then demonstrated good to excellent interrater reliability. Shultz et al. demonstrated poor interrater reliability with five raters that were trained in FMS™ and one rater that was self-trained. Many other studies continue to demonstrate good to excellent interrater reliability however, no study has looked at the new criteria for the FMS™ with the addition of the ankle clearing test and the updated scoring criteria for the rotary stability test.

The FMS™ was updated for two reasons: (1) the ankle clearing test was added because it was difficult to globally screen for ankle mobility deficits and pain, which caused clinicians to miss ankle dorsiflexion restrictions and (2) the rotary stability test was modified because the original test only discovered about 15% of rotary asymmetries, where the updated test is able to discover about 57% of rotary asymmetries. The updated FMS™ appears to improve the validity of the screen as compared to the original FMS™ by screening specifically for dorsiflexion restrictions in the ankle and by discovering rotary asymmetries, which may potentially help an athlete or active adult improve their performance and reduce a risk factor for injury.

It is important to understand whether the updated FMS™ is reliable because it could allow a variety of clinicians to confidently screen the quality of movement of athletes or active adults. If poor movement qualities are observed, then recommendations can be made to improve the movement pattern, potentially reducing a risk factor for future injury risk. Many authors have reported that having a total score of less than 14 on the FMS™ increases the individual’s risk of injury.

USE OF FMS™

Most of the research involved in the original FMS™ has been focused on athletes or fit individuals. There has been a lack of research completed on individuals that are older, are not involved in sports, and may have other health complications. Multiple studies have examined if the FMS™ can be used as a diagnostic tool and used as a tool to predict fu-
tured injury. A study done by Kiesel et al.\textsuperscript{17} asked the question; “If injuries sustained in professional football could be predicted and prevented by a functional movement screen done in the preseason?” It was found that athletes with a score of 14 or less on the FMS\textsuperscript{TM} had a higher risk for injury. Bardenett et al.,\textsuperscript{26} found that the screen was better off used as an “assessment of quality” rather than used for diagnostic purposes. Another study by Dorrel et al.,\textsuperscript{27} found that the screen did not provide discriminatory predictive values for future musculoskeletal and overall injury. On the other hand, a study by Bushman et al.,\textsuperscript{28} agreed with the study listed above by Kiesel et al.,\textsuperscript{17} which said that physically active men who scored lower on their FMS\textsuperscript{TM} (<14) put them at higher risk for future injury. At this time, there is mixed evidence as to whether the FMS\textsuperscript{TM} may or may not be a good predictive tool for future injuries.

Smith et al.,\textsuperscript{29} examined intrarater reliability and intrarater reliability for individuals who took a two-hour training course on the original FMS\textsuperscript{TM} and then scored subjects across two assessment sessions. It was found that the intrarater reliability was good for both session one and session two (ICC of 0.89 and 0.87, respectively). The intrarater reliability of each individual rater was examined across the sessions, resulting in good reliability as well (ICC range from 0.81-0.91). A systematic review of six studies on the reliability of the original FMS\textsuperscript{TM} found the overall intrarater and intrarater reliability to be ICC 0.81,\textsuperscript{18} Both studies involved researchers that varied in FMS\textsuperscript{TM} experience or only received a short training period before rating the subjects. Past studies have suggested that the original FMS\textsuperscript{TM} intrarater reliability was strong and appeared to strengthen when the individuals had experience using the FMS in addition to clinical experience.\textsuperscript{26} The purpose of this study was to determine if the updated FMS\textsuperscript{TM} has acceptable intrarater reliability, so that various practitioners can utilize it with their patients.

METHODS

EXPERIMENTAL APPROACH TO THE PROBLEM

The study was designed to have four raters who had all received the same education, perform the FMS\textsuperscript{TM} to determine intrarater reliability. Participants were taken through the FMS\textsuperscript{TM} with standard instructions per FMS\textsuperscript{TM} guidelines. Each rater observed and scored 45 participants based on the scoring criteria created by the FMS\textsuperscript{TM}. The study was approved by the Institutional Review Board (IRB) at the University of North Dakota.

SUBJECTS

Participants were recruited from a student cohort in a physical therapy department. The inclusion criteria for this study were current physical therapy students with no reports of a recent injury (recent defined as less than or equal to four weeks prior). The exclusion criteria were any recent injury, an injury that contraindicated complete weight-bearing activities, and a participant’s inability to attend the scheduled videotaping sessions. Recruitment was done through email in which the subjects received an explanation of the nature, purpose, and risks of the study and were asked to volunteer to assist in the research. Fifty-five volunteers were recruited, and out of the 55 volunteers contacted, 10 volunteers declined. Before the FMS\textsuperscript{TM} was completed and videotaped, participants and raters signed an informed consent document approved by the Institutional Review Board at the University of North Dakota.

RATERS

The four student raters were halfway through their second year in the Doctor of Physical Therapy Program at the University. All the raters had received the same amount of prior learning and education in the field of physical therapy. For the FMS\textsuperscript{TM} screen specifically, each rater had received a brief one-hour presentation on how the FMS\textsuperscript{TM} was conducted and used, four months prior to testing. Two weeks before testing, the raters were presented with a two-hour lecture on the FMS\textsuperscript{TM} in a class. Each rater practiced completing and scoring the FMS\textsuperscript{TM} three times, one week before videotaping the participants. Following the screening of the participants, the raters attended a 1.5-hour FMS\textsuperscript{TM} review session given by a licensed physical therapist who was certified in the FMS\textsuperscript{TM}. The raters were not certified in FMS at any time during the study. To be certified in FMS\textsuperscript{TM}, it takes approximately eight hours to get through the content. The rater training for this study was based on current classes in the PT curriculum at the University and a review of material to allow for accuracy in scoring the participants.

PROCEDURE

Two experts, both licensed physical therapists, one of whom was certified in FMS\textsuperscript{TM}, conducted the FMS\textsuperscript{TM} screening for this study. No warmup was allowed for the subjects before the screening. Next, tibial tuberosity height (from the ground to the top center of the tibial tuberosity) and hand length (from the distal wrist crease to the end of the longest digit) were measured using the FMS\textsuperscript{TM} equipment per standard FMS\textsuperscript{TM} instructions. Tibial height and hand length measurements were used for each participant during the hurdle step, inline lunge, and shoulder mobility movement patterns. Each participant then underwent one FMS\textsuperscript{TM} testing session while being recorded on video, which lasted approximately 15 minutes. For reliability purposes, word for word instructions were read to the participants on how to complete the seven movement patterns and four clearings tests of the FMS\textsuperscript{TM} (Appendix A), in addition to demonstrations of each movement pattern. If the subject needed more clarification, instructions or demonstrations were repeated, but no further directions were given. Instructions were provided immediately before each individual movement. After demonstrative and verbal instructions were given, the participants were allowed three attempts to complete the movement pattern per FMS\textsuperscript{TM} instructions, with the best score recorded. After each movement, the participant was asked if any pain was associated with the movement. During each movement, the participants were video recorded from both the sagittal and frontal planes.
Table 1. Intraclass Correlation Coefficient (ICC) for Final Scores on the Movement Patterns

<table>
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<tr>
<th>Movement Pattern</th>
<th>ICC</th>
<th>Confidence Interval (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep Squat</td>
<td>0.78</td>
<td>0.66, 0.87</td>
</tr>
<tr>
<td>Hurdle Step</td>
<td>0.92</td>
<td>0.88, 0.95</td>
</tr>
<tr>
<td>Inline Lunge</td>
<td>0.92</td>
<td>0.88, 0.95</td>
</tr>
<tr>
<td>Shoulder Mobility</td>
<td>0.94</td>
<td>0.91, 0.97</td>
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<tr>
<td>Active Straight-Leg Raise</td>
<td>0.94</td>
<td>0.90, 0.96</td>
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<tr>
<td>Trunk Stability Push Up</td>
<td>0.95</td>
<td>0.92, 0.97</td>
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<td>Rotary Stability</td>
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<td>Total FMS™ Score</td>
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<td>0.93, 0.97</td>
</tr>
</tbody>
</table>

in a closed environment. Once the video recordings were completed, the four raters then individually observed and scored the FMS™ on each recorded participant. The videos were stored securely labeled only with a number (i.e. - Participant 1). The four raters each completed the scoring from the video recordings in the same environment each time, and in the absence of any outside distractions.

STATISTICAL ANALYSES

The scores for each participant were put into Statistical Package for Social Sciences (SPSS) and reliability analysis statistics were run for each movement. Descriptive statistics were calculated as mean values with standard deviation for normal interval data. Intraclass Correlation Coefficients (ICC’s) were calculated to determine the interrater reliability of each individual exercise component of the FMS™ and the participant’s overall FMS™ score. Interrater reliability was defined as poor for an ICC below 0.50, moderate for 0.50–0.75, good for 0.75–0.90, and excellent for 0.90 or higher.30

RESULTS

Forty-five individuals participated (male=14 and female=31). The overall ICC for the total score was 0.95 (95% CI: 0.93, 0.97), demonstrating excellent interrater reliability between raters (Table 1).

As far as new criteria on the FMS™ regarding the clearing tests, the ankle mobility clearing test for the right inline lunge was ICC 0.76 (good), while the left side was ICC 0.63 (moderate). These tests both show good and moderate interrater reliability, respectively, and are shown in Table 2. All other clearing tests suggest good to excellent interrater reliability.

Table 3 displays the raw scores of the individual movement patterns. Examination of the individual movement patterns of the FMS™ showed rotary stability as the most reliable ICC 0.96 (95% CI: 0.93, 0.97), whereas the least reliable was deep squat ICC = 0.78 (95% CI: 0.66–0.87). The deep squat was still considered to have good interrater reliability.

Mean total scores are shown in Figure 1. The results suggested that each rater’s score was highly correlated with one another. The ICC of the final score of each movement pattern was above 0.90, except for the deep squat. This is in the “excellent” category for interrater reliability.

DISCUSSION

The purpose of this study was to determine if the updated FMS™ has good to excellent interrater reliability, so that various practitioners can apply it to their patients. It is anticipated that the updated FMSv will have good to excellent interrater reliability and its application may reduce a risk factor for future injury and potentially improve performance of athletes and active adults. Previous literature has examined interrater reliability using videotaping and multiple raters, but these studies were prior to the additions and modifications to the FMS™ and warranted further study. To the best of the authors’ knowledge, this study is the first study to assess interrater reliability following the addition of the ankle clearing test and modifications to the rotary stability scoring criteria.

Past studies9–11,13 have all demonstrated good to excellent interrater reliability of the original FMS. In the current study, the updated FMSv continues to demonstrate good to excellent interrater reliability. The new criteria for the FMS™ were found to show good to excellent interrater reliability, except for the left ankle clearing mobility test, which had a moderate agreement among raters. These results suggest that the new criteria are reliable between raters. There was a large difference between the right and left ankle mobility clearing test (ICC = R: 0.76, L: 0.63), indicating that an outside variable may have caused this difference in reliability. This may be due to viewing difficulties when participants wore pants rather than shorts, when participants did not hold the position long enough to view the end position, and when participants let the heel lift off the ground. Future studies should be aware of these factors when completing the mobility clearing test on the ankle.

There were limitations related to rating the participants. The first limitation included a non-standard distance that the participant was from the video recording making some videos easier to see than others. The second limitation included the rater’s choice of an area that was non-distracting to observe and score the participants. This location was supposed to be used each time the rater observed and
Table 2. Intraclass Correlation Coefficient (ICC) for the Clearing Tests

<table>
<thead>
<tr>
<th>Clearing Test</th>
<th>ICC</th>
<th>Confidence Interval (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Ankle Clearing Test for Pain</td>
<td>0.92</td>
<td>0.88, 0.95</td>
</tr>
<tr>
<td>Right Ankle Clearing Test for Mobility</td>
<td>0.76</td>
<td>0.55, 0.87</td>
</tr>
<tr>
<td>Left Ankle Clearing Test for Pain</td>
<td>1.00</td>
<td>-</td>
</tr>
<tr>
<td>Left Ankle Clearing Test for Mobility</td>
<td>0.63</td>
<td>0.34, 0.79</td>
</tr>
<tr>
<td>Shoulder Clearing Test for Mobility (Right and Left)</td>
<td>1.00</td>
<td>-</td>
</tr>
<tr>
<td>Spinal Extension Clearing Test</td>
<td>0.88</td>
<td>0.82, 0.93</td>
</tr>
<tr>
<td>Spinal Flexion Clearing Test</td>
<td>1.00</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 3. Intraclass Correlation Coefficient (ICC) for Raw Scores on the Movement Patterns

<table>
<thead>
<tr>
<th>Movement Pattern</th>
<th>ICC</th>
<th>Confidence Interval (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep Squat</td>
<td>0.78</td>
<td>0.66, 0.87</td>
</tr>
<tr>
<td>Right Hurdle Step</td>
<td>0.85</td>
<td>0.76, 0.91</td>
</tr>
<tr>
<td>Left Hurdle Step</td>
<td>0.91</td>
<td>0.86, 0.95</td>
</tr>
<tr>
<td>Right Inline Lunge</td>
<td>0.81</td>
<td>0.70, 0.88</td>
</tr>
<tr>
<td>Left Inline Lunge</td>
<td>0.82</td>
<td>0.72, 0.89</td>
</tr>
<tr>
<td>Right Shoulder Mobility</td>
<td>0.85</td>
<td>0.77, 0.91</td>
</tr>
<tr>
<td>Left Shoulder Mobility</td>
<td>0.94</td>
<td>0.88, 0.96</td>
</tr>
<tr>
<td>Right Active Straight-Leg Raise</td>
<td>0.94</td>
<td>0.88, 0.96</td>
</tr>
<tr>
<td>Left Active Straight-Leg Raise</td>
<td>0.95</td>
<td>0.92, 0.97</td>
</tr>
<tr>
<td>Trunk Stability Push Up</td>
<td>0.96</td>
<td>0.94, 0.98</td>
</tr>
<tr>
<td>Right Rotary Stability</td>
<td>0.88</td>
<td>0.80, 0.93</td>
</tr>
<tr>
<td>Left Rotary Stability</td>
<td>0.96</td>
<td>0.94, 0.98</td>
</tr>
</tbody>
</table>

Figure 1. Mean Total Scores Between Raters
scored a participant; however, the only way that this was
monitored was through verbal confirmation. Lastly, all the
participants were in their 20s or 30s, healthy, active, and in
graduate school. Future studies could examine various ages
of participants and include participants that have comor-
bidities.

CONCLUSION

The results of this study indicate that four novice raters
who were minimally but adequately (4.5 hours of training
and three practice attempts) trained can reliably score indi-
viduals on the updated FMS™. A reliable screening tool al-
 lows physical therapists to observe and intervene with their
patients, clients, or active adults quickly, so that they can
be proactive and potentially reduce the likelihood of future
injury and/or pain.

DISCLOSURES

The authors of this study express that there are no conflicts
of interest. The results shown are not endorsed or funded
by the authors of the National Strength and Conditioning
Association or any outside source.

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CDT
REFERENCES


SUPPLEMENTARY MATERIALS

Appendix A
Evaluation of the Back-in-Action test Battery In Uninjured High School American Football Players

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Keywords: American Football, injury prevention, youth, test battery, knee

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Background
Return to sport testing is an established routine, especially for athletes who have ruptured their anterior cruciate ligament (ACL). Various tests are performed, often combined in test batteries, such as the Back-in-action (BIA) test battery. Unfortunately, pre-injury performance is often unknown, and only few athletes pass the high demands of these test batteries.

Purpose
The aim of the study was to determine the performance of under 18 American football players on the BIA to establish pre-injury sport specific benchmarks for future RTS testing and to compare these values to data from an age-matched reference group.

Methods
Fifty-three healthy male American football players underwent a functional assessment using the "Back-in-action" test battery evaluating agility, speed (Parkour-Jumps and Quick-Feet test), balance (using a PC based balance board), and power (Counter-Movement-Jump [CMJ]) as objective measures. Their results were compared with a previously tested reference group (RP) and within the American football players (AF) through three subgroups according to field playing position.

Results
Overall, the American football (AF) athletes showed lower balance scores for both legs (AF: 3.71/3.57/3.61; RP: 3.4/3.2/3.2; p<0.002) compared to the reference population (RP). CMJ height and Quick-Feet results were not statistically different (p>0.05), Parkour-Jump times (AF: 8.18/8.13 sec.; RP: 5.9/5.9sec.; p<0.001) were significantly slower. Power output in all CMJ’s (AF: 46.86/36.94/37.36 W/kg; RP: 43.2/29.5/29 W/kg; p<0.001) was significantly higher than the RP. Passing and running game involved players (G2 & G3) showed significantly better balance scores (G2+G3: 3.56/3.27/3.33; G1: 4.22/4.06/4.10; p<0.001), higher jump height (G2&G3: 38.87/24.02/24.96 cm; G1: 32.03/19.50/18.96 cm; p<0.001) and more watts/kg (G2&G3: 48.83/37.21/37.64 W/kg; G1: 45.95/36.88/36.53 W/kg; p<0.001) compared to blocking players like Linemen (G1) and to the age matched reference population (RP).

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Conclusion

Only 53% of the healthy athletes would have been cleared for sport using the BIA test criteria, which highlights the challenging passing criteria. Despite significantly greater power measurements, scores of balance and agility were poorer compared to the reference group, especially for linemen. These data may serve as sport and position specific reference for high school American football players, instead of using the non-specific reference group data.

Study design

cross-sectional study-

Level of evidence

IIb

INTRODUCTION

American Football is the most popular contact team sport, especially at the high school level. Nevertheless, injury profile and injury risks are high. The knee is most commonly affected by injury (20%) and overuse conditions (39% in under 14-year aged players, 19% in high-school players), mainly involving structures such as the ACL, MCL and meniscus.1–4 While technical and tactical teaching reduces risk of injury due to contact, performance training may effect intrinsic risk factors positively.5 Therefore, performance and skill training counteracts intrinsic factors for injury. This is especially important in young athletes as repetitive trauma or overuse may lead to early osteoarthritis in adulthood.6

Commonly, drills and exercises such as quick changes of direction, fast movements on toes, jumping jacks, and strength training have become a part of routine training in American football. Strength, speed, and power are known to have an impact on becoming a starter and are tested in athletes on a regular basis and are important components of the NFL combine test.7 Balance as indicator for subsequent injuries is not included, despite the known effect of injury on an American football career.8–10

Moreover, within the course of return to sport after injury, balance measures, such as the Y- Balance test, or the single leg hop test are proposed to be predictors for a safe return.11–15 Unfortunately, these tests rely partly on subjective impression of the evaluator and are criticized as uncertain as predictive tools.16,17 In contradiction, computerized wobble boards have shown a good reliability compared to conventional tests.17,18 Consequently, various test batteries which include strength, agility, and balance measures have been suggested and implemented, but recent research has questioned the value of these batteries.19–22 The "Back-in-Action" (BIA) field test battery uses data derived from five functional tests (one-legged and two-legged balance; one-legged and two-legged Counter-Movement-Jumps; Plyometric Jumps; one-legged Parkour Jumps and Quick Feet), to provide objective cut-off values for return to sport (RTS) post injury.19,21,23 In the introduction of the BIA test battery, an unspecific reference group giving "normal" values was established for comparison and benchmarking. Unexpectedly, the proposed cut-off values for return to sport are hard to meet and limb symmetry demands of >90% are a matter of discussion.24–27 Several studies on healthy untrained boys as well as professional athletes have discovered significant limb symmetry differences as well, and with this in mind, achieving limb symmetry seems desirable, but may be unrealistic.28,29

Normative performance values for American football players (outside of those reported from the NFL combine) test are missing, and cutoff values for the BIA, related RTS for these athletes are unknown. Due to the broad variety of physical demands of different field positions in football, athletes have widely variant physical properties/abilities matching these requirements. Commonly, athletes of different playing positions train separately.

Therefore, the aim of the study was to determine the performance of under 18 American football players on the BIA to establish pre-injury sport specific benchmarks for future RTS testing and to compare these values to data from an age-matched reference group. It was hypothesized that significant differences would exist in BIA performance among position-specific groups of which may help establish position-specific benchmarks.

MATERIALS AND METHODS

The study was approved by the local responsible ethic / IRB approval (AZ 19-8899-BO). Athletes (aged 16–17 years) were recruited from an American football state team. Participation was only granted with a signed informed consent of the parents. All athletes were tested during the first three days of the annual autumn training camp of the 2021/2022 season.

Athletes were divided into three groups according to field playing position. This was done due to the training differences as well as the position-specific requirements of the game. Therefore, playing positions with similar requirement profiles were combined and detailed description is outlined below:

Group 1 (G1) includes players of defense (D-LM) and offense line (O-LM), centers (C), offensive guards (OG), offensive tackles (OT) and defensive tackles (DT). They only cover short distances on the field and have no ball carrying tasks. Explosive movement and a stable stand in tackling are beneficial.

Group 2 (G2) includes linebacker (LB), defensive back (DB) and tight end (TE), defensive ends (DE) athletes with...
limited movement on the field. These positions require blocking and tackling and rarely ball-carrying. Explosive movement and agility are beneficial.

**Group 3 (G3)** includes running backs (RB), wide receiver (WR), quarterback (QB) as well as cornerbacks (CB), safeties. These athletes are the ball carrying athletes majorly involved in yard gain. High acceleration and agility are of importance.

**PROCEDURE**

All athletes answered a questionnaire just before participation. Anthropometric data including height, weight and dominant leg were obtained before testing. Prior to testing, participants completed their regular five-minute warm-up of jumping jacks, shuttle run, stretching and agility exercises. Athletes who were injured, undergoing rehabilitation, or those with less than three years of sports experience were excluded from the study. The assessment was performed according to the guidelines without footwear on plain firm ground without rebound property. In case of an invalid trial, the (sub-)test was repeated once.

**TEST SETUP**

The study was conducted with the Back-in-Action (BIA) test battery (CoRehab, Trento, Italy). This assessment was originally designed for patients after ACL surgery to guide the return to sport process. Moreover, this series of test offers objective cut-off values for athletes before a return to competition. A detailed description of the test battery has been published, with an observer independent test-retest reliability that varies between 0.688 and 0.921.\(^\text{19,21}\)

The test battery determines agility, strength, balance, and speed. Subtests are performed two-legged and one-legged with the dominant (d) and non-dominant (nd) leg in the following order.

The dominant leg was defined as the leg, which an athlete described as his stronger leg in the questionnaire before participation.

**BALANCE**

Balance was measured for 20 seconds by a computer-based balance board (MFT Challenge Disc, TST, Trendsport, Grosshöflein, Austria) with biomechanical feedback given on a screen. A moving point on a target indicated the actual center of gravity. Increasing distance to the center (of the target) results in higher and thereby worse balance scores (1 to 5). Two-legged (TL Bal.) and one-legged balance (OL d/nd Bal.) was evaluated separately.

**STRENGTH**

Counter-movement-jumps were recorded by a sensor (Myotest S.A., Sion, Switzerland) placed on the iliac crest, recording jump height (cm) and calculating power (W/kg). Good reliability regarding the placement and max. velocity measurements have been demonstrated by others before.\(^\text{30-32}\) The use of arms while jumping was prohibited, and the hands were placed on the waist. In the one-legged CMJ, athletes were asked to jump off with the respective leg but were allowed to land with both legs. Two-legged (TL CMJ) and one-legged (OL d/nd CMJ) counter-movement jumps were recorded separately.

**SPEED AND AGILITY**

The Parkour jumps include four alternating forwards/backwards and sideways jumps (sequence: 4x forward-backward-forward-sideways) over 1cm wide soft bars for time. Correct execution of the jump sequence was a mandatory requirement, a failed trial (falling, setting the opposite foot down) resulted in a restart. Time (sec.) was monitored by the test operator. One-legged Parkours jumps (OL d/nd Pk.) with the dominant and non-dominant leg were recorded sequentially.

The Quick-feet exercise (QF) requires completing fifteen alternating steps with the feet, inside and outside a box (40x40cm), which was built of soft bars. Repetitions (sequence: inside-inside-outside-outside) was performed as quickly and accurately as possible. Only a correct execution was counted as repetition. A failed trial resulted in a restart. Repetition counting and time monitoring (seconds) was done by the test operator.

The test battery compared the results of the single-leg tests and calculated a symmetry index between the limbs for each assessment. LSI was calculated by dividing the measured value of the non-affected leg by the value of the injured side and multiplying by 100. LSI indicates equivalence in performance (%) between the legs. A symmetry of 100% implies that there are no differences in performance between both limbs.

The respective results are compared with a healthy, untrained age and gender matched reference population (no American football athletes), collected by Herbst et. al.\(^\text{19}\)

The procedure and exercise set-up used for this investigation are previously described in detail by Herbst et al. and Hildebrandt et al. and were accordingly undertaken without variation.\(^\text{19,21}\)

**STATISTICAL ANALYSIS**

The collected data were processed and analyzed using SPSS 26.0 (IBM Statistics, Armonk, NY, USA). Normal distribution was tested using the Kolmogorov-Smirnov-test. Depending on the results analysis of variance (ANOVA), Mann-Whitney-U test (2 groups), or the Kruskal-Wallis test (3 groups) were used for further analysis. For correlation analyses, Pearson correlation was applied. The correlational values (r= Pearson’s r) were interpreted as negligible (0.00-0.30), low (0.30-0.50), moderate (0.50-0.70), strong positive (0.70-0.90) and very strong positive (0.90-1.00). Statistical significance was determined at p<0.05.

**RESULTS**

A total of fifty-three male athletes were included in this investigation. Among these, 19 athletes had to be assigned to
Table 1. Anthropometric data of the U18 Football athletes overall and the data of the particular position groups

<table>
<thead>
<tr>
<th></th>
<th>U18 (n=53)</th>
<th>Group 1 (n=19)</th>
<th>Group 2 (n=20)</th>
<th>Group 3 (n=14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>90.70 ± 19.92</td>
<td>110.4 ± 16.3</td>
<td>79.25 ± 11.8</td>
<td>80.29 ± 11.1</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>184.85 ± 6.8</td>
<td>188.37 ± 6.9</td>
<td>181.35 ± 5.4</td>
<td>185.07 ± 6.3</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>26.42 ± 5.0</td>
<td>31.13 ± 4.3</td>
<td>24.06 ± 3.1</td>
<td>23.39 ± 2.8</td>
</tr>
</tbody>
</table>

Anthropometric data of the U-18 athletes overall and of the three position-specific groups; kg= kilograms; cm= centimeter

Table 2. Balance scores of wobble board performance (1= best score; 5= worst score)

<table>
<thead>
<tr>
<th></th>
<th>Reference Population RP (n=430)</th>
<th>U 18 (n=53)</th>
<th>Group 1 (n=19)</th>
<th>Group 2 (n=20)</th>
<th>Group 3 (n=14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balance TL</td>
<td>3.4</td>
<td>3.71 ± 0.7</td>
<td>4.22 ± 0.5</td>
<td>3.46 ± 0.6</td>
<td>3.36 ± 0.7</td>
</tr>
<tr>
<td>Balance OL d</td>
<td>3.2</td>
<td>3.57 ± 0.8</td>
<td>4.06 ± 0.6</td>
<td>3.30 ± 0.7</td>
<td>3.27 ± 0.7</td>
</tr>
<tr>
<td>Balance OL nd</td>
<td>3.2</td>
<td>3.61 ± 0.7</td>
<td>4.10 ± 0.6</td>
<td>3.34 ± 0.5</td>
<td>3.33 ± 0.6</td>
</tr>
</tbody>
</table>

Balance results of the reference population, U18 overall and the 3 position-specific groups in the BIA Balance-Tests; higher balance scores represent a worse balance; "**" highlight p-values <0.001 and therefore statistical significant differences; "*" indicates a better result than the reference population, while "↓" indicates a worse result than the reference population; TL= two-leg; OL= one-leg; d= dominant leg; nd= non-dominant leg; RP= reference population

For leg symmetry, 25 of 53 athletes (47%) showed a leg difference of over 10%.

COUNTER-MOVEMENT-JUMPS

A summary of all CMJ measurements is presented in Table 3 for height measures (cm) and Table 4 for power measures (watt/kg). Absolute jump height was not significantly different between all of the football athletes and the untrained subjects (RP) in the CMJ TL, OL/d and OL/nd (p>0.05). In the TL-CMJ, G3 achieved significantly higher jump heights than G1 (p<0.001), but not in comparison to G2 (p>0.05) or the RP (p>0.05). G1 and G2 showed not statistically different jump heights compared to each other and to the RP (p>0.05).

Jump heights of the OL-CMJ d showed no significant differences between all groups (G1 vs. G2 vs. G3 vs. RP: p>0.05). For the non-dominant limb (OL-CMJ nd) G1 showed significantly lower jump heights than G2, G3 and the RP (p<0.001), which were not significantly different.

The football players overall generated a significant higher power output in all jump tests (CMJ TL: p<0.001; OL/ d: p<0.001; OL/nd: p<0.001) than the RP.

CMJ jump height symmetry over 90% was achieved by 18 of 53 athletes (34%).

The power as measured during the TL-CMJ showed no significant differences in G1, G2, G3 (p>0.05). However, G2 and G3 showed significantly better power output values compared to the RP (p<0.001), while G1 did not (p>0.05). Regarding the power output in the single-leg CMJ, no differences were found between the groups OL/d and OL/nd, but athletes were superior to the RP (G1 vs. RP: p<0.001, G2 vs. RP: p<0.001, G3 vs. RP: p<0.001).

53% (28 of 53) of the tested subjects achieved a symmetry index of >90% for power development in the CMJ.
Evaluation of the Back-in-Action test Battery In Uninjured High School American Football Players

Table 3. Jump height results in the CMJ

<table>
<thead>
<tr>
<th></th>
<th>Reference Population RP (n=430)</th>
<th>U18 (n=53)</th>
<th>Group 1 (n=19)</th>
<th>Group 2 (n=20)</th>
<th>Group 3 (n=14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMJ TL Height (cm)</td>
<td>35</td>
<td>36.3 ± 7.4</td>
<td>32.03 ± 6.2</td>
<td>38.56 ± 7.3</td>
<td>38.87 ± 6.9</td>
</tr>
<tr>
<td>CMJ OL d Height (cm)</td>
<td>22.4</td>
<td>22.21 ± 5.6</td>
<td>19.50 ± 4.7</td>
<td>23.52 ± 5.6</td>
<td>24.02 ± 5.6</td>
</tr>
<tr>
<td>CMJ OL nd Height (cm)</td>
<td>21.75</td>
<td>22.80 ± 5.8</td>
<td>18.96 ± 4.7</td>
<td>24.92 ± 4.8</td>
<td>24.96 ± 5.8</td>
</tr>
</tbody>
</table>

Jump height results in centimeter in the CMJ of the reference population, U18 overall and the 3 position-specific groups; *** highlight p-values <0.001 and therefore statistical significant differences, "↑" indicates a better result than the reference population, while "↓" indicates a worse result than the reference population; CMJ= Counter-Movement Jump; TL= two-leg; OL= one-leg; d= dominant leg; nd= non-dominant leg; RP= reference population.

Table 4. Power Development: results in the CMJ

<table>
<thead>
<tr>
<th></th>
<th>Reference Population RP (n=430)</th>
<th>U18 (n=53)</th>
<th>Group 1 (n=19)</th>
<th>Group 2 (n=20)</th>
<th>Group 3 (n=14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMJ TL Strength (W/kg)</td>
<td>43.2</td>
<td>46.86 ± 5.3</td>
<td>43.95 ± 3.4</td>
<td>48.55 ± 6.1</td>
<td>48.43 ± 4.8</td>
</tr>
<tr>
<td>CMJ OL d Strength (W/kg)</td>
<td>29.5</td>
<td>36.94 ± 3.9</td>
<td>36.68 ± 3.0</td>
<td>37.00 ±4.3</td>
<td>37.21 ± 4.5</td>
</tr>
<tr>
<td>CMJ OL nd Strength (W/kg)</td>
<td>29</td>
<td>37.36 ± 3.7</td>
<td>36.53 ± 2.7</td>
<td>37.95 ± 3.8</td>
<td>37.64 ± 4.7</td>
</tr>
</tbody>
</table>

Power development in Watts per kilogram in the CMJ of the reference population, U18 overall and the 3 position-specific groups; *** highlight p-values <0.001 and therefore statistical significant differences, "↑" indicates a better result than the reference population, while "↓" indicates a worse result than the reference population; CMJ= Counter-Movement Jump; TL= two-leg; OL= one-leg; d= dominant leg; nd= non-dominant leg; RP= reference population.

Table 5. Results of the Parkour Jump and the Quick-feet assessments

<table>
<thead>
<tr>
<th></th>
<th>Reference population RP (n=430)</th>
<th>U18 (n=53)</th>
<th>Group 1 (n=19)</th>
<th>Group 2 (n=20)</th>
<th>Group 3 (n=14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parkours d time (sec)</td>
<td>5.9</td>
<td>8.18 ± 3.2</td>
<td>9.70 ± 4.7</td>
<td>7.42 ± 1.3</td>
<td>7.17 ± 1.2</td>
</tr>
<tr>
<td>Parkours nd time (sec)</td>
<td>5.9</td>
<td>8.13 ± 4.1</td>
<td>10.21 ± 6.3</td>
<td>6.99 ± 1.0</td>
<td>7.05 ± 1.3</td>
</tr>
<tr>
<td>Quick Feet time (sec)</td>
<td>8.9</td>
<td>8.96 ± 1.3</td>
<td>9.50 ± 1.4</td>
<td>8.82 ± 1.3</td>
<td>8.42 ± 0.9</td>
</tr>
</tbody>
</table>

Time performance of the reference population, U18 overall and the 3 position-specific groups in the Parkours-jumps and the Quick-Feet test; *** highlight p-values <0.001 and therefore statistical significant differences, "↑" indicates a better result than the reference population, while "↓" indicates a worse result than the reference population; d= dominant leg; nd= non-dominant leg; RP= reference population.

PARKOUR JUMP AND QUICK-FEET (SPEED AND AGILITY)

Time measure results of the Parkour and Quick feet task are presented in Table 5. In the Parkour jumps, American football players overall and each group individually were slower than the RP (p<0.001).

G1 performed significantly slower compared to G2 and G3 with the dominant (G2 vs G1: p<0.001; G1 vs. G3: p<0.001) and non-dominant legs (G2 vs. G1: p<0.001; G3 vs. G1: p<0.001).

Regarding the Quick-Feet test completion times between football athlete and RP groups (p>0.05) were not significantly different. However, G3 was significantly faster than G1 (p=0.05), while no other significant differences between the groups occurred (G1 vs. G2: p>0.05; G2 vs. G3: p>0.05).

For correlation measures, a low correlation was found for on legged balance scores with increased time in the parkour test. (OL/d Bal-OL/d Park.: r = +0.46, p<0.05; OL/nd Bal - OL/nd Park.: r = +0.43, p<0.05). A Correlation for power measures of the CMJ and parkour times of the same limb was not found.

SYMMEtRY

Average symmetry index measures are given in Table 6. Mean measures of the differences in performance between the two legs (symmetry index) of the American football athletes for the one-legged balance and one-legged CMJ jump height were over 10% (mean under 90%) for all three position groups. There were no significant differences between the position groups (p>0.05).

DISCUSSION

BIA performance measures of 53 high level U-18 American football players were reported in order to establish benchmark levels to consider for cutoff values for return to sport test decisions. These young football players showed deficits
Table 6. Symmetry-index (in %) of the one-legged performed subtests

<table>
<thead>
<tr>
<th></th>
<th>U18 (n=53)</th>
<th>Group 1 (n=19)</th>
<th>Group 2 (n=20)</th>
<th>Group 3 (n=14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symmetry Balance</td>
<td>88.54 ± 7.9</td>
<td>88.58 ± 9.5</td>
<td>87.35 ± 7.2</td>
<td>89.79 ± 6.9</td>
</tr>
<tr>
<td>Symmetry CMJ jump height (%)</td>
<td>84.37 ± 12.0</td>
<td>83.74 ± 12.3</td>
<td>82.50 ± 14.2</td>
<td>87.57 ± 8.1</td>
</tr>
<tr>
<td>Symmetry CMJ power (%)</td>
<td>93.3 ± 5.8</td>
<td>94.89 ± 5.3</td>
<td>91.45 ± 7.1</td>
<td>93.64 ± 4.03</td>
</tr>
<tr>
<td>Symmetry Parkour Jumps (%)</td>
<td>91.46 ± 7.3</td>
<td>90.00 ± 9.9</td>
<td>92.10 ± 5.2</td>
<td>92.36 ± 5.7</td>
</tr>
</tbody>
</table>

Symmetry index (%) for one-legged performed assessments: balance, Counter-Movement Jump height & power and parkours time; symmetry shows the equivalence in performance between both legs. An index of 100% indicates no difference in performance between both legs. CMJ = Counter-Movement Jump

in balance and rapid/complex movements, while showing comparable results in counter-movement-jumps (jump height), and greater power compared to an untrained reference population. Significant performance differences were also found among the different position groups in several parameters.

**FOOTBALL PLAYERS PRESENT ONLY WITH HIGHER POWER OUTPUT DURING COUNTER MOVEMENT JUMPS COMPARED TO THE REFERENCE POPULATION**

For counter-movement jumps, football players generated about 46.86W/kg (TL), 36.94 W/kg (OL/d) and 37.56W/kg (OL/nd), which significantly greater than the reference population. For American Football, explosive power in movement is an important performance parameter, as it is a discontinuous sport with a series of recurrent intense anaerobic power peaks. Vertical jumps, broad jumps, the 40m Dash, and CMJ are part of the NFL Combine and therefore a fundamental part of the training routine used by football players, which likely affects the development of power. The fact that jump heights of 56.5cm (TL), 22.21cm (OL/d) and 22.8cm (OL/nd) were similar to untrained individuals, is probably due to the elevated body weight of players.

Although the power measures of the American football athletes were superior to the untrained reference group, they are worse when compared to values seen in prior studies. Leutzinger et al. evaluated high school athletes (15-17y) using the NFL Scouting Combine tests, including the vertical jump. Their athletes achieved a vertical jump height of 62.9 cm. This may be due to the fact that the vertical jump test of the NFL combine (as investigated by Leutzinger et al.) is executed with help of the arms, which can lead to about 25% increase in jump height of CMJs according to Sayers. Still, after multiplication by 1.25, the current results add up to 45.28 cm, which is still diminished, but comparable to 12-year-old players. This may be due to the methods used in the current study: the digital Myotest accelerometer versus Leutzinger’s analogue Vertec jump trainer are different and accuracy might be impaired. Unfortunately, only a limited number of studies depict power development in Watt/kg of CMJ in 16-17 years old American football players. McKay and Leutzinger reported approx. 6008 watts, 64.99 W/kg body weight. When applying Sayers formula, peak anaerobic power output averaged at approximately 4806 watts, about 53 W/kg in this investigated population of American football players.

Once again, different measurement devices may partly account for these differences or even hide greater differences, as calculation of watt/kg with the Myotest sensor remains unanalyzed and Vertec measurements in an analogue manner rely on half inch increments only. Power development itself is the most useful performance parameter in football: it is associated with the career longevity, a predictor for injury risk and the RTS capability. As the BIA test battery was originally designed to discriminate athletes recovering from an ACL injury regarding their readiness to return to sport, this aspect may be particularly interesting. Regarding ACL injury, the quadriiceps to hamstring ratio is an important indicator of function in ACL deficient knees. Additionally, quadriiceps strength predicts the long term function after ACL reconstruction. Clearly, isometric measures of strength were not undertaken in this field test investigation and therefore comparison is insufficient. Worth mentioning, power development ratio in counter movement jumps measured by a force platform was most recently correlated to ACL injury in the future by Pontillo.

**FUNCTIONAL TESTS REVEAL MAJOR DEFICITS IN KNEE CAPABILITY MEASURES**

In comparison to an untrained population (RP), the American football players of this study performed significantly worse in multiple subtests. The results in the one-legged balance test (Bal. OL d/nd) were particularly notable, in which American football players performed significantly worse. Previous researchers report ambiguous data on wobble board performances in association with body height, limb length, and the related center of gravity. In the current study there was only a low correlation between body height and worse balance scores. During NFL Combine testing balance is not measured, but agility, coordination, and explosiveness are with a three-cone drill, which is similar to the Parkour Jumps used in the BIA test battery. It is debatable whether single-leg balance or the single-leg CMJ results are associated with the results in the single-leg Parkour Jumps. A low correlation between worse one-legged balance scores and higher Parkours times was found in our athletes. However, there is no correlation between power measures in the respective OL CMJs and parkour times, even though the parkour consists of a sequence of repetitive single-leg jumps.

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The results of the Quick-Feet test are not significantly different to the results of the reference population. This is surprising, as similar exercises like the Quick-Feet Ladder are an elementary part of football training routine. A better result for football players was expected in this assessment as was seen in the power results from the CMI.

In addition to the performance parameters mentioned above, the symmetry values regarding balance, jump height, jump force and parkour times are also relevant for the evaluation of the RTS permission of the BIA test battery. Moreover, this measure has been proposed by many researchers before with varying target values between 85-95%. Unexpectedly, the symmetry indices of the BIA test battery were commonly not met by athletes nine months post ACL reconstruction surgery. Further research on limb symmetry has shown decrements in physical performance in athletes with inter-limb symmetries as measured by the balance test. In contradiction, regained limb symmetry after ACL injury may overestimate knee function.

For the BIA test battery, a inter-limb difference >10% (symmetry index>90%) is set as cut off for the RTS, which was validated by testing healthy, uninjured athletes. Only 53% of the American football athletes in the current study (28 of 53) achieved a symmetry index of >90% for power development in the CMJ, only 18 (34%) in jump height measures, only 25 (47%) in balance scores. This may also be relevant to performance parameters, as Fort-Vanmeerhaeghe et al. demonstrated that increased asymmetry is associated with lower acceleration and consequently slower 30m sprint times, as well as increased risk of injury. This relationship is illustrated in the current results, as G1 players with low symmetry indices and overall worse BIA results have also been considered in the literature to be the most injury-prone playing position.

Research on healthy high-level athletes in Judo and Taekwondo has revealed inter-limb differences in a different test, the so called "5-hop test", of over 10 percent in almost 25% of the athletes and the significance of inter-limb differences in uninjured trained athletes remains a matter of debate. Therefore, it remains questionable whether inter-limb symmetry is a reliable marker for a RTS decision. Also, the ratio between the extremities does not consider absolute performance results. Normalized data for jump and hop tests are necessary.

Considering the original purpose of the BIA-assessment, the results of the current study are particularly interesting. The test battery sets a threshold of a BIA-score of 3.0, a calculated score after all tests, for a RTS permission. This score has a scale from 1 (best) to 5 (worst) in all four qualities/categories: balance, agility strength and speed. Among these qualities, different tests used to form a score for each quality, which is later averaged in the BIA-Score. In the hypothetical case of injury or rehabilitation, only 17% (9 out of 53) of the athletes would achieve RTS permission. Herbst et al. applied even more restrictive thresholds for high-risk sports (e.g. alpine skiing, soccer, handball or American football), requiring at least a BIA-score of 4.0 to receive RTS permission. Considering these cut-off values, none (0%) of the athletes would reach RTS criteria with their performance, although none of the athletes were recovering from injury, but were participating in routine practice and games. This is consistent with results from Australia and the Netherlands, where the RTS criteria of this test battery were met by only 2.5% and 17.5% 9 months / 11 months post ACL surgery respectively. There are two possible explanations for these unexpected results. It may be that the BIA test battery has too high standards for RTS and therefore may have limited utility. This is consistent with the low passing rates post ACL surgery as described above. Or, in contradiction, the examined American football players just did not perform well at all which may be a warning signal for coaches and staff. Uncovered deficits should be addressed by specific training to minimize the potential risk of injury. In this context, the BIA test battery can be used as a training tool as well for progress measurement.

POSITION-DEPENDENT DIFFERENCES IN TEST-PERFORMANCE AND INJURY RISK

Significant differences in performance were noted among the respective position groups in certain tests. Athletes from G2 and G3 had similar anthropometry and achieved equivalent results in the tests, whereas differences in anthropometric characteristics and results were noted with G1, which performed significantly worse in most assessments, but not in power development (CMJ) and the Quick-Feet task. It is likely that these assessments are most likely to be part of the training routine and therefore well known to most of the athletes.

BMI itself appears to correlate with outcomes and injury risk, as has been postulated for the NFL roster status of linebackers and defensive linemen. The current results affirm these findings, as low to moderate significant correlations were found between increased BMI and worse results in the assessments. As expected, lower BMI (G2 and G3) was associated with better results in balance and agility, which is contrary to the power measurements. When calculating anaerobic peak performance according to Sayers, athletes from G1 showed significantly higher absolute values in anaerobic peak force development (p<0.05), but not with respect to body weight (power per kg). These findings are consistent with results by Leutzinger et al., where athletes of the offensive line and defensive line (G1) performed worse in the pro-agility drill and L-cone drill, which also require good agility and balance. These results are interesting as they present in the early stage of the career, not only in athletes joining the NFL combine. Playing positions that require tackling (G1) had heavier athletes and showed higher power outputs. This is likely due to the requirements of this position which demands explosive power in just a few steps and in one direction. Players, who participate more in the passing and running game, are lighter, show better agility and balance, and similar power when normalized by mass (kg).

Within the context of injury and prevention, the categorization among these three groups is relevant, as well. In youth and professional football, linemen have a three-fold increased risk of injury, followed by running backs and
wide receivers, possibly due to frequent involvement in play actions and tackling. The current measurements reveal impaired results for the above listed position Group 1 including linemen (G1), which were alarmingly even below results of an age matched reference population. Comparably, recent studies have found a correlation between injury risk of the lower extremity and BMI >26 kg/m^2 in high school aged linemen. In recent studies, high quadriceps strength has been determined as an important predictor of a safe RTS ability. In the assessments that determine power (CMI), G1 achieved high power-output performance values with a high inter-limb symmetry over 95%. Contrary to this, other symmetry values of G1 athletes and assessment results are below the thresholds of a safe RTS. Further investigation is needed to determine which predictor (e.g. symmetry of power or balance) has the strongest influence and how performance parameters as well as functional assessment results should relate to each other for a safe RTS. The usefulness of the BIA test battery with the existing cut off values for high school American football players has to be questioned.

LIMITATIONS

This study has several limitations. The study was only performed on a small sample of 53 uninjured athletes. In the context of performance measurement, focus is mostly on the knee and influence of the neighboring joints or core stability are not well assessed.

The study was done during the pre-season, so it cannot be assumed that all athletes had already reached their highest fitness level at that time. Currently, the BIA test battery results have no proven predictive value for injury. Future research should therefore clarify the effect of the BIA test battery performance on injury risk and reevaluate the threshold for a RTS in high school American football players.

CONCLUSION

The results of the current study provide detailed performance measures of high school American football players with the BIA test battery. Measurements vary broadly from measures of the reference population and it remains questionable if athletes’ performance is alarmingly insufficient or if the BIA is of limited use among American football athletes. Especially heavier players including linemen, guards, and tackles, showed impaired results and may be at risk for later injury. Nevertheless, this data gives sport specific benchmarks for high-school American football players and results may serve as reference in case of injury.

DISCLOSURE OF INTEREST

The authors report no conflicts of interest.

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REFERENCES


Case Reports

Isokinetic Training Program to Improve the Physical Function and Muscular Performance of an Individual with Partial Injury of the Medial Meniscus: A Case Report

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Keywords: dynamometer, knee, meniscus, muscle strength, torque

International Journal of Sports Physical Therapy

Background and Purpose

One of the best alternatives for the treatment of meniscal injuries in relation to surgical procedures, is exercise. This case report aimed to describe the effects of isokinetic training and a neuromuscular/proprioceptive exercise program on muscle performance and physical function in an individual after a rupture of the posterior horn of the medial meniscus.

Study Design

Case report.

Case Description

A 40-year-old man injured his right knee during a soccer match, with a partial lesion of the medial meniscus confirmed by magnetic resonance imaging. He completed an isokinetic training program in addition to exercises that targeted proprioception (22 sessions, 11 weeks) to improve physical function and performance, which were assessed before and after treatment and at a six-month follow-up. An individual with similar anthropometric characteristics was chosen to be used as a control for understanding the patient’s assessment values.

Outcomes

Muscular performance of the knee flexors and extensors was evaluated isokinetically using the Biodex System-4 in a concentric mode at angular velocities of 60, 120, and 300 °/s. The main results indicated that after 11 weeks, the peak torque normalized to body mass (PT/BM), at 60 °/s of the knee extensors remained unchanged (2.54 N.m/kg) (below the control value - 3.06 N.m/kg), and at the six-month follow-up, increased by approximately 20% (3.08 N.m/kg). For the hamstrings, at 60 °/s, an increase of 18% occurred after intervention (1.98 N.m/kg) and by approximately 30% at the six-month follow-up (2.12 N.m/kg) - values much higher than the control 1.55 N.m/kg). This increase in the PT/BM was also reflected in the Hamstrings:Quadriceps ratio (78%) after treatment which improved at follow-up (68%).

Discussion

The results showed that the isokinetic training and neuromuscular/proprioceptive exercises improved the muscle performance of the knee flexors and extensors, after...
eleven weeks of intervention, and remained (or continued to improve) at the six-month follow-up.

**Level of evidence**
5, single case report

**BACKGROUND AND PURPOSE**

Meniscal injuries are common, with an annual incidence of 79 injuries per 100,000 individuals aged 15–40 years, men and the medial meniscus (compared with the lateral meniscus), is most commonly affected.1–3 Although the diagnosis is made through history and clinical examinations, this lesion type is challenging and usually requires magnetic resonance imaging (MRI) for confirmation.4 Surgery is often the treatment of choice, and for many years, it has been a standard practice for surgeons, with total or partial removal of the affected menisci to mitigate the clinical symptoms arising from meniscal injuries.5–7 In 2014, 516,800 meniscectomies were performed in the United States alone, generating an annual cost of US $ 4 billion.8,9

These paradigms have undergone changes because surgical procedures do not present greater benefits than conservative treatment, when analyzed through surgical recurrences and development of knee osteoarthritis (OA) after meniscectomy.2,5 Therefore, surgery should not be the first option, and accordingly, in recent years, the number of surgical procedures has reduced.10–14 Englund et al.15 and Chirichella et al.16 pointed out that conservative treatment remains one of the pillars for the treatment of meniscal injuries, particularly in stable meniscus tears, to preserve this tissue whenever possible. Through a systematic review and meta-analysis, Swart et al.17 assessed the effectiveness of exercise therapy for the treatment of patients with meniscal injuries and concluded that exercises were comparable to meniscectomy in terms of pain, function, and knee performance outcomes. However, exercise therapy showed higher value related to short-term strength gain, making it more effective. In addition, patients who underwent exercise therapy showed better pain and knee function outcomes, both before and after meniscectomy surgery, than patients who did not undergo exercise.

Currently, the isokinetic dynamometer is an accepted resource for the conservative treatment of the locomotor system, and is useful for evaluation and strength training, especially for knee injuries.18,19 Isokinetic exercise for strength training is characterized by constant velocity that accommodates the individual’s muscular work throughout the range of motion (ROM).20 Testing can provide objective outcomes related to power, total work, and peak torque, which can be represented as a percentage when normalized to body mass.21 Another way to explore isokinetic results is to divide the ROM into three components: time to reach velocity, load range (LR), where the specific velocity set is sustained, and deceleration time. These distinct phases can provide additional information, such as reaction time and ability to maintain velocity, which may assist in the clinical evaluation and implementation of specific treatment protocols to optimize treatment.22

In a study by Belhaj et al.,23 patients with meniscal injuries received classical conservative and isokinetic interventions to increase muscle strength in the quadriceps and hamstrings. They reported improvements at the end of the treatment and the highlighted the importance of the intervention to conserve the meniscus, demonstrating the isokinetic dynamometer as a resource to be used not only for evaluation but also in treatment. However, no studies have investigated an intervention protocol “with emphasis” on the use of the isokinetic dynamometer for strength training in individuals undergoing conservative treatment after meniscus injury. Thus, this case report aimed to describe the effects of isokinetic training and neuromuscular/proprrioceptive exercise program on muscle performance and physical function in an individual after a rupture of the posterior horn of the medial meniscus.

**SUBJECT CHARACTERISTICS**

A 40-year-old man with a body mass index of 27.8 kg/m² was referred for evaluation at the Laboratory of Biomechanics and Clinical Epidemiology of the University Hospital/UEL. During a soccer match, he suffered a contact injury of the right knee, clinically diagnosed as a meniscal tear. The MRI results indicated medial and lateral patellofemoral and tibiofemoral chondropathy, vertical/oblique rupture with a horizontal component characterized on the periphery of the posterior horn of the medial meniscus, and tendinopathy of the semimembranosus. From this, an exploratory meniscectomy was proposed by the surgeon responsible for the case; however, the patient opted for conservative treatment.

The treatment plan consisted of 22 sessions of isokinetic and neuromuscular/proprrioceptive training over the course of 11 weeks. Muscle performance and physical function were assessed before and after treatment, and at a six-month follow-up. The participants (the subject and the matched control) signed an informed consent form and the study was approved by the IRB (#00768812.0.5251). The use of uninvolved limbs after musculoskeletal injuries as a control is not desirable, as this limb may be compromised. In order to avoid any interference, the authors chose to invite an athlete with similar anthropometric characteristics to participate and serve as a control for strength data.

**OUTCOMES**

**INITIAL EXAMINATION/CLINICAL MEASURES**

Initially, an examination was carried out – one month after the injury (personal data, history of the injury, and physical examination), followed by the Apley and McMurray tests and ligament analysis: the Lachman, anterior drawer, Slocum, varus and valgus stress, and Pivot Shift tests. More
information is available in the Supplementary Material (#1).

PHYSICAL FUNCTION

The Lower Extremity Functional Scale (LEFS) was used to assess functional activities. This questionnaire consists of 20 items with gradual responses from 0 to 4 points, with a maximum score of 80 points. The higher the score obtained, the better the participant’s reported function. The cut-off for clinically meaningful improvement is 11 (area under the receiving operator curve = 0.96; 95% CI [0.88;0.99]). The patient’s LEFS scores were 74 points at the initial examination, 72 points after treatment, and 76 points at the six-month follow-up, with no limitations on activities of daily living.

MUSCLE PERFORMANCE – DYNAMOMETRY

Muscle performance of the quadriceps and hamstrings was assessed using the Biodex System 4 (Biodex Medical System Inc., Shirley, NY, USA) in a concentric mode at angular velocities of 60, 120, and 300 °/s, with a sampling frequency of 100 Hz (Video Supplementary Material #2). The participant was instructed to not perform any physical activity on the testing day. First, the patient completed a 10-min warm-up on a cycle ergometer, without resistance, at a speed of 30 km/h. Then, a familiarization process was conducted which consisted of two sets of 10 repetitions (in each velocity). (Video Supplementary Material #2)

The individual was positioned on the dynamometer seat and stabilized with straps around the trunk, pelvis, and thighs per Biodex protocol. Hip flexion was adjusted to 85 °, the dynamometer axis was aligned with the lateral femoral epicondyle, and the ankle pad was positioned just above the medial malleolus. Active ROM (AROM) of 90 ° for flexion and 0 ° for extension was chosen for testing. However, the extension ROM was defined according to individual limits. All calibration and gravity correction procedures followed the manufacturer’s instruction manual. Five repetitions at each test velocity were performed with a rest interval of 90 s between sets. The participant was instructed to perform at maximum strength during all repetitions, and verbal encouragement and visual feedback were provided. For reliability purposes, a variation coefficient of <10 % for each series was considered acceptable.

The peak torque/body mass (PT/BM) and Hamstrings:Quadriceps ratio (H:Q) were calculated only during the portion of sustained velocity (load range phase). The raw data were extracted using Biodex software and further processing was performed using a specific Matlab® algorithm to accomplish this calculation. Average values of the five repetitions were calculated for all variables at each velocity. The percentual of sustained velocity was calculated in relation to the total ROM.

To create the torque-angle-velocity relationship or surface maps (TAV3D), the mathematical “surf” function of Matlab® was used. All five repetitions of each velocity were interpolated according to the phase duration. The algorithm estimated the intrinsic geometry considering the torque (z axis), the joint angle (x axis), and the speed (y axis) in the same time interval. The z axis defined the height of the map in relation to the force intensity, while the x and y axes formed the surface boundaries. Qualitative analysis with TAV3D surface maps improves the interpretation of the test results, making it possible to observe the interaction between torque, velocity, and range of motion. This interpretation can be added to the other results of iso-

Figure 1. Left knee MRI Scan of a medial meniscus tear.
Figure 2. Flymoon® device.

kinetic tests, as the assessment of movement or functional activity could contribute to the decision making and treatment (Supplementary Material #3).29,30

INTERVENTION

Based on the history of the injury, isokinetic measures, and functional status of the lower limb, new neuromuscular/propr ioceptive training and an isokinetic strengthening program were considered the ideal treatment for this patient. It was expected that there would be improvement in neuromuscular control after the proposed training.

INNOVATIVE INTERVENTION

The treatment plan and regimen were distributed among 22 sessions, over 11 weeks. Each treatment session was divided into three components: 1) re-assessment and analysis of the clinical condition; 2) warm-up and strength training with the isokinetic dynamometer, according to the stipulated weekly program, based on the evolution and clinical signs presented; and 5) proprioceptive and stretching exercises on Flymoon® (Figure 2) as described in Table 1. The Flymoon® proprioceptive training intervention consisted of eight proprioceptive and two active stretching exercises (table 2). All movements were performed in three sets of 30 s each.

The velocity-specific training at 300 °/s was used as a warm-up and power training. It started with 70 % of the maximum force (according to initial evaluation – using visual feedback from the isokinetic screen), with 25 repetitions. In addition, the 120 °/s angular velocity was used in the first week for explosive power, with 15 repetitions. This first stage continued until week 3.

From week 4 on, the load was increased to 80 % of maximum force for both velocities. From week 8, the velocity of 300 °/s was used only for the warm-up, 120 °/s was maintained (with 90 %), and 60 °/s was introduced with 60 % of the maximum force. Contractions at slower velocities were applied to align with near maximum tension development.31 At week 9, there was a 10 % increase in strength (to 80%) at 60 °/s velocity, which continued in weeks 10–12.

The patient finished the protocol performing 15 reps at 90 °/s (120 °/s) and 10 reps at 80 %, for three sets (60 °/s).

The training program carried out with Flymoon® followed the exercises described in Table 2, consisting of proprioceptive exercises and active stretching (Video - Supplementary Material #2). All movements were performed in series with activities per minute or for a number of repetitions during all treatment sessions. Sessions were supervised by a licensed physical therapist. In addition to proprioception, Flymoon® encourages neuromuscular control by creating an unstable surface that challenges the proprioceptive system to respond and adapt to the changing conditions; it can be adjusted in degrees of difficulty and can be used in different planes of movement. The equipment allows the challenges of ROM in the ankle, in addition to working the fascia in multiple directions. When standing on the Flymoon®, the principle of biotensegrity is triggered: putting tension on the feet and maintaining this tension while performing movements seems to provide a stimulus for stability in the knee.32 The greatest support occurs between the hallux and the first metatarsals, which activates the anterior deep line. By keeping this line activated, hyperextension (recurvatum) can be avoided.

RESULTS

The anthropometric characteristics of the patient were: 40 years-old and BMI of 27.8 kg/m² and the individual used a control: 40 years-old and BMI of 21.8 kg/m². Table 3 shows the % of sustained velocity (LR) normalized by ROM, values of PT/BM, range of motion, and agonist/antagonist ratio at angular velocities of 60, 120, and 300 °/s for extension and flexion of both knees, involved and uninvolved, of the patient with meniscal injury in the pre, post, and follow-up period and in the control individual. The TAV3D figures are available in the supplementary material #3A and 3B.

DISCUSSION

The results demonstrate a lower PT/BM value in the extensors pretreatment at all velocities, 60, 120, and 300 °/s in relation to the control, while the same was not observed for flexion. This muscle weakness in the knee extensors is expected in patients with medial meniscal lesions because after an injury, the quadriiceps muscle can be affected by neural inhibition, commonly described as arthrogenic muscle inhibition, which results from changes in sensory information related to pain, inflammation, and damage to mechanoreceptors. This reduces strength, which negatively affects movement patterns, contributing to the reduction in joint and postural stability.33–38 Therefore, it has been suggested that intervention be initiated early because the association between meniscal changes combined with knee extensor muscle weakness results in more severe joint changes, such as knee osteoarthritis.39–41

However, at the end of the intervention, the PT/BM value increased in both flexion and extension, at different velocities, in relation to the control and baseline. These findings
Table 1. Training program.

<table>
<thead>
<tr>
<th>Week</th>
<th>Type of exercise/activity</th>
<th>Frequency and volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weeks 1 and 2, Session 1, 2 and 3</td>
<td>Cycle ergometer&lt;sup&gt;a&lt;/sup&gt; Isokinetic Flymoon®&lt;sup&gt;a&lt;/sup&gt; (&lt;table 2&gt;)</td>
<td>Velocity 30 km/h - 10 min. Isokinetic Protocol 70 % of PT at 300 °/s - 4 sets x 25 reps 70 % of PT at 120 °/s - 4 sets x 15 reps &quot;Mobilization of ankle&quot; - 1 rep x 30 s &quot;Ferris Wheel&quot; - 2 reps x 1 min &quot;Frontal Sailboat&quot; - 2 reps x 30 s &quot;Moon dancing&quot; - 2 reps x 1 min &quot;Running in the moon&quot; - 2 reps x 1 min &quot;Squat&quot; - 2 reps x 1 min &quot;Hamstrings stretching&quot; - 2 reps x 30 s &quot;Piriform stretching&quot; - 2 reps x 30 s</td>
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<td>Week 3, Sessions 4-5</td>
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<td>Weeks 4, 5 and 6, Sessions 6 - 11</td>
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<tr>
<td>Week 8, Sessions 14 - 15</td>
<td>Cycle ergometer Isokinetic Flymoon®</td>
<td>300 °/s - free - 3 sets - 25 reps 90 % of PT at 120 °/s - 3 sets x 15 reps 70 % of PT at 60 °/s - 3 sets x 8 reps</td>
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<tr>
<td>Week 9, Sessions 16 - 17</td>
<td>Cycle ergometer Isokinetic Flymoon®</td>
<td>300 °/s - free - 3 sets - 25 reps 90 % of PT at 120 °/s - 3 sets x 15 reps 80 % of PT at 60 °/s - 3 sets x 8 reps</td>
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<td>Week 10-12, Sessions 18 - 22</td>
<td>Cycle ergometer Isokinetic Flymoon®</td>
<td>300 °/s - free - 3 sets - 25 reps 90 % of PT at 120 °/s - 3 sets x 15 reps 80 % of PT at 60 °/s - 3 sets x 10 reps</td>
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</tbody>
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<sup>a</sup> - The cycle ergometer and Flymoon exercises were repeated with the same parameters in all sessions ;
PT = peak torque

Can be attributed to the isokinetic training program because isokinetic exercise is a muscle-strengthening modality that can enable the development of maximum tension by the muscles at all joint angles during ROM, as it is performed at constant velocity, recruiting the largest number of muscle fibers and thus offering greater muscle performance. 42,43

Regarding the muscle H:Q ratio, improvement was seen after treatment compared with that before the treatment by 13.5 % (64.7–78 %) and 6.6 % (68.4-75 %), respectively, at velocities of 60 and 300 °/s. The imbalance in the agonist/antagonist muscular strength ratio may increase the likelihood of injury. 44 Numerous factors are presumed to influence the ratio, for example, age, sex, limb dominance, physical activity, movement velocity, and functional demands of the patient. 45

In the ROM results (Table 3) for extension and flexion, the values obtained before treatment were higher in the patient than in the control, with approximately 8 ° of difference (before = 8 °) at all velocities. These data must be viewed with caution because of the learning factor since the control was only exposed to the dynamometer once. This slight ROM increases may be related to the recovered strength of the quadriceps. 46,47

Overall, these findings suggest that isokinetic variables may be more related to the functional status or capacity knee than to the capacity to generate strength because the control individual had better segment functional capabilities than the patient with meniscal injury, who stood out for demonstrating a predominance of strength. However, in the torque–angle–velocity relationship/surface map (Supplementary Material 3A and 3B), which provides a qualitative analysis, the patient had greater capacity to sustain torque, higher torques at different velocities in both the flexors and extensors, generating greater torque at the end of the movement than the control, with higher values after treatment and at 6 month follow up in relation to baseline.

The limitations of this study include the lack of assessment of muscle eccentric capacity and proprioceptive measure. Future studies involving patients with a partial meniscal tear should include isokinetic muscle training as well as neuromuscular/proprioceptive exercise program.

CONCLUSION

The results of this case report demonstrate that 11 weeks of isokinetic muscle training and neuromuscular/proprioceptive exercises led to an increase in the PT/BM for the knee extensors and flexors at different velocities in the included subject. These results indicate that isokinetic dynamo-
<table>
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<th>Exercises</th>
<th>Position and commentary</th>
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<tbody>
<tr>
<td>1. “Mobilization of ankle”</td>
<td>Stand barefoot in the middle of the Flymoon® performing plantiflexion/dorsiflexion movements.</td>
</tr>
<tr>
<td>2. “Ferris Wheel”</td>
<td>Stand inside the equipment, one foot touching the metatarsal and the other the distal metatarsal. Perform a combination of movements of one leg, with hip, knee, and dorsiflexion and the other leg hip extension, knee extension, and plantiflexion.</td>
</tr>
<tr>
<td>3. “Frontal Sailboat”</td>
<td>Stand between the edges of the arch. One leg with knee extension and heel touching the lateral of the instrument and the other leg with a combination position of hip internally rotated, knee flexion touching the edge of the tool, and foot supported inside the device. Combined movements of bilateral knee flexion associated with squat.</td>
</tr>
<tr>
<td>4. “Moon dancing”</td>
<td>Stand between the edges of the Flymoon®. One leg in the position of hip internally rotated, knee extension, and heel touching the lateral of the equipment and the other leg hip, knee flexion, and foot supported in the apparatus. Combined opposite movements of lower extremities.</td>
</tr>
<tr>
<td>5. “Walk in the moon”</td>
<td>Stand with feet touching the edge of the instrument. With the feet parallel and gaze focused ahead, perform a combination of movements simulating walking.</td>
</tr>
<tr>
<td>6. “Squat”</td>
<td>Stand inside the instrument. Both feet supported with metatarsals on one edge of the Flymoon®. Knees touching the other edge. Stand holding the arms straight out in front of the body at shoulder mark, parallel to the floor. Push the hips back and lower the body as far as possible. Pause, then push the body back to the starting position.</td>
</tr>
<tr>
<td>7. “Running in the moon”</td>
<td>Stand with feet touching the edge of the equipment. With the feet parallel and gaze focused ahead, perform a fast combination of movements simulating walking.</td>
</tr>
<tr>
<td>8. “Random walking”</td>
<td>Stand inside the instrument. Perform a random combination of movements of heel-to-toe motion.</td>
</tr>
<tr>
<td>9. “Hamstrings stretching”</td>
<td>Stand with right foot inside the apparatus, set slightly in front of the body, and flex right foot toward face. Use hands to secure the base of the device, arms close to the sides of the body, and hinge forward at the hip without rounding the spine.</td>
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<tr>
<td>10. “Piriform stretching”</td>
<td>Start with the hands touching the lateral of the device. Put right knee forward and out to the right, together with right foot forward, until the heel is in line with the left hip and the shin is at about a 45-degree angle. Maintain the foot flexed to protect the knee.</td>
</tr>
</tbody>
</table>

Proprioceptive training with Flymoon® may play a role in muscle training for patients with meniscus injury.

FUNDING

The authors wish to thank the FINEP (MCT/AÇÃO TRANSVERSAL PRÓ-INFRA #01/2007 / #01/2009) for the funding to obtain the isokinetic dynamometer. KO and MFS received doctoral financial support from CAPES (Funding Code: 001). JRC also thanks the CNPq for his productivity scholarship.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

Submitted: March 29, 2022 CDT, Accepted: March 08, 2023 CDT
### Table 3. % of sustained velocity (LR), peak torque/body mass, range of motion, and Hamstrings: Quadriceps ratio, at different angular velocities.

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*˚/s: degrees per second, LR: load range, %: percentage of the LR in relation to total range of motion; PT/BM: peak torque/body mass; N.m/kg: Newton meter/kilogram; ROM: range of motion; deg: degrees; and H-Q: Hamstrings:Quadriceps ratio.*
REFERENCES


SUPPLEMENTARY MATERIALS

Supplemental File 3

Supplemental File 2

Supplemental File 1
Clinical Commentary/Current Concept Review

Posterior Shoulder Instability in Tennis Players: Aetiology, Classification, Assessment and Management

Lyn Watson¹, Gregory Hoy²,³, Timothy Wood⁴, Tania Pizzari¹,⁴, Simon Balster⁵, Shane Barwood⁶, Sarah Ann Warby⁷

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Background

Micro-traumatic posterior shoulder instability (PSI) is an often missed and misdiagnosed pathology presenting in tennis players. The aetiology of micro-traumatic PSI in tennis players is multifactorial, including congenital factors, loss of strength and motor control, and sport-specific repetitive microtrauma. Repetitive forces placed on the dominant shoulder, particularly combinations of flexion, horizontal adduction, and internal rotation contribute to the microtrauma. These positions are characteristic for kick serves, backhand volleys, and the follow-through phase of forehands and serves. The aim of this clinical commentary is to present an overview of the aetiology, classification, clinical presentation, and treatment of micro-traumatic PSI, with a particular focus on tennis players.

Level of Evidence

5

INTRODUCTION

Shoulder pain in the overhead athlete has frequently been associated with anterior instability, superior labral anterior to posterior (SLAP) lesions, internal impingement, and rotator cuff pathology.¹ Posterior shoulder instability (PSI) of the glenohumeral joint as a potential cause of shoulder pain in tennis players is rarely discussed.² PSI symptoms typically occur in combinations of flexion, horizontal adduction, and internal rotation (IR) which challenge the posterior labrum, capsule and rotator cuff.³,⁴ The dominant arm of tennis players is frequently subjected to high forces in these combined positions during the follow-through phase of a forehand, preparation for a backhand, backhand volleys, and kick serves.⁵ This repetitive motion may induce microtrauma and lead to symptomatic posterior translation of the glenohumeral joint which may be associated with capsulolabral, muscular and bony structural lesions.³

The aim of this clinical commentary is to present an overview of the classification, aetiology, clinical presenta-

tion, and treatment of micro-traumatic PSI, with a particular focus on tennis players.

INCIDENCE

PSI in the general population is often missed and therefore underdiagnosed.³ The estimated incidence according to data from emergency and trauma settings suggests that PSI accounts for 2 and 3% of all shoulder instabilities.⁶ This is likely underestimated since only 23 % of traumatic posterior instabilities require reduction.⁷–⁹ The incidence of micro-traumatic and atraumatic PSI is even more elusive as small subluxations are easily missed by clinicians, who mistake secondary pathology, such as rotator cuff pathology, internal impingement and acromioclavicular joint pain, as the primary diagnosis.¹⁰ The delay in correctly diagnosing and appropriately managing symptomatic PSI has the potential to sideline young tennis athletes for an extended period,¹¹ interrupting circuit tours, impacting contractual arrangements,¹² and affecting physical conditioning¹³ and mental wellbeing.¹⁴,¹⁵

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CLASSIFICATION

A consensus via Delphi process was recently reached for classifying PSI.\textsuperscript{16} Shoulder experts agreed on three subgroups: traumatic, atraumatic, and micro-traumatic, linked to a cluster of typical associated factors.\textsuperscript{16,17} (Figure 1) Traumatic PSI is associated with a significant history of trauma, glenohumeral joint dislocation and structural lesions such as reverse Bankart lesions and reverse humeral avulsion of the glenohumeral ligament (HAGL). Atraumatic PSI has no seemingly obvious mechanism of injury or cause of onset and is typically associated with multiple directions of instability, a high incidence of congenital factors (e.g., glenoid dysplasia, glenoid retroversion, shoulder hyperlaxity), subluxations, a lack of structural lesions and aberrant motor patterning. Micro-traumatic PSI is caused by tasks with a repetitive or gradual increase in load, such as months of continuous tennis with a heavier than usual racquet.\textsuperscript{18} This subgroup may or may not have congenital factors contributing to their presentation and could acquire structural lesions due to repetitive forces imposed on the shoulder.

AETIOLOGY OF PSI IN THE OVERHEAD ATHLETE

MECHANISM OF INJURY

PSI in baseball batters (known as "batter's shoulder")\textsuperscript{19,20} and other throwing sports\textsuperscript{3} has been previously described and attributed to the extreme forces imposed on the posterior glenohumeral joint during the deceleration phase of a swing or throw. In baseball, the combination of rotational velocity transferred from the lower limb to the shoulder pre-swing (up to 95\textsuperscript{70} \text{°s}\textsuperscript{-1} at the shoulder) and linear bat velocity (31m/s) along with the mass of the bat needs to be counterbalanced by the posterior glenohumeral joint capsule and rotator cuff (to resist distraction, horizontal adduction and IR of the shoulder) during arm deceleration.\textsuperscript{21} These high decelerative loads, performed repetitively may deform or damage the posterior capsulolabral complex and rotator cuff - structures that normally function to limit posterior humeral head translation.\textsuperscript{1,21} This mechanism can lead to micro-traumatic PSI in the setting of overtraining, muscle imbalances and/or shoulder congenital abnormalities.\textsuperscript{2,22,23} The dominant arm of tennis players is frequently subjected to decelerative forces during the follow-through phase of a forehand, preparation for a backhand, backhand volleys, and kick serves.\textsuperscript{5,24} The rotational velocities associated with tennis, especially serving, may be even higher (3000\textsuperscript{9} \text{°s}\textsuperscript{-1})\textsuperscript{5} than demonstrated in baseball batting, suggesting that stress to the posterior capsulolabral complex and rotator cuff, and therefore risk of PSI, may be even greater in tennis players.

PASSIVE STRUCTURES

The posterior capsule becomes taut in positions of flexion, horizontal adduction and IR.\textsuperscript{25} Deformation or stretching of the posterior capsulolabral complex due to the repetitive mechanical stress and load of tennis may result in greater humeral head posterior translation during these movements.

Although not pathological, the presence of shoulder hyperlaxity may predispose players to posterior instability.\textsuperscript{26–28} Shoulder hyperlaxity may be present in 13% of sports men and up to 42% of sportswomen.\textsuperscript{29} It is important to distinguish laxity from instability. Hyperlaxity is an increase in joint translation due to elongation of soft tissue structures and is asymptomatic. Instability is when translation is not controlled by the sensorimotor system and is symptomatic.\textsuperscript{30} Ligament laxity might precipitate a decreased stimulation of proprioceptive afferents in the shoulder, reducing efferent muscle control.\textsuperscript{31,32} This phenomenon is likely to lead to instability in the presence of microtrauma.\textsuperscript{26}

Glenohumeral internal rotation deficit (GIRD) has been associated with shoulder pain in the overhead athlete and posterior capsule stretching commonly recommended to increase IR range of motion.\textsuperscript{33} However the link between the soft tissue and bony adaptations of the overhead athletes’ shoulder and the incidence of shoulder injury has yet to be firmly established,\textsuperscript{34} particularly in tennis players. A thickened or stiff (reduced elasticity) posterior capsule in the dominant compared to the non-dominant shoulder is a normal finding in asymptomatic shoulders of overhead athletes and may be an advantageous adaption to further protect the glenohumeral joint against the large deceleration forces of a swing or throw.\textsuperscript{35–37} GIRD is typically associated with a thickened or stiff posterior capsule,\textsuperscript{38} and is also a normal adaption in overhead throwing athletes if it is accompanied by a concomitant increase in external rotation (ER) to maintain the total rotational range of motion (TR-ROM- the sum of internal and external rotational range of motion) similar to the non-dominant side.\textsuperscript{39–41} A TRROM loss of more than 5 degrees on the affected side compared to the TRROM of the other has been suggested as potentially problematic,\textsuperscript{42} however significant differences in TRROM between dominant and non-dominant sides can be present in tennis players with asymptomatic shoulders.\textsuperscript{43} Humeral torsion (the rotation of the humerus that is a normal adaptation to those exposed to overhead throwing type sports) will also have an effect on range of motion measures\textsuperscript{44} and has been shown to correlate with the presence of GIRD in asymptomatic baseball pitchers.\textsuperscript{45} When IR range of motion is corrected by accounting for humeral torsion (using ultrasound), GIRD is often no longer present, indicating that soft- tissue tightness is unlikely to be responsible for the reduced IR that may be found clinically in baseball pitchers.\textsuperscript{46} Comparable findings may be present in tennis players given the sporting similarities of overhead, high force, and repetitive use of the dominant arm.

Care must be taken not to misinterpret PSI for GIRD or a tight posterior capsule. In some cases of micro-traumatic PSI, IR and horizontal adduction range of motion can appear limited due to muscle guarding and /or pain as an attempt to limit positions of vulnerability.\textsuperscript{47} Prescribing posterior capsule stretches (e.g. sleeper or cross body adduction stretches) in such cases can be detrimental to recovery as these positions (i.e. shoulder flexion, horizontal
adduction and IR) not only aggravate symptoms of PSI but may contribute to further unwanted elongation of glenohumeral joint passive structures. Conversely, PSI can present with an increase in horizontal adduction and IR range of motion, with pain at end of range due to a voluminous or elongated posterior capsule with concomitant pathological posterior humeral head translation.

GLENOID

Glenoid retroversion (a glenoid facing more posteriorly), glenoid hypoplasia/dysplasia (under-development of the posterior inferior glenoid rim) and glenoid bone erosion are statistically significant risk factors for developing PSI. Glenoid retroversion angles can vary within a normal shoulder population, though most authors agree that a retroversion angle of 10 or more degrees would be considered excessive (Figure 2a). The degree of glenoid version is considered to be largely genetically determined in the general population, however repetitive overhead use of the arm before the age of 12 years (prior to the development of secondary ossification centers) could impact glenoid development. Recent evidence identifies an increased incidence of posterior glenoid dysplasia in adolescents who participate in demanding unilateral upper limb sports (such as baseball or tennis).

Posterior humeral head subluxations can cause glenoid erosion due to shearing of the humeral head across the posterior glenoid rim which can further progress PSI (Figure 2b). These anomalies further reduce bony contact between the humeral head and the glenoid predisposing to a loss of humeral head control, particularly in unilateral upper limb dominant sports such as tennis.

**Figure 1. Overview of contributing factors and management plan in the tennis player with PSI.**

HAGL = Humeral avulsion glenohumeral ligament. MOI = Mechanism of Injury. PSI = posterior shoulder instability. GHJ = glenohumeral joint. TRROM = total range of motion (the sum of internal and external rotational range of motion). PROMs = Patients Reported Outcome Measures. *Surgical stabilization typically warranted for optimal outcomes in the sporting patient with traumatic structural PSI. **Basic scapula and humeral head motor control need to be established prior to surgery. *Adequate TRROM depends on type of sport played (see return to sport section).
Figure 2. a. Glenoid retroversion angle above 10 degrees. Retroversion was measured as the angle between a line from anterior to posterior glenoid rim and a line extending from the medial aspect of the scapula to the middle of the glenoid on the axial slice midway between the most proximal slice containing the glenoid and the most distal slice containing the glenoid. b. Posterior-inferior glenoid bone loss, denoted by the red arrow.

SCAPULA

In tennis, optimal function of the scapular muscles is required to transmit potential energy generated from the lower extremities to kinetic energy in the upper limb. Any aberrant motion of the scapula increases the potential for injury through compensatory mechanisms.\(^5^9\) Aberrant scapular motion, particularly reduced upward rotation, has been implicated in shoulder pathology in the overhead athlete.\(^6^0\)-\(^6^4\) A lack of scapular upward rotation reduces the relative contact area of the humeral head on the glenoid, especially as the arm elevates into overhead positions, contributing to less bony stability and the potential for subluxations through range.\(^6^5\)-\(^6^6\) A reduction in bony congruency between the glenoid and the humeral head places additional strain on the surrounding passive structures and inhibits the optimal length-tension relationship of the rotator cuff muscles\(^6^7\)-\(^6^8\) - all of which affect the concavity compression mechanism of the humeral head on the glenoid. In tennis players, serving induced upper limb muscle fatigue has been shown to significantly reduce scapula upward rotation compared to pre-training position,\(^6^9\) which has implications for monitoring serving loads.

The scapular stabilizers have been shown to contribute up to 50% of the force generated in shoulder external rotation.\(^2^,^3\),\(^7^0\) A reduction in scapular stability may place excessive strain on the rotator cuff muscles and/or affect the amount of force the external rotators can generate which will not only affect shoulder performance but may reduce the active support to the posterior humeral head.\(^2^6\) It is unknown if aberrant scapular motor patterning is a cause or effect of glenohumeral joint instability,\(^7^1\) however previous studies have shown that in asymptomatic overhead athletes, a lack of upward rotation is associated with developing shoulder pain.\(^7^2\)

MUSCLE CONTROL AND STRENGTH

Weakness in the external rotators of the shoulder has been demonstrated in throwing athletes with shoulder pain potentially due to overload and fatigue of the posterior musculature (supraspinatus, infraspinatus, and posterior deltoid).\(^7^3\)-\(^7^5\) Increased tension of the suprascervical nerve, which can occur in late cocking phase of a serve (maximal external rotation), has also been muted as a potential cause of weakness for the external rotators.\(^7^6\)

The posterior cuff (supraspinatus, infraspinatus, and teres minor) in combination with posterior deltoid provide a mechanical buttress to the posterior aspect of the gleno-humeral joint.\(^2^6\) Any weakness in these structures could allow the humeral head to translate posteriorly in movements of flexion and horizontal adduction placing greater tensile loads on the posterior structures such as posterior capsuloligamentous complex, labrum, and posterior rotator-cuff.

A deficiency in the kinetic chain may result in overload of distal segments.\(^7^7\) The leg and trunk segments of the body are considered to be force generators as well as the stable base for distal mobility; with their integrated function considered to represent core stability.\(^7^8\) In a normally functioning kinetic chain, leg and trunk segments develop 51 to 55% of the kinetic energy and force delivered to the
hand, with the shoulder producing only 13% of the entire kinetic energy of the service motion.78 Thus, a deficit in core stability is likely to affect the force contribution at the shoulder, which will overload glenohumeral joint structures. Specifically, Elliot and colleagues79 found that a reduction in knee flexion during the cocking phase while serving resulted in a 17% increase in load at the shoulder if ball velocity was to be maintained.

CLINICAL PRESENTATION

Symptoms of PSI may include vague or sharp posterior shoulder pain due to the posterior humeral head abutting the posterior cuff, capsule and labrum30 (Table 1). Anterior shoulder pain is commonly present, potentially due to compression of the top edge of subscapularis and biceps long head as the humeral head translates posteriorly.26 Players with PSI frequently present with multiple sites of rotator cuff pain (posterior, anterior, superior and/or lateral). Impingement symptoms (internal and subacromial) may also be present. The impingement is secondary to pathological posterior translations and poor scapular mechanics, but often diagnosed as the primary condition.81 Reports of pain are more common than frank dislocations or subluxations,20,26,82 although subluxations may be evident on examination. A decrease in upper limb power generated during any phase of the tennis swing is often reported.19

Typically, players will report a history of microtrauma that precipitated their symptoms.16 This may include an increase in the load (e.g., number of serves particularly associated with going deep into tournaments/winning matches, training frequency, volume, new technique, racquet weight24) or similarly a significant reduction in load and then a resumption of activity, such that may occur after illness. Players should be questioned regarding any history of shoulder trauma (such as a backhand or kick serve with a sudden awareness of pain) that may indicate structural damage to the shoulder. If the patient reports a significant shoulder trauma in the history, imaging is warranted.68,83,84

PHYSICAL EXAMINATION

The posterior apprehension test, Kim, and Jerk tests are provocative manoeuvres that have been traditionally described for diagnosing PSI.85 The posterior apprehension test has high specificity (sensitivity: 19.2%, specificity: 99.2%) when apprehension is used as a criteria for a positive result86 and the Kim test (sensitivity: 80%, specificity: 94%) may have some clinical utility in diagnosing patients with posterior labral lesions.87 The O’Brien test (sensitivity: 83%, specificity: 25%) may also have some clinical value in diagnosing posterior labral tears in young, noncontact overhead athletes.87,88 The posterior drawer test may be used to detect posterior laxity though are not necessarily diagnostic of PSI (sensitivity: 42% specificity: 92% for instability).89,90 The sulcus test may indicate rotator interval laxity27 or inferior glenohumeral instability (sensitivity: 28-72%, specificity: 85-97%).91 If the test produces symptoms of instability.92 In a recent Delphi study, Sadi and colleagues16 reported that examiner agreement was reached on a selection of tests to use for diagnosing micro-traumatic PSI (the posterior apprehension test or jerk test, subjective history, and symptom improvement with humeral head correction) though note that these tests have never been studied in a cluster. Sensitivity and specificity values for shoulder tests should be interpreted with some caution given that positive and negative likelihood ratios with confidence intervals (often lacking in studies that examine shoulder tests) are a truer reflection of a test’s ability to detect a health condition.93

Although the provocative manoeuvres may have some clinical utility in diagnosing patients with PSI, most (i.e., Kim and Jerk tests) have only been validated in patients with structural lesions and/or use the presence of gleno-humeral joint subluxation and apprehension as a positive result (i.e., posterior apprehension test). Given the aetiology of PSI in the overhead athletes is often micro-traumatic, with patients commonly presenting with pain rather than subluxations and frank dislocation,20,26,82 these tests used in isolation have the potential to miss non-structural posterior humeral head translation which is still pathological.10,20

Given that aberrant motor control of the scapula and humeral head are often contributing factors to PSI, assessing active and loaded movement strategies in association with symptoms can provide valuable information to the clinician and assist with treatment decisions. At a minimum, active flexion and abduction range of motion should be assessed to determine the presence of scapular dyskinesia and aberrant humeral head translations. The therapist might observe a lack of scapular upward rotation at rest and through range of motion, and possibly some scapular medial rotation (winging) compared to the unaffected side. Scapular medial rotation may be a compensatory strategy to place the glenoid under the humeral head during movement in the sagittal plane as an attempt to increase bony stability.47

The presence of posterior humeral head translation should be assessed through combinations of active flexion, IR, and horizontal adduction. Humeral head translations may range from observable and obvious subluxations to subtle increases in posterior humeral slide on palpation associated with symptoms. Range of motion may appear “blocked” due to subluxation of the humeral head off the back of the glenoid or deficient motor control preventing smooth articulation of the humeral head on the glenoid fossa through range.47,94 More provocative tests may be needed to assess posterior humeral head translation under load47 in the elite tennis player, such as loaded external rotation in the horizontal adduction plane, or any other position that mimics the players’ position of aggravation.

THE EFFECT OF CORRECTION

Once the presence of aberrant scapular motion and/or posterior humeral head translation has been established, the effect of correction the scapula and humeral head can be used to i) confirm the diagnosis, ii) determine if the patient
will respond to rehabilitation and iii) what type of exercise strategies to employ.

The effect of manual correction involves the therapist choosing an objective test and noting the patient's faulty scapular and/or humeral head biomechanics during that test in association with symptoms.^{17,94,95} The clinician then applies manual correction of the scapula (Figure 3), humeral head (Figure 4a and 4b) and possibly a combination of both to correct the faulty mechanics while re-assessing the test, noting any improvements in range of motion, pain, subluxations/dislocations, and/or strength on reassessment.

For the effect of scapular correction, the therapist typically corrects the scapula by placing one hand under the axilla (often to achieve increased upward rotation and/or elevation), while using the other hand to guide the medial boarder of the scapula through the corrected range of motion (or apply the resistance during a special test) (Figure 3). For the effect of posterior humeral head correction, the therapist uses the pad of their thumb/s on the posterior glenohumeral joint line to prevent the humeral head gliding excessively posteriorly during reassessment of a test which is typically active flexion, (Figure 4a) or horizontal adduction (Figure 4b). A positive corrective test should be at least 20° improvement in active range before symptoms, or an improvement in strength and/or pain on a loaded test.^{96}

Scapular corrective techniques have good inter-rater reliability (reliability coefficients ranging from 0.53 to 1.0),^{97–99} and variations of scapular assistive manoeuvres have been previously published by a number of authors for different shoulder pathologies. Kibler^{61} describes the scapular assistance and scapular retraction test for scapular dyskinesia. Watson describes corrective techniques in atraumatic^{47,100} and multidirectional shoulder instability,^{95} and Lewis^{97} discusses the shoulder symptom modification procedure. The effect of supporting the posterior humeral head during active range of motion has been previously described by Watson in PSI^{47} and MDI^{94,95,101,102} and by Boilette and colleagues (the Thumb assistance test) for PSI.^{103} While correction of the anterior humeral head has good inter-rater reliability (sensitivity: 63.89%; specificity: 98.91%).^{104} The psychometric properties of posterior humeral head correction have yet to be evaluated.^{105}
Figure 3. Manual correction of the scapula into upward rotation.

Starting position: Patient standing with affected arm at rest. Motion tested: Typically, active flexion and abduction range of motion. Motion is first observed for faulty scapular biomechanics in association with symptom onset. Application of correction: the therapist typically corrects the scapula by placing one hand under the axilla (often to achieve increased upward rotation and/or elevation), while using the other hand to guide the medial border of the scapula through the corrected range of motion (or apply the resistance during a special test). Changes in symptoms (including range of motion) is noted.

Figure 4a

Figure 4b.

Figure 4. a. Correction of the posterior humeral head during active flexion and b. horizontal adduction.

Starting position: Patient standing with affected arm at rest. Motion tested: Typically, active flexion and/or horizontal adduction range of motion. Motion is first observed for symptomatic posterior humeral head translation, subluxation, or dislocation. Application of correction: therapist uses the pad of their thumb/s on the posterior glenohumeral joint line to prevent the humeral head gliding excessively posteriorly during reassessment of a test. Changes in symptoms (including range of motion and/or subluxation) is noted.
spective of the corrective method used, the aim of shoulder assistive techniques should be to determine which position produces the largest reduction in symptoms for the patient.

The effect of correction can be used to determine if aberrant scapular motion and posterior humeral head translation are contributing to the patient’s symptoms as well as assist in differential diagnosis.\textsuperscript{47,61,103} For example, apparent restrictions in horizontal adduction and/or IR range are common findings in PSI and patients may be misdiagnosed as having a tight posterior capsule and/or GIRD.\textsuperscript{46} If therapist-assisted support of the humeral head to prevent posterior translation improves range of motion (Figure 4), then pathological capsular restriction is unlikely to be a contributing factor to the patient’s presentation.\textsuperscript{47,103}

Similarly, the findings of tests for ‘impingement’ and SLAP tears may change. For example, although the O’Brien’s test can be diagnostic of a SLAP tear,\textsuperscript{105} if correction of the posterior humeral head improves symptoms, then posterior humeral head translation may be contributing to a positive O’Brien’s test, and not necessarily a structural lesion. Manual corrections also assist in exercise selection. If a patient’s objective tests improve with upward rotation of the scapula, then scapular upward rotation is the motor strategy to retrain.

The ability to ameliorate symptoms in these functional provocation positions can also indicate if further investigation with imaging is required (if not already performed) and if the patient is likely to respond to rehabilitation. If manual corrections do not prove effective, a structural lesion of significance may be a larger contributing factor to the patient’s pathology. If a structural lesion of significance is suspected, early referral for imaging may be warranted. Alternatively, if the therapist suspects that rotator-cuff tendon reactivity

**IMAGING**

MRI is the gold standard when assessing capsular and labral integrity associated with PSI.\textsuperscript{106} MRI scanning without contrast has been used to successfully diagnose most cases, but MR arthrogram may be required for subtle lesions. A significant proportion of tennis players with micro-traumatic PSI will have an absence of significant structural lesions on MRI, indicating that loss of humeral head motor control and/or excessive capsular laxity\textsuperscript{107} may be contributing to their symptoms. Posterior labral tears, avulsion of the posterior band of the inferior glenohumeral ligament, reverse Bankart lesions and muscle atrophy may be found in players with a history of trauma or longstanding symptoms.\textsuperscript{77,107,108} Labral lesions may not be isolated to the posterior aspect of the glenohumeral joint and may extend to the anterior and/or superior labrum which has been shown in up to 47% of cases in a cohort of young, active military cadets presenting with PSI.\textsuperscript{11}

Rotator cuff tendinopathy and partial articular surface tears (PASTA) of the supraspinatus and/or infraspinatus are commonly observed on MRI in patients with PSI as poor scapula mechanics and pathological humeral head translation overloads and damages the surrounding active tissues. Tendinopathy of the subscapularis and/or fluid around the long head of biceps tendon are common in PSI as chronic posterior translation of the humeral head compresses and stresses anterior/superior structures. The presence of glenoid retroversion and dysplasia should be assessed in all players with PSI, which may present for the first time when extra stresses of elite training are instituted. Computer Tomography (CT) scanning (with or without 3D reconstructions) is helpful in cases of underlying bony pathology,\textsuperscript{22} or those where the posterior instability has become macro-instability with bone wear posteriorly.

**MANAGEMENT**

There is a growing body of evidence that traumatic PSI with significant structural lesions have better outcomes with surgical stabilization.\textsuperscript{18,80} Patients with atraumatic PSI (commonly with no structural lesions) generally have good outcomes with rehabilitation.\textsuperscript{26} If patients with atraumatic PSI fail three to six months of good conservative management, surgery may be considered once basic scapula and humeral head motor patterning has been normalised. Patients with micro-traumatic instability (plus or minus a structural lesion) are more varied in their presentation and typically require three to six months of good conservative management. If this fails, surgery may be considered (refer back to Figure 1).\textsuperscript{77} Failure of conservative management refers to a player’s inability to return to play due to ongoing shoulder symptoms.\textsuperscript{109}

**CONSERVATIVE MANAGEMENT**

The aim of conservative rehabilitation is to restore optimum scapular biomechanics, prevent pathological posterior humeral head translation and address any deficits in the kinetic chain. Restoring efficient scapular mechanics ensures maximal bony congruency\textsuperscript{65,66} and rotator cuff efficiency of the glenohumeral joint.\textsuperscript{68} Regaining motor control, then endurance, then strength of the rotator cuff and deltoid muscles assists in preventing excessive humeral head translation. Optimizing all segments of the kinetic chain reduces the forces required at the shoulder for the same power output.\textsuperscript{78,79,110}

A systemic review\textsuperscript{26} of rehabilitation programs for PSI found overall favourable outcomes for pain, instability recurrence, functional scores (Rowe Score, Constant Score, Subjective Shoulder Rating System) and return to activity levels for programs that focused on re-establishing scapular control and a focus on posterior rotator cuff and deltoid, although included studies were not specific to overhead athletes. After the publication of that systematic review, Blacknell et al.,\textsuperscript{111} reported on 19 patients with atraumatic PSI using a retrospective case series. They found significant improvements in patient reported outcome measures (mean WOSI from 49.8% to 87% and mean Oxford Instability Shoulder Score from 22.7 to 40.9) and functional outcomes (able to return to study, sport and/or occupation) after a rehabilitation program that focused on motor control movement re-education, initially of simple movements then progressing to more functional movements. Many participants were involved in overhead sports, although only one in ten-
nism. Specific exercise drills and parameters were not reported.

To date, there is only one published rehabilitation program specific for PSI with enough detail to replicate in the clinical setting. The Watson Instability Program for Posterior Shoulder Instability (WIP-p) is based on the Watson Instability Program (WIP) for multidirectional instability (MDI). In a randomized controlled trial, the WIP has been shown to result in significant improvements in functional outcomes over a general rotator cuff and deltoid strengthening program in MDI patients, as well as significant improvements in strength, scapular upward rotation, and functional outcomes in single group study designs in MDI and high-level circus performers. In these studies, more than half of the participants had a component of posterior instability.

The WIP-p focuses on regaining patient-specific control of any observed scapular dysfunction (scapula phase) prior to the addition of rotator cuff and deltoid exercises (arc of motion phase) over five stages (Table 2). Scapular resistance (SR) bands are often looped around the scapula to provide resistance and enhance scapular stability with exercise drills. Exercises are progressed into functional and sports-specific ranges as per the individual’s functional requirements. The program has a particular focus on posterior deltoid and rotator cuff function to control posterior humeral head translation and progresses exercises are eventually progressed into the sagittal (flexion) and horizontal adduction plane to gain control over previously vulnerable positions. Dosage for drills typically commence at a motor control dosage (1–2 sets x 20 repetitions, 2–3 times a day, light load) and progress to an endurance (2 sets x 15 repetitions, 1 x day, medium load) then strength (3 sets x 10–12 repetitions, 3 times a week, heavy load) then hypertrophy dosage if required (4 sets x 6–8 repetitions, 1–2 times a week, heavy load). In addition to addressing dysfunction at the shoulder, kinetic chain dysfunctions are assessed and normalized throughout the shoulder rehabilitation process.

The WIP-p has been evaluated in a single group study design in overhead athletes (n=24) with micro-traumatic PSI. Sporting categories of participants included four tennis players, two swimmers, four Australian football players, two cricketers, four netball players, and eight overhead weightlifters. Three participants had a structural lesion including a small tear of the posterior band of the inferior glenohumeral ligament and two posterior labral tears. After 24 weeks of the WIP-p (maximum 18 sessions) participants had significant improvements at 12 (effect size: 1.1, p<0.001) and 24-weeks (effect size: 1.8, p<0.001) on the Western Ontario Shoulder Index (WOSI) and significant improvements at six (effect size: 0.74, p=0.036), 12 (effect size: 0.41, p=0.007) and 24 weeks (effect size: 1.7, p=0.001) for the Melbourne Instability Shoulder Score (MISS). For return to sport, 22 of the 24 (91.6%) participants returned to full activity at the 24-week time point. The remaining two participants were unable to return to their overhead sport and went on to have reconstructive surgery. One of these participants was a tennis player and the other was an overhead weightlifter, neither had a structural lesion.

**SURGICAL MANAGEMENT**

The threshold for surgical intervention is typically lower for overhead athletes, owing to the demands placed on the glenohumeral joint. Surgery aims to restore passive integrity of the joint by repairing structural lesions and/or excessive capsular laxity. This is primarily achieved through labral repairs and/or capsular plication. The outcomes of soft tissue stabilization for traumatic and micro-traumatic PSI are generally good with improved American Shoulder and Elbow Score (ASES) scores from baseline and return to sport rates of between 55 and 90%, though not all at their pre-injury level.

Treatment selection is typically based on aetiology (i.e., surgery for traumatic PSI and failed conservative management for micro-traumatic or atraumatic PSI). Heterogenous patient populations (e.g., sporting with non-sporting, overhead sports with non-overhead sports, and traumatic with micro-traumatic populations), non-injury specific outcomes measures and a lack of control groups make synthesis of the true effect of surgery on PSI and return to sport challenging. To date, there is only one study that has investigated the effect of surgical stabilisation on 13 tennis players with PSI and posterior labral tears. Hoy et al. found that post arthroscopic posterior shoulder stabilisation, there were significant improvements in MISS and WOSI scores at 12 month follow up. Return to sport data were available for nine players with 89% returning to play and 56% at their previous level.

In patients with higher levels of glenoid retroversion (e.g. higher than 20 degrees) and/or glenoid dysplasia, an osteotomy may be considered in order to achieve a more congruent articulation at the glenohumeral joint, although there is no current evidence of its use in tennis players. Bone grafting procedures are not without risks and complications (e.g. failure of the graft, iatrogenic fractures, degenerative joint change) and should be considered only in cases where soft tissue reconstruction is likely to fail.

**RETURN TO SPORT**

Return to training and competition should be based on pain free shoulder function and reliable objective measures (refer back to **Figure 1**). Shoulder instability patients who pass an objective shoulder strength test (with assessment of isokinetic and isometric IR and ER strength and ER endurance) prior to returning to training and competition, may reduce their incidence of an instability recurrence by nearly five times compared to patients cleared to return to sport based on time from injury alone (5% vs. 22%; odds ratio, 4.85; p<0.001). A “pass” was classified as having 90% strength and endurance of the unaffected side. Isokinetic machines are not always available clinically, however handheld dynamometry for evaluating shoulder strength over a range of positions has good inter- and intra-rater reliability when used by experienced practitioners (Intrarater ICC; 0.84 -0.96. Inter-rater ICC: 0.82-0.96). A detailed strength testing protocol for shoulder instability using a hand held dynamometer has been previously published and should include a range of shoulder posi-
### Table 2. Overview of stages and phases of the WIP-p

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<tr>
<th>Scapula Phase</th>
<th>Aims</th>
<th>Potential Drills</th>
<th>Dosage/Load</th>
<th>Goals</th>
<th>Considerations</th>
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<tr>
<td><strong>Develop scapular motor control to center the HH</strong></td>
<td>Scapular UR in standing +/-elevation +/- posterior tilt*</td>
<td>Motor control: 1-2 sets x 20 reps 5 sec holds 2-3 x day 0.5-1.5kg in hand +/- SR band</td>
<td>Standing UR 2-3 sets x 20 reps 1.5kg +/- green SR band (to move onto arc of motion phase)</td>
<td>Side lying scapula drills if unable to do &gt; 5 reps standing</td>
<td>Must have normal cervical spine strength to perform standing scapula drills</td>
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<tr>
<th>Arc of Motion Phase</th>
<th>Stage</th>
<th>Aims</th>
<th>Potential Drills</th>
<th>Dosage/Load</th>
<th>Goals</th>
<th>Considerations</th>
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<tr>
<td><strong>Stage 1: Coronal Plane 0° Abd</strong></td>
<td>Develop posterior HH control in coronal plane 0° Abd</td>
<td>ER/IR/Ext isometrics Standing Ext to neutral with TB Standing ER with TB (0°-30-45° ER) Standing IR with TB (from 30-45° ER to 0°IR) Side lying ER from a support (to prevent shoulder falling into IR) Bent over row with weight</td>
<td>Isometrics: 5-10 reps x 5 second holds (20-30% MVC), 2-3 x day TB drills: 1-2 sets x 15-20 reps, 2x day Yellow-red-green TB (Double TB for Rows; ie: red+ green) SL: 1-3 sets x 15-20 reps 2x day 0-0.5-1.5kg Bent over row with weight BOR: 0.5-4kg 1 set x 20 – 2 x 15 reps BOR: 5kg + 3 sets x 10 reps</td>
<td>Ext/ER/IR 1-2 sets x 15-20 reps Red-green TB SL: 1-3 sets x 15-20 reps, 1-1.5kg Bent over row with weight BOR: 5 kg + 3 sets x 10 reps 3 x week</td>
<td>Isometrics if arc cannot be controlled/drill is pain provoking Ext/ER/IR = Short arc to larger arc of motion ER initially from 0° to limit IR and possible posterior HH translation. ER after Ext control established IR after ER control established Palpate posterior HH for unwanted posterior translation when prescribing exercises If the patient can’t control the HH in any drill, return to scapular phase and improve endurance then strength</td>
<td></td>
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<td>Stage 2: Coronal/Sagittal Plane</td>
<td>Develop posterior HH control in coronal and sagittal plane</td>
<td>Standing Ext Row with TB at 45° Abd</td>
<td>ER with TB at 45°</td>
<td>IR at with TB 45°</td>
<td>SL: progress load</td>
<td>BOR at 45°: 0.5-1-1.5kg, 2 sets x 15-20 reps</td>
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<td>Standing flexion in scapular to sagittal plane from 0-45° elevation</td>
<td>Continue UR drill with increased load</td>
<td>TB drills: 1-3 sets x 15-20 reps, 2x day</td>
<td>Yellow-red-green TB</td>
<td>ER at 90° with weight: 1-2-3-4 kg (endurance to strength dosage)</td>
<td>BOR at 90° with weight: 3-4 kg</td>
<td>Motor control- endurance dosage</td>
</tr>
</tbody>
</table>

**Scapula Phase**

| 3 x week | 3 sets x 10-12 reps, 3 x week | 3 sets x 10-12 reps, 3 x week (appropriate strength load) |

Seated Row @ gym

Continue scapular UR drill from endurance to strength

UR: 3-4kg, 2 sets x 15 reps |

1 x day to 5kg + 3 sets x 10-12 reps

Stage 3: Coronal/Sagittal Plane 45°-90°

Develop posterior HH control in coronal and sagittal plane 45°-90° Abd

Standing Ext Row with TB at 90°

ER with TB at 90° supported to unsupported.

ER at 90° with weight: 1-2-3-4 kg (endurance to strength dosage)

BOR at 90°: 0.5-1-1.5kg; 2 kg Motor control- endurance dosage | 2kg + kg strength dosage | Ext at 90°: Green TB | ER at 90°: Red-green TB | IR at 90°: Red-green TB | ER at 90° with weight: 3-4 kg in coronal plane | 3 sets x 10 reps, 3 x week | Drills from Stage 2 can be progressed to a strength dosage with increased load | Ext row at 90° performed before adding ER at 90° | IR after ER control established. | Some patients may not require supported before unsupported ER/IR. | ER unsupported progressed into sagittal plane to prepare for flexion to Posterior Shoulder Instability in Tennis Players: Aetiology, Classification, Assessment and Management | International Journal of Sports Physical Therapy |
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<th>90°</th>
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<td>Develop posterior HH control in coronal and sagittal plane &gt;90° elevation and HF control</td>
<td>weight unsupported progressed from coronal plane to sagittal plane</td>
<td>BOR at 90°: 3-8 kg*</td>
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<tr>
<td>ER &gt; 90- EROM IR&gt; 90-EROM Flex&gt; 90-EROM With TB Overhead press</td>
<td>IR at with TB 90° supported to unsupported BOR at 90° with weight</td>
<td>3 x sets 10 -12 reps, 3 x week</td>
</tr>
<tr>
<td>Recruitment/endurance (1-2 sets x 20 reps, 2 x day) to strength (3 sets x 10-12 reps) to ballistic (1-2 sets x 10+ reps) dosage depending on patients needs. Yellow-red-green-blue TB*</td>
<td>Flexion: 1-3 sets x 15-20 reps, 2x day</td>
<td>Flexion: sagittal plane Red- green TB, 2-3 sets x 15-20 reps</td>
</tr>
<tr>
<td>Weight for overhead press: 0kg-0.5-1.2 kg*</td>
<td></td>
<td>Palpate posterior HH for unwanted posterior translation especially when prescribing flexion exercises</td>
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<tr>
<td>Dosage and load depend on patient’s functional goals and ability to control movement. Guide: ER/IR: Red- Green HF with TB: Red-Green HF with weight 1-2.5+kg Flex TB: Red- Green Flex weight: 1.5-2-3-4+ kg</td>
<td></td>
<td>Drills from Stage 3 can be progressed to a strength dosage with increased load</td>
</tr>
<tr>
<td>Flexion &gt; 90° typically commences with TB in scapular plane moving around to sagittal plane. Flexion weights typically commence after green flexion band in sagittal plane achieved.</td>
<td></td>
<td>Flexion &gt; 90° typically commences with TB in scapular plane moving around to sagittal plane.</td>
</tr>
</tbody>
</table>

*Dosage and load can be progressed from a recruitment and endurance dosage to a dosage and load functionally required and by the patient. Exercises may need to be progressed to blue or black bands or heavier weights if functionally required by the patient.
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<th>Part Practice (example): Acceleration phase of tennis serve</th>
<th>Whole Practice: Participation in training/sport/occupation</th>
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<th>Specific middle deltoid or anterior deltoid drills may need to be prescribed if atrophy or weakness remains</th>
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<tr>
<td>Scapula Phase</td>
<td>Horizontal Flexion Drill With TB With weight</td>
<td>HF with TB: 1-3 sets x 15-20 reps</td>
<td>HF with weight: 1-4 sets x 6-20reps 0.5-3kg*</td>
<td>Horizontal flexion load progressed by having patient move torso around to commence drill in more HF</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yellow-Red- Green’</td>
<td></td>
<td>Once HF drills established, flexion drills in gym commenced (i.e., supine press, controlled bench press, overhead press with weights)</td>
<td></td>
</tr>
</tbody>
</table>

Note: Clinical decision making should guide appropriate exercise selection, dosage, and load for individual patients. Abd= abdication, kg= kilograms, reps= repetitions, UR= upward rotation, SR= Scapular Resistance, BOR= Bent Over Row, Ext=Extension, ER= external rotation, IR= internal rotation, HF=Horizontal Flexion, HH= humeral head, MVC=Maximal Voluntary Contraction, TB=theraband™. EROM= End Range of Motion, SR= Scapula Resistance Band.

*Dosage and load can be progressed from a recruitment and endurance dosage to a dosage and load functionally required by the patient. Exercises may need to be progressed to blue or black bands or heavier weights if functionally required by the patient. *Care must be taken with posterior scapula tilting as excessive scapula posterior tilt may increase PSI symptoms.
tions, including those in the sagittal plane. Quantifying adequate glenohumeral range of motion for return to sport in PSI can be challenging as it depends on the intervention administered (surgery versus conservative), if the patient's sport is unilateral or bilateral and pre-injury (or normal/adaptive) side to side TRROM differences. In the authors' experience, achieving 90% TRROM post-surgery and 100% TRROM post conservative management of the unaffected side is required for commencing overhead competition in patients participating in non-unilateral sports (e.g., football, swimming). However, given the normal TRROM differences that may exist in unilateral, repetitive, overhead athletes (which may be up to 46 degrees), comparing side to side differences may be unreliable. In such cases, it may be more appropriate to use normative dominant-arm TRROM values as a guide, which for adolescent tennis players has been shown to be 155.6 degrees in males and 160 degrees in females. Instability specific PROMs should reach at least 80% of the unaffected side prior to return to training.

CONCLUSIONS

PSI in tennis players can be the result of repetitive micro-trauma in combinations of shoulder flexion, horizontal adduction, and IR, which are characteristic shoulder positions for backhands, backhand volleys, and the follow-through phase of forehands and serves. Initial management of micro-traumatic PSI typically involves rehabilitation focusing on posterior rotator cuff and deltoid function and eventually progressing exercises into the sagittal and horizontal adduction plane. Due to the large demands placed on the shoulder in tennis, some individuals may require surgery if they fail appropriate evidence-based conservative management.

CONFLICT OF INTEREST STATEMENTS

Lyn Watson, Simon Balster, Tania Pizzari and Sarah Warby were involved in the development and testing of the WIPp that is discussed in this paper. The Melbourne Shoulder Group pays consulting fees to Lyn Watson, Simon Balster and Sarah Warby. Lyn Watson and Simon Balster are directors of the Melbourne Shoulder Group. Sarah Warby provides research services on a contractual basis for Mr. Greg Hoy and the Melbourne Shoulder Group.

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Clinical Commentary/Current Concept Review

The Golfer’s Fore, Fore+, and Advanced Fore + Exercise Program: An Exercise Series and Injury Prevention Program for the Golfer

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Golf is increasing in popularity with 24.8 million golfers in the U.S. in 2020, a 2% increase from the previous year. This number increased to 37.5 million in 2021 which can be further broken down to 25.1 million on course and 12.4 million participating in off course activities. Playing golf does not come without risk of injury, with an annual incidence between 15.8% and 40.9% in amateurs and 31% in professional golfers. Most injuries in golf occur due to overuse (82.6%) and only a small percentage occur from a single traumatic event (17.4%). Injuries most commonly occur at the low back followed by the wrist. Injury prevention programs have shown to be successful in other sports however to date there are no studies assessing a golfer’s specific program. The purpose of this clinical commentary is to describe three individualized and unsupervised golf exercise programs (The Golfer’s Fore, Fore+, and Advanced Fore+), of varying difficulty, designed to reduce the risk of injury, improve strength/mobility, and optimize performance.

Level of Evidence

5

INTRODUCTION

According to the National Golf Foundation (NGF), golf is increasing in popularity now being played in 209 of 249 countries, including six continents, with 24.8 million golfers in the U.S. in 2020.¹⁻³ This was a 2% increase (500,000 golfers) over 2019, which is the most significant net increase in 17 years.¹ One possibility for the recent rise in the number of golfers may be due to the recent COVID-19 pandemic, allowing more time to be outside and start a new hobby. This number increased to 37.5 million in 2021 which can be further broken down to 25.1 million on course and 12.4 million participating in off course activities,² including the driving range, TopGolf, mini golf, etc. Women golfers were also a part of the 2020 surge, jumping 8% (450,000 golfers) and making up nearly a quarter of all golfers reaching upwards of six million.¹

Despite the increase in popularity, playing golf does not come without risk of injury. One systematic review in 2009 described golf as an overall moderate risk activity for injury compared to other sports.⁴ In amateur golfers the incidence of injury annually has been reported to be between 15.8% and 40.9%,⁵⁻⁷ with a lifetime incidence between 25.2% and 67.4%.⁷ This contrasts with professional golfers, who have a slightly higher incidence for injury at 66% during their career and 31% in the last year.⁹ Professional golfers have a much higher volume of repetitive practice as compared to amateur golfers, which tends to be the most frequent cause of injury, compared to suboptimal swing biomechanics in amateurs.⁵⁻⁸ In most cases (82.6%) injuries reported in golf are due to overuse, with only 17.4% occurring because of a singular traumatic event.¹⁰

COMMON INJURIES IN GOLF

The most common injury sites documented in professional golfers are the low back followed by the wrist.⁹,¹¹,¹² percent breakdown per joint includes lower back (44%), wrist (44%), elbow (23%), neck (20%), and shoulder (19%).⁹ It has also been noted that men are 2.5x more likely to sustain a lower back injury than women.⁹ Vad et al. found that a history of low back pain in golfers was significantly correlated with a decrease in lead hip internal rotation, FABER’s distance (knee to table measurement), and lumbar extension.¹³ In amateurs the most common site of injury is the elbow (24.9%) and shoulder (18.6%), followed by the lumbar spine (15.2%).¹² Nearly half (46.2%) of injuries reported are sustained during the golf swing with 23.7% occurring at the...
point of ball impact, with the remainder of injuries occurring outside of the golf swing. Barber et al. reported that of those who sustain an injury golfing, 72% take time off, relying on time to heal, whereas 85% seek out the assistance of a physical therapist.

BIOMECHANICS OF THE GOLF SWING

The mechanics of the golf swing can be broken down into five distinct phases including the takeaway, forward swing, acceleration, early follow-through, and late follow through. This was initially described by Stover et al and Hosea et al in which they discussed the difference between the classic and modern golf swing. The most significant difference between the two is the emphasis on hip and trunk dissociation, which has been shown to improve performance, but has also been described as a risk factor for recurrent injury. The classic golf swing involves the pelvis and trunk rotating equally throughout finishing in a relaxed and upright position towards the target. The modern golf swing encourages further hip and trunk dissociation leading to an increase in elastic potential energy resulting in the ability to generate more force and maximize club head speed. McLean described this as the "X-factor" and noted that a larger X-factor (increase in the shoulder/pelvis dissociation) resulted in better performance. Despite the increase in performance, the modern golf swing has also been associated with an increased risk of injury due to the nature of finishing in a hyperextended position. This has been described as the "reverse C" finish which can lead to increased incidence of low back pain possibly due to increased facet joint irritation. Therefore, to maximize performance while minimizing the risk of injury, it is essential to optimize swing mechanics.

INJURY PREVENTION/PERFORMANCE

Golf has been shown to provide moderate intensity aerobic physical activity. As a result, a beneficial effect in both physical and mental health can be expected. Uthoff et al found that an eight-week program consisting of a combination of nonspecific and golf specific training enhanced both club head speed (4.1%) and hitting distance (5.2%) demonstrating the importance of golf specific training for performance enhancement. McHugh et al looked at the importance of transverse plane flexibility in golfers and found that proficient golfers, compared to those of similar skill level, had significantly better glenohumeral and hip joint flexibility as well as spinal mobility in the transverse plane with no difference in the sagittal and frontal plane. They noted that transverse plane hip flexibility accounted for 48% of the variability in ball speed and 45% of the variability in total distance which they attributed to greater separation between pelvis and trunk (known as the "X-factor").

Injury prevention programs have shown to be successful in other sports, however to date there are no studies assessing a golfer's specific program. Gladstones et al. designed a protocol for a Golf Related Injury Prevention Program (GRIPP intervention) consisting of six different movements (legs swings, arm in the air, arm rotations, sideways bending, rotation of the upper back, powerful rotations) in which they plan to compare to their typical warm up. The Titleist Performance Institute (TPI) screening is also growing in popularity among health care professionals to evaluate a golfer for physical limitations which may inhibit swing efficiency and durability. Currently, there is no proven gold standard for screening. A systematic review completed by Ehler et al. suggested that various warm-up protocols may enhance golf performance, however observational data suggests that many golfers do not regularly perform them. A good conditioning and warm up routine can help golfers train their body to better withstand the repetitive forces involved in the golf swing.

The purpose of this clinical commentary is to describe three individualized and unsupervised golf exercise programs (The Golfer's Fore, Fore+, and Advanced Fore+), of varying difficulty, designed to reduce the risk of injury, improve strength/mobility, and optimize performance. The progressive program consists of three levels; therefore, they apply to all ages, level of competition, and training experience. It can be modified to be utilized as a warm prior to a round or serve as a foundation to your regular exercise program.

THE GOLFER’S FORE PROGRAM(S)

The three programs outlined in this commentary (The Golfer’s Fore, Fore+, and Advanced Fore+) can be utilized for performance enhancement and/or injury prevention with an emphasis on strength, mobility, and core activation. The purpose is to create a simple and easy to follow program that incorporates the entire kinetic chain with multi-planar movements while preparing the golfer for the demands of their sport. All exercises performed are completed utilizing body weight and/or a single piece of Thera-Band CLX, making them easy to perform and accessible for all athletes regardless of talent level or training age. The athlete is instructed to perform 2 sets of 10 repetitions for each exercise with minimal to no rest between movements. The intensity level and/or timing of season will dictate the number of sessions per week. Each program in its entirety can be found in Appendices 1-3, as well as a QR code with a video of each individual section, (mobility, strength, and core) for all three programs.

The Golfer’s Fore (Appendix 1) program begins with four mobility movements, followed by ten strengthening and four core exercises. This program serves as the foundation for the remaining two programs. Starting with mobility, the program begins with standing cross body adduction. The athlete is instructed to stand against a wall to stabilize the scapula and maximize the stretch. The horizontal adduction stretch has been advocated to improve flexibility of the posterior shoulder region which is important throughout the golf swing in both the lead and trail arm. Next exercise includes, around the world with a golf club, emphasizing glenohumeral joint mobility in all planes, which is essential for the dynamic nature of the golf swing. The last
two mobility exercises, half kneeling thoracic rotation (Figure 1) and squats with rotation, begin to incorporate lower extremity and thoracic spine mobility. Zouzias et al. noted the importance of a well-rounded golf specific exercise program including lower extremity and thoracic spine mobility.10

Next, the strengthening aspect of the program begins with low row in a split lunge. The exercise starts with the athlete in a split stance lunge with opposite arm forward (example: left leg and right arm) holding a TheraBand in their hand. Maintaining a stable base, they are instructed to row with the right arm and reach with the left until their right arm is parallel with their side. The reach on the opposite side incorporates thoracic spine mobility and emphasizes the dissociation between the lower half (pelvis). To perform the second set, the athlete will switch their footing such that their lead leg in the first set will now be their trail leg in the second, and vice versa. The purpose of the sustained split lunge is to incorporate the lower half into the movement and elicit activation of the entire kinetic chain. It also emphasizes single limb stability/control which is important throughout the weight shift from lead to trail leg during the golf swing.

This is followed by proprioceptive neuromuscular facilitation (PNF) D1 and D2 flexion/extension in a squat. For this movement the athlete will stand parallel to the TheraBand and will be pulling across their body from low to high. D1 flexion begins with the TheraBand in their inside hand and on the inside hip as compared to D2 flexion which begins with the TheraBand in the outside hand on the inside hip. It is important to educate the athlete on the importance of both D1 and D2 extension as well to maximize eccentric control. Reverse wall slides (Figure 2) are next emphasizing upper extremity flexibility, thoracic mobility, and posterior rotator cuff activation. The athlete is instructed to complete this movement in a sustained squat maintaining contact with the wall at the hand, elbow, and lower back.

Next, is the scapular series including the prone horizontal abduction (T), prone high row into external rotation (W), and the modified robbery (Figure 3). Both the prone T and W are completed lying on a table, face down, and one arm off the side. The modified robbery is an alteration of the original robbery exercise described by Kibler et al.31 It is completed in a mini squat utilizing one piece of TheraBand, holding onto one handle in each hand with elbows bent to 90° and at their side. Thumbs should be positioned outwards with palms towards the ceiling. Maintaining elbows in contact with their side, the athlete rotates arms outward squeezing shoulder blades together. They are instructed to hold this position for two seconds then return to starting position. A pilot study completed at the American Sports Medicine Institute (ASMI) in Birmingham, AL examined the EMG activity of various scapular strengthening exercises noting that the modified robbery demonstrated the greatest lower trapezius activation with minimal upper trapezius contribution (unpublished).

Both double and single leg bridges further facilitate increased lower extremity strengthening. Power generation during the golf swing combines trunk and pelvis dissociation, optimal mechanics, as well as lower extremity strength. The athlete begins on their back with knees bent to approximately 90 degrees and feet shoulder width apart. Pushing through their heels, with both core and gluteal muscles engaged they will lift their bottom off the ground, hold for two seconds then return to starting position. Incorporating single leg bridges will increase the demand on the lateral hip musculature to optimize pelvic stability. The strength portion of the program finishes with a forward lunge into rotation. The athlete begins standing with arms
straight out in front holding a golf club and feet shoulder width apart. They are instructed to perform a lunge, rotate towards the forward leg maintaining arms straight, then push from the front leg, returning to the starting position.

The three core movements within the Golfer’s Fore include a palloff press, quadruped arm/leg reaches (bird dogs), and supine arm/leg movements (dead bugs). For the palloff press the athlete begins in a mini squat facing perpendicular to the TheraBand holding it with both hands against their body just below chest height. Maintaining the squat, they are instructed to push both hands out directly in front until their arms are straight and not allowing the trunk to rotate. This movement works on transverse plane strength and stability in which McHugh et al demonstrated the importance of during the golf swing. The bird dog begins with the athlete in a quadruped position, shoulders stacked above wrist and hips above knees with core engaged and neutral spine positioning. The movement be-
gins by reaching forward with one arm and at the same time kicking backwards with opposite limb, keeping both as straight as possible. After holding the finishing position for two seconds, they will then return to the starting position and complete with the opposite limbs, repeated for the desired number of repetitions. The dead bug is similar however completed while lying on their back and alternating arms and legs maintaining a stable core.

Both The Golfer’s Fore + and The Advanced Golfer’s Fore + progress from the foundational exercise program described above with continued emphasis on upper and lower extremity mobility/strength, core stability, and spinal mobility. The Golfer’s Fore + (Appendix 2) program begins with seven mobility movements, followed by seventeen strengthening and three core exercises (Figures 4-6).

The Golfer’s Advanced Fore + (Appendix 3) program begins with eight mobility movements, followed by nineteen strengthening and three core exercises (Figures 7-10). For a more detailed description of the Fore + and Advanced Fore + programs refer to Table 2 and Table 3 as well as the QR codes provided.

SUMMARY

The golf swing is a physically demanding and repetitive task that can lead to a variety of upper body, lower body, and/or spinal injuries. In recent years, there has been a rise in the number of golfers both in the U.S. and globally resulting in an increasing number of injuries. With a lack of consensus and research on a golfer’s specific injury prevention or performance enhancement program, it is imperative to educate the golf community on ways to train for the demands of the sport safely, efficiently, and effectively. Although not a full comprehensive or stand-alone program, The Golfer’s Fore, Fore +, and Advanced Fore + presented in this commentary provide a foundational program(s) which can be utilized for golfers of all ages and varying levels of competition to prepare for participation.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

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The Golfer’s Fore, Fore+, and Advanced Fore+ Exercise Program: An Exercise Series and Injury Prevention Program for the...

Figure 5. PNF D2 flexion in squat (The Golfer’s Fore+)

Figure 6. Palloff press in squat (The Golfer’s Fore+)
Figure 7. Unilateral row and reach with lateral step down (The Advanced Golfer’s Fore+)

Figure 8. Scapular series: High row into ER ("W") on stability ball (The Advanced Golfer’s Fore+)
Figure 9. Resisted forward lunge with rotation (The Advanced Golfer’s Fore+)

Figure 10. Bird dog with row (The Advanced Golfer’s Fore+)
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SUPPLEMENTARY MATERIALS

Appendix 3

Appendix 2

Appendix 1
ABSTRACT
The shoulder is an area that can be prone to a variety of injuries, including subscapularis tendon tears. The subscapularis muscle is one of the four muscles that make up the rotator cuff in the shoulder and plays an essential role in stabilizing the shoulder joint while at the same time facilitating internal rotation of the humerus. Injuries to the subscapularis can occur due to trauma, overuse, or degeneration, leading to pain, weakness, and limited mobility. When injury occurs, subscapularis tendon tears are often difficult to diagnose and evaluate due to their location deep within the shoulder joint. While traditional imaging techniques like radiographs, and magnetic resonance imaging may give us insight into the structures present, they do not always provide detailed enough information for clinicians. Ultrasound has become increasingly popular in musculoskeletal (MSK) rehabilitation as it allows for direct visualization of soft tissue abnormalities like tendinopathies or subtle rotator cuff tear patterns. In this Ultrasound Bites article, we will discuss how MSK ultrasound can be used in the evaluation of subscapularis tendon pathology with a specific focus on its utility in the physical therapy clinic.

MSK ultrasound is a non-invasive imaging modality that uses high-frequency sound waves to create real-time images of soft tissues, including muscles, tendons, and ligaments. This non-invasive imaging method provides clear and highly detailed images of the soft tissues in the shoulder area, allowing for a more precise diagnosis.

SUBSCAPULARIS

Figure 1a: Patient Position.
Patient can be in a seated position or in a supine position. Shoulder at 0 degrees of abduction and externally rotated, elbow flexed with forearm supinated. Probe placement is represented in a short axis.

Figure 1b. Transducer Placement.
Short Axis (SAX) Probe placed transversely on the proximal anterior aspect of the shoulder, over the long head of biceps tendon.

Figure 1c: Transducer Placement.
Long Axis (LAX) Probe placed parallel with the biceps tendon in order to be perpendicular to the subscapularis tendons.

Note: Probe placement/description is relative to the axial spine. In the long axis/longitudinal view, the left side of the image is cephalad. In the short axis/transverse view, the left side of the image is the patient’s right.
Figures 2a and 2b: Look for the tapering contour of the subscapularis tendon to the lesser tuberosity and the linear tendon footprint. The tendon is displayed as a hyperechoic, fibrous echotexture tapering to a sharp point along the lesser tuberosity. The linear, anechoic/black area between the lesser tuberosity cortex and the tendon is the normal appearance of the “tendon footprint”. Loss of tendon contour, and an irregular/non-linear tendon footprint are indicative of a compromised, weakened tendon attachment.

Figures 3a and 3b: With a LAX view, you can see the hyperechoic tendon slips (3 here for the subscapularis) as it attaches to the lesser tuberosity. This is viewed as a multipennate appearance with the three tendon slips shown with the yellow arrows.

Normal subscapularis anatomy is represented in Figures 2 and 3. As the subscapularis crosses the proximal humerus, multiple hyperechoic tendinous slips can be visualized tapering into an anechoic point (sometimes referred to as a “tendon footprint”) as it inserts on the lesser tuberosity.

Some common findings that can be seen on MSK ultrasound images include tears, inflammation, fluid accumulation, and tendinopathy. These issues can be identified with great accuracy, allowing clinicians to better understand a patient's condition and develop an effective treatment plan. More specifically, the following are some of the key features that an MSK ultrasound can reveal in subscapularis injuries:
**TENDINOSIS IN SHORT AXIS (SAX) AND LONG AXIS (LAX):**

- Muscle thickness: An MSK ultrasound can measure the thickness of the subscapularis muscle, which can be an indicator of muscle atrophy or wasting.
- Muscle integrity: An MSK ultrasound can detect tears or disruptions in the subscapularis muscle, as well as any associated inflammation or fluid accumulation.
- Tendon attachment: An MSK ultrasound can assess the attachment of the subscapularis tendon to the humerus at the lesser tuberosity, which can be a site of injury in some cases.
- Dynamic evaluation: An MSK ultrasound can evaluate the subscapularis muscle in real-time, allowing the clinician to assess its function during active movement of the shoulder joint.

Figures 4 and 5 represent common sonographic findings in pathologies of subscapularis tendinosis as increased thickness and hypoechoic tendon structures. Subscapularis tears and disruptions can also be visualized as hypoechoic or anechoic areas within the muscle or tendon.

In summary, MSK ultrasound is a valuable tool in the evaluation of subscapularis injuries, providing detailed information on the muscle's structure and function. Its use offers the benefits of being non-invasive and cost-effective, while providing an accurate diagnosis making it an excellent choice for initial evaluation and monitoring of subscapularis injuries. The techniques employed in an MSK ultrasound scan help to give a clear picture of the injury which helps to differentiate between different types of subscapularis injuries such as tears, tendinosis and strain. Ultimately, when combined with clinical examination, MSK ultrasound proves to be a powerful diagnostic tool in assessing subscapularis pathology.

**INTRA-TENDINOUS FAILURE IN SHORT AXIS (SAX) AND LONG AXIS (LAX):**

*Figure 4a & 4b: Subscapularis Tendinosis. The ultrasound images of subscapularis tendon in short axis (3a) and long axis (3b) show increased thickness and hypo-echogenicity of the subscapularis tendon (arrows). Note in figure 3b the increased thickness of the 2 tendon slips that are outlined with the white arrows.*

*Figure 5a: Intratendinous fiber failure in Short Axis (SAX). Note the linear, hypoechoic partial subscapularis tendon tear in the middle of the subscapularis tendon.*

*Figure 5b: Intratendinous focal defect in Long Axis (LAX). Note the hypoechoic focal defect referred to as a “bullet hole” that is seen in a long axis view, perpendicular to the tendon fibers.*