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In 2011, World Physiotherapy published the Standards of Physical Therapy practice (https://world.physio/sites/default/files/2020-06/G-2011-Standards-practice.pdf), which indicates that “the physical therapist performs an initial examination/assessment and evaluation to establish a diagnosis and prognosis/plan of care prior to intervention/treatment.” Since assessment is considered mandatory for a clinical decision-making process in Physical Therapy, it is expected to find sports physical therapists performing pre-season assessment with their athletes. A Pre-season Assessment (PA) is a battery of tests chosen to identify and characterize the health status of athletes (screening) to prevent injuries and improve performance. In addition, the PA might identify athletes with increased likelihood of being injured and guide the initial phase of the preventive program planned by sport physical therapists.

Screening athletes is mandatory in other professions. For example, the American College of Sports Medicine proposes a preparticipation health screening on athletes to access exercise-related cardiovascular events. The argument commonly used that “general prevention programs work, so why the concern on assessing and building tailored programs?” is not enough to abandon the standards of our profession. Athletes’ health and safety should be our main concerns and our interventions should be specific for each health condition, each sport injury, each athlete. Therefore, we should deliver our efforts to targeting the best health and safety status. The purpose of this editorial is to discuss the execution of pre-season assessment (PA) and planning preventive programs based on the PA results.

To understand injury occurrence, we should know about the sport action and most common movements, collect athlete’s injury history and sport practice, and identify and measure athletes’ needs (physical, psychological, sport performance, etc) to facilitate the outcome measurement (dysfunctions linked to the injury). If injury is an established problem in sport practice, how can we prevent it without knowing/understanding it? An important process that sports physical therapists should do to understand athletic injury is to assess, quantify, define the diagnosis, implement interventions, follow-up and re-assess. Mehl et al indicated that screening, identification, and correction of endangering movement patterns like the dynamic valgus are the first crucial steps in order to prevent knee injuries in athletes. Interestingly, Mendonça et al developed an international survey and the authors reported a frequency of 75% sports PT performing PA in their athletes. The fact that about one third of these sports physical therapists use the results of the PA to build the prevention program was surprisingly negative.

PA would be recognized as mandatory and properly implemented (and even disseminated) if it is validated. To accomplish this, it is necessary to apply the PA results in sport injury prevention program implementation and follow-up injury occurrences to actually validate the prevention program and also the PA itself. Bittencourt et al recently published a cohort study which identified that a tailored preven-
tive program reduced the incidence of patellar tendinopathy in elite youth jumping athletes. The necessity of performing this preseason screening has been questioned, mainly based on the statement of lack of strong evidence.  

Considering that the pre-competition season usually involves athletes being exposed to frequent training sessions and friendly matches before a break-time. Even a global non-specific prevention program, such as FIFA 11+, could benefit the athlete. However, we might not do all in our power to help our athletes throughout the whole season. For example, Slauterbeck et al did not find a reduction in lower extremity injury in schools using the FIFA 11+ program compared with schools using their usual pre-practice warm-up program. In elite athletes, although some studies indicate that FIFA 11+ reduces injury incidence in soccer, Ekstrand et al found that hamstring injuries have increased 4% annually, during 13 years follow-up, in elite male soccer teams.

So maybe the problem is not about the PA itself, but how to perform the PA. Which tests to choose? How to apply it? How to do analyze the data? Relative limitations in performing the PA might be the time needed to organize and execute, high-cost equipment and lack of methodological rigor. However, those limitations could be easily addressed with strategies such as substituting tests using expensive equipment for clinical tests, keeping the scientific rigor (i.e. LESS), and possibly involving university students to make the process easier to execute. The purpose of the PA is not to predict injury, but it to screen our athletes, identify risk profiles, and set specific parameters to improve their capacity to deal with sport demands. We should use PA results to build a tailored preventive program to help our athletes achieve the strength and skill to perform. Considering that PA procedures could be performed on the field using low-cost equipment, these regimens should be promoted and facilitated in sports organizations world-wide, by means of shared consensus amongst the organization's medical and technical staffs.

References
3. Kennedy et al. Can pre-season fitness measures predict time to injury in varsity athletes?: a retrospective case control study. SMARTT. 2012; 4:26


Addressing Psychological Factors in Sports Injury Rehabilitation – What is a Physical Therapist to do?

Niklas Cederström, MSc, PhD student, Simon Granér, PhD, Eva Ageberg, PhD

1 Department of Health Sciences, Lund University, Lund, Sweden, 2 Department of Psychology, Lund University, Lund, Sweden

Keywords: sports psychology, rehabilitation

Best practice guidelines for musculoskeletal injury rehabilitation include recommendations to address psychological factors. A recent return to sport consensus statement has emphasized a biopsychosocial perspective in regards to preparing injured athletes for return to play, in which aspects including satisfaction and confidence in performance are taken into account. However, physical therapists’ knowledge of practical application is lacking, and athletes still experience negative psychological outcomes upon completing rehabilitation.

Interventions directly assessing this tend to focus on psychology as something separate and “other,” creating a gap which physical therapists are unable to effectively fill. The important question to ask is, therefore, whether this can be addressed by physical therapists in the clinic?

Communication and goal-setting can emphasize individually meaningful tasks, making it easier to focus externally on real-world connections, such as understanding how an exercise is related to jumping up for a ball. From a psychological standpoint, external focus does not only mean an external stimulus; it should include re-creating situations from an individually-relevant context. Typically, external focus may include watching oneself in a mirror or reaching towards a point on the wall to establish ‘desirable’ movement patterns. However, letting athletes simulate part or all of a sport-specific and meaningful situation may help connect them to their own reality, leading to motivated and natural movement patterns. Physical therapists can and should monitor for safety, but allowing the patient to solve their own puzzles is an effective tool in motor learning. The OPTIMAL theory of motor learning states that self-determined, challenging, and successfully executed meaningful movements can aid in developing more automatic and realistic movement patterns.

Injured athletes often refer to lack of fun and desire for more activity-specific rehabilitation, and express lower physical activity motivation and sport self-confidence. The most appropriate tools to address these are simpler than one might think. Effective goal setting and shared decision-making according to Self-Determination Theory can be an easily implemented method of addressing psychological factors. The patient knows their sport and pre-injury skills. Therefore, involving the patient in whether and how they will return, and basing strategies on individual skills and desires, such as sport-specific jumping and cutting, for example, can create a sense of meaning and ‘ownership’ in rehabilitation. Person-centered discussions about strategies can boost motivation and self-confidence by addressing patients’ lack of rehabilitation knowledge and highlight progress in reference to smaller process goals. It also provides a ‘friend’ in rehabilitation, as the physical therapist shows that they care about the individual, and not only the knee.

Common Psychological Skills Training interventions include goal-setting, arousal regulation, and imagery (Figure 1). Dynamic motor imagery is done by creating mental images of relevant and meaningful situations based on previous experiences, while simultaneously physically simulating the movement. We have reported that exercises commonly used in rehabilitation training with integrated dynamic motor imagery, known as Motor Imagery to Facilitate Sensorimotor Re-Learning (MOTIFS), may improve enjoyment and feelings of control in uninjured athletes, without sacrificing movement quality. It takes longer to implement, but positive psychological reactions may be worth the time investment. The MOTIFS training model is currently being evaluated with knee-injured people.

Integrating externally focused sport-specific dynamic motor imagery in the clinic is distinctive due to reality- and experience-based re-creation of individually relevant and
Psychological Skills Training

Practice of mental skills with the aim of enhancing performance, increasing enjoyment, and improving satisfaction with activity

**Goal-setting** includes discussing with a patient the details and strategies of rehabilitation to achieve individualized outcome, performance, and process goals. This can encourage patient motivation, involvement, and compliance.

**Examples:** Involving the patient in design and short-term goal setting for particular exercise (i.e., sport-specific movement quality), or long term such as return to play

**Arousal Regulation** includes techniques to teach appropriate coping mechanisms to increase self-awareness, reduce negative perceptions and impacts of stress and anxiety, regulate focus, and confront adversity and setbacks.

**Examples:** Breathing exercises, self-talk, stress inoculation training, biofeedback (i.e., heart rate monitors) in order to regulate emotion by reconstructing and accepting emotional states

**Imagery** uses individual memory and experiences to mentally prepare for activity by recreating mental states to simulate a relevant situation. This aids in increasing meaning, understanding, and skill learning, and teaches coping mechanisms.

**Examples:** Re-creating physical, emotional, and cognitive states in order to simulate sport before, during, or after activity

Figure 1. Psychological skills training can be used with injured or non-injured people to prepare for activity

meaningful situations. This does not simply mean pushing them off balance, reaching towards an external object, or putting a ball in their hands; it means striving for total immersion. Upon receiving instructions, a basketball player may interpret a toe- or shoulder-raise movement as a lay-up, for example. Realism is achieved by imaging sport-specific physical execution, environments (sights, sounds, smells), timing, speed, and relevant emotional experiences. Practically, this includes other players, time left in the game, and where to pass the ball. This translates into realistic physical execution which simulates sport experience. The situation-specific rehabilitation exercise may then be applied by taking an approach step with a basketball in their hands, performing the exercise, and following through with a shot. This training can create self-determined (i.e., based on autonomy, competence, and relatedness), meaningful and enjoyable external focus, and relates directly to patient and physical therapist goals, ensuring physical and psychological relevance to returning to activity.

Application of psychology in rehabilitation has received increasing attention in the literature. Physical therapists can implement psychological training using self-reflection and discussion with colleagues by asking questions such as: How involved is the patient in rehabilitation goals and exercise design? Are prescribed exercises in line with patient goals? Is the main goal to rehabilitate the knee, or to prepare for return to sport? How can I implement sport-specific equipment, timing, environment, and/or meaningful obstacles into exercises to increase realism? Awareness and active incorporation of these aspects stimulates psychological training which clinicians can implement in the clinical environment.

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REFERENCES


Clinical Viewpoint

Current Views of Scapular Dyskinesis and its Possible Clinical Relevance

Aaron Sciascia, PhD, ATC, PES, SMTC, FNAP, W. Ben Kibler, MD

Institute of Clinical Outcomes and Research, Lexington Clinic, Shoulder Center of Kentucky, Lexington Clinic

Keywords: scapular dyskinesis, shoulder, shoulder rehab

Scapular dyskinesis is a condition that is frequently observed clinically but not often understood. Too often it is viewed as a diagnosis which is not accurate because it is a physical impairment. This misclassification of dyskinesis has resulted in literature that simultaneously supports and refutes scapular dyskinesis as a relevant clinical entity as it relates to arm function. These conflicting views have not provided clear recommendations for optimal evaluation and treatment methods.

The authors’ experience and scholarship related to scapular function and dysfunction support that scapular dyskinesis is an impairment that has causative factors, that a pathoanatomical approach should not be the primary focus but should be considered as part of a comprehensive examination, that a qualitative examination for determining the presence or absence of a scapular contribution to shoulder dysfunction is currently the best option widely available to clinicians, and that rehabilitation approaches should be reconsidered where enhancing motor control becomes the primary focus rather than increasing strength.

INTRODUCTION

The scapula has been identified as a key component of effective shoulder and arm function, due to its roles in scapulohumeral rhythm and its association with a wide variety of clinical shoulder injuries. A series of investigations, consensus groups, and clinical commentaries have established: the definition of scapular dyskinesis,1,2 the relationship of dyskinesis to shoulder pain and injury,3–6 guidelines for operative and non-operative treatment,6–8 and an algorithm for the clinical evaluation process.9 However, the existence of disparate reports on how scapular function can both positively and negatively influence shoulder function has not provided clinicians with clear understanding of the clinical importance the scapula. This is likely due to 3 key characteristics related to scapular function. First, the multitude of muscles that attach to the scapula allow for simultaneous and synchronous muscle activation and stabilization to occur during arm movement. This allows for numerous degrees of freedom to exist which results in variations between individuals performing the same task.10 Second, the thorax has an ellipsoid design which does not allow for single planar movement to occur exclusively. The lack of single planar movement is due not only to the shape of the thorax but also due to the varied fiber orientation of the muscles acting upon the scapula. Scapular motion is comprised of complex rotations and translations which are necessary to allow the scapula to function as part of scapulohumeral rhythm, the integrated coupled motion of the moving arm and scapula that is the basis for effective upper extremity use. The scapular rotations (anterior/posterior tilt, upward/downward rotation, and internal/external rotation) are described as accessory arthrokinematic motions while the scapular translations (elevation/depression and medial/lateral translation) can be characterized as physiologic motions such as the voluntary gross actions of humeral flexion, abduction, or rotation.11–16 Medial translation (dynamic movement of the scapula around the thorax posteriorly towards the vertebral column) and lateral translation (dynamic movement of the scapula around the thorax anteriorly towards the chest) should be used to describe active motion while retraction and protraction should be used to described the end position of the scapula after the movement has ceased.15 Scapular roles involve almost every aspect of shoulder and arm function. It is the "G" of dynamic glenohumeral concavity/compression, the "A" of stable acromioclavicular joint articulation, and "S" of scapulohumeral rhythm.6 Finally, the scapula is a link within the kinetic chain (the coordinated, integrated proximal to distal muscle activity sequencing that allows arm tasks to occur).17 The scapula has a number of crucial roles but most importantly, it serves as
the link that transfers energy from the large muscles of the trunk, lower extremity, and core to the smaller muscles of the arm during arm movements.\textsuperscript{17}

\section*{SCAPULAR DYSKINESIS}

When scapular motion becomes altered, the appropriate term to use would be scapular dyskinesis. "Dys" (alteration of) "kinesis" (motion) is a general term that reflects loss of control of normal scapular physiology, mechanics, and motion. Scapular "winging" has been used as a term synonymous with dyskinesis; however, "winging" is best reserved for altered scapular motion driven by neurological compromise.\textsuperscript{18} Neurologically based winging is clinically observed when any portion of the scapula excessively departs from its contact with the thorax immediately upon the initiation of arm motion and remains disconnected throughout the ascent and descent phases of the arm movement. Conversely, altered scapular positioning can be observed in the resting position of the arm but is more often seen dynamically in the descent phase of arm motion. During the dynamic arm movement, scapular dyskinesis can be clinically characterized by medial or inferior medial border prominence, early scapular elevation or shrugging upon arm elevation, and/or rapid downward rotation upon arm lowering.\textsuperscript{2} The leading theory is that arm function suffers when scapular dyskinesis is present due to an alteration in the coupled glenoid and humerus relationship.\textsuperscript{2} However, a cause versus effect relationship between scapular motion and shoulder injury has not been concretely established.\textsuperscript{8} Considering the literature has consistently noted that scapular dyskinesis, in isolation, is not an injury or a musculoskeletal diagnosis but rather a physical impairment,\textsuperscript{6} scapular dyskinesis should be viewed as an impairment with a causative origin.

\section*{RECONSIDERING THE CLINICAL EXAMINATION}

Eighty-three percent of patients with shoulder pain report that the reason for seeking treatment was an inability to achieve their desired function in important activities – they perceived a dysfunction that they wish to be addressed.\textsuperscript{19} Function can be modelled as anatomy acted upon by physiology to produce mechanics that facilitate accomplishment of a specific task. In this model, dysfunction results from various combinations of pathoanatomy, pathophysiology, and pathomechanics that create ineffective or inefficient decompensations or possible injury that are manifested as symptoms.\textsuperscript{9,20} This model can be a useful framework to organize the clinical evaluation process. Systematic reviews have attempted to compile and critique the value of examination maneuvers and have concluded that there are deficiencies in clinical utility, stark contrasts in methodologies between studies, and less than optimal levels of critical appraisal results.\textsuperscript{21,22} Interestingly, the focus of clinical utility conflicts with scapular dyskinesis as an entity because clinical utility is rooted in diagnostic accuracy. Considering scapular dyskinesis is not a diagnosis but is instead an impairment, clinical utility is not attainable. The difficulty in establishing diagnostic accuracy for an impairment is that there is no consistent acceptable gold standard to compare to. Although several attempts have been made to utilize biomechanical assessments (i.e. 3-dimensional analysis) as a gold standard,\textsuperscript{23–35} the establishment of where anatomical landmarks reside in space in relation to the equipment based on surface markers are in essence surrogates for actual location. Bone pin studies that insert sterile pins directly into the bone are likely best characterized as a gold standard but their invasive nature and difficulty in utilization prevent them from being routine clinical tools.\textsuperscript{12–14,16} As such, qualitative assessments of scapular position and motion currently serve as the best clinical tools for identify alterations although there are inherent concerns with the subjective nature of the assessments.

The aforementioned algorithm consists of 3 stages of this qualitative assessment (Figure 1). The first is the establishment of the presence or absence of dyskinesis, using the scapular dyskinesis test.\textsuperscript{36,37} The second is establishing the relationship between the observed dyskinesis and the clinical symptoms using the corrective maneuvers, the Scapular Assistance Test and the Scapular Retraction Test.\textsuperscript{1,2,6} The third is the evaluation of the possible causative factors, using a step wise evaluation process and standard testing (Figure 2).\textsuperscript{18}

The establishment of the presence or absence of scapular dyskinesis is best accomplished with the scapular dyskinesis test.\textsuperscript{6,36,37} The exam is conducted by having the patient raise the arms in forward flexion to maximum elevation, and then lower them 3–5 times (Figure 3). If the clinician is not sure if an alteration of motion is present, the patient can be asked to repeat the scapular dyskinesis test with a 3–5 pound weights in each hand and/or by performing up to 10 repetitions of arm elevation. The added weight and additional repetitions may help accentuate any altered motion. As noted earlier, scapular dyskinesis is more easily observed in the descent phase of arm motion. Prominence of any aspect of the medial scapular border on the symptomatic side is recorded as "yes" (prominence detected) or "no" (prominence not detected).

Three muscle tests: manual resistance of the arm at 130° of flexion (targets the serratus anterior),\textsuperscript{38,39} manual resistance of the arm at 130–150° of abduction (targets the lower and middle trapezius),\textsuperscript{38} and extension of the arm at the side (targets the rhomboids)\textsuperscript{40} should be performed. The distinction between these testing maneuvers and other muscle tests for the shoulder is that the clinician attempts to "break" the patient’s arm position and observe if the scapula is visibly moving out of position. The combination of both the break in position and scapular movement are suggestive of scapular muscle weakness.

Finally, the corrective maneuvers designed to "correct" scapular motion and/or scapular positioning should be employed.\textsuperscript{6} The scapular assistance test helps evaluate scapular contributions to shoulder pain based on motion alterations, the scapular retraction test evaluates scapular contributions to rotator cuff strength, and the low row evaluates contributions to arm strength. The scapular assistance test is performed when the examiner applies pressure to the medial aspect of the inferior angle of the scapula to assist scapular upward rotation and posterior tilt as the patient elevates the arm (Figure 4). A positive result occurs...
when the painful arc during arm motion is relieved and the arc of motion is increased. The scapular retraction test is performed when the examiner first grades the strength in forward flexion using standard manual muscle testing procedures with the patient in their normal posture (Figure 5A). The examiner then places and manually stabilizes the medial border of the scapula in a retracted position while retesting the arm strength (Figure 5B). A positive test occurs when the demonstrated strength increases while the scapula is in the retracted position and stabilized by the clinician. In the low row test, the patient is asked to place his or her arm in slight humeral extension and then instructed to resist movement of the arm into forward flexion (Figure 6). The examiner (positioned posterior to the pa-
tient) then instructs the patient to contract the gluteal muscles while applying the same anterior force on the arm. If strength increases with the gluteal contraction, this is an indication that scapular and shoulder muscle activation may be facilitated by involving hip and core strength, which suggests lower extremity/core strengthening should be included in the treatment plan for the shoulder. A positive corrective maneuver informs the clinician that the rehabilitation should primarily focus on scapular mobility, scapular strength, or core strength rather than take a rotator cuff activation or strengthening focus.

This qualitative approach aligns well with recent proposals on applying a classification system in the clinical setting that is based on movement-impairments rather than pathoanatomy. The system begins broad but can be subclassified based on the examination findings. The focus of the system is to help identify causes of dysfunction in order for the examination to better guide the treatment. For example, if altered scapular motion is identified via the scapular dyskinesis test, the clinician should initially identify the specific observable components (i.e. medial border prominence, scapular body positioning, etc) and simultaneously consider what is the likely cause of the alteration (i.e. deficiencies in mobility, strength, and/or motor control, or overt anatomical injury). The additional examination components of the corrective maneuvers, mobility testing, strength testing, and kinetic chain testing would help the clinician better identify the contributing cause.

All these efforts have been directed towards establishing the clinical diagnosis of dyskinesis and identifying the anatomical (pathoanatomy) and physiological (pathophysiology) factors underlying the observed alterations of position and motion as a basis for developing treatment protocols. An unpublished survey from our institution of 462 consecutive patients with shoulder pain who met the algorithm stage 1 and stage 2 criteria were examined for all causative factors, using the step wise testing protocols. This survey revealed that 34.7% of the patients had a pathoanatomical basis for their dyskinesis (clavicle fractures, acromioclavicular joint disorders, glenohumeral joint internal derangements, neurological injury, periscapular muscle injury), while 65.3 % had a pathophysiological basis (muscle imbalance, inhibition, tightness/inflexibility, serratus anterior/lower trapezius insufficiency). In addition, some of those with a pathoanatomical basis also had primary or secondary pathophysiology as well.

These findings suggest a 2-part evaluation process for patients with observed scapular dyskinesis that can be linked to the clinical symptoms. One part should identify those patients whose dyskinesis is secondary to identified pathoanatomy. Treatment may include rehabilitation but frequently will require surgical means of restoration of the anatomy. Those whose dyskinesis is secondary to pathophysiology will need a comprehensive evaluation process to understand the muscular alterations that will serve as the basis for treatment.

In summary, scapular dyskinesis associated with clinical symptoms results from pathoanatomy in roughly 1/3 of the cases. The absence of demonstrable pathoanatomy is common and should direct the evaluation process to a comprehensive evaluation of the many possible alterations of physiology.
RECONSIDERING TREATMENT APPROACHES

As an impairment, scapular dyskinesis has been posited to be primarily the result of soft-tissue deficiencies, thus the treatment focus has centered on mobility and strength enhancement. However, various reports have noted that interventions directed at correcting these deficiencies, mostly manual therapy and therapeutic exercise, have little influence on the scapular motion itself. There are several possible reasons for these findings.

First, mobility alterations are rarely acute in the scapula and/or shoulder. Although overhead athletes often experience an acute decrease in glenohumeral rotation following a throwing episode/exposure, the decrease in motion can resolve within 24–96 hours on average both with and without intervention. The chronicity of mobility deficits tends to be lengthy resulting in bony adaptations, capsular thickening, and various tendon responses. Although immediate gains in motion have been reported following the application of manual therapy interventions, they have not been shown to be long lasting. These interventions have positively impacted pain and self-reported function which is more likely rooted in the neurophysiological effects related to endogenous pain control. In other words, the immediate clinical but unsustainable result of increased motion after the application of manual therapy is not related to tissue correction but rather pain modulation that results in immediate demonstrable motion increases.

Second, therapeutic exercises designed to target specific shoulder and scapular muscles have been described but these were primarily identified with electromyographic methodologies. Although electromyography has helped identify which positions and maneuvers bias specific muscles, the often mistaken interpretation of the results is that the muscle activity is an occurrence specific to individual muscles. This thought process conflicts with the known summation of activation phenomenon that has been consistently reported in the literature. Furthermore, the foundational work was performed on asymptomatic individuals. It is quite possible that differences exist between individuals with shoulder pathology or impairments such as scapular dyskinesis compared to those who are asymptomatic. Finally, the identified maneuvers were often performed in an isolated manner with the body in vertical or horizontal (prone or supine) stationary positions. These positions could lead to a less than optimal rehabilitation outcome likely due to the encouragement of inefficient or improper motor patterns. Taken together, these results suggest that a focus on increasing strength may not be the ideal intervention.

Finally, if strength shouldn’t be the focus, then it is possible scapular dysfunction is more likely rooted in issues related to motor control. One of the primary principles of motor control is based on the type and amount of feedback a person receives during task performance. In most upper extremity tasks, visual feedback is utilized for joint positioning and error correction. However, the scapula cannot be visualized due to its posterior location on the thorax. It is possible that the lack of visual feedback leads to the alterations in motion that manifests as scapular dyskinesis. Previous reports have shown that intentional attempts at repositioning the scapula prior to elevating and/or rotating the humerus, called conscious correction, increases scapular muscle activity and enhances scapular kinematics. Additionally, visual feedback, auditory feedback, and kinesthetic feedback have been shown to positively influence scapular muscle activity and positioning. Considering the scapula as a ‘link’ within the kinetic chain, the feedback approach may be better suited for re-establishing scapular control as it relates to the sequential activation within the kinetic chain. The isolated strengthening approach may not re-establish scapular mobility and control as they are single-planar by design and...
do not allow for the patient to intently focus on the scapula directly. Using motor control as the focus, previous reports have suggested employing an integrated approach where the patient is required to perform exercises from a sitting or standing position to perform (and learn) the necessary motor patterns that require integrated use of the majority of the kinetic chain segments (i.e., the legs and trunk to facilitate scapular and shoulder movement and muscle activation). However, although these works have verified increased shoulder and scapular muscle activation when trunk and/or leg movements are integrated into the exercise maneuvers, there are no empirical reports or randomized control trials that have compared a motor control/kinetic chain focused program against a program that does not utilize this approach.

To date, clinical recommendations supporting motor control/kinetic chain-based rehabilitation approaches have been made via expert opinion/consensus papers. An example of such a program has been provided with the clinical highlights being:

1. Short lever progression
2. Sitting and standing preferred over prone or supine exercises
3. Target impairments in the order of mobility, motor control, strength (if necessary) and endurance
4. Utilize longer lever maneuvers later in the rehabilitation program
5. Advance to plyometric based maneuvers just prior to discharge

An example of short lever exercise application would be to begin with exercises that require the arms to be in an adducted position (i.e. the arms position against the thorax) rather than positions that require the arms to be elevated or abducted for exercise performance (Figure 7A-B and Figure 8). These early interventions attempt to establish proper scapular positioning early in the rehabilitation and begin to utilize the major of kinetic chain segments to create the integrated muscle activation and sequencing. Although they could be classified as short lever exercises, maneuvers such as scapular shrugging or elevation should be avoided in the first 4-6 weeks of rehabilitation. This is intentional to not overly bias the upper trapezius which could delay the restoration of balance amongst scapular muscle activation. Progression into more dynamic motions that would still be considered short lever maneuvers (Figures 9 and 10) may be added to the treatment progression once the patient has demonstrated that the initial exercises can be performed without exacerbating the previous symptoms. Progression into dynamic motions that begin to include limited amounts of arm elevation or abduction (approximately 30-45°) (Figures 11 and 12), and then culminating with traditional long lever exercises (90° of arm elevation or abduction) in the later or last stages of rehabilitation can be incorporated into the treatment program in the later phases of rehabilitation, but only when the previous maneuvers have been mastered by the patient and have demonstrated little to no symptom exacerbation. Dosage recommendations include beginning with 1-2 sets of 5-10 repetitions with no external resistance. Additional sets and repetitions can be added based on symptoms and exercise tolerance, with a goal of 5-6 sets of 10 repetitions being able to be performed without an increase in symptoms before adding resistance. Resistance may be added next beginning with light free weights (2-3 pounds maximum) and then progressing to elastic resistance. The stability of free weights allows those devices to be utilized prior to elastic resistance because elastic resistance, although effective at increasing scapular muscle activity, has high variability when used by patients, especially when arm position is progressed throughout a treatment program. If elastic resistance were to be utilized, it can be adequately monitored and progressed using perceived exertion scales. Feedback may be incorporated throughout the treatment program but there is not an exclusive type to recommend considering various forms of feedback have been shown to have positive clinical influence. However, it should be noted that too much feedback can be detrimental to learning as the patient becomes reliant on the knowledge of performance.

CONCLUSIONS

Scapular dyskinesis is an impairment that has causative factors, and those factors should be discerned from a comprehensive physical examination. The examination should not exclude assessments related to identifying pathoanatomical causes but the pathoanatomical approach should not be the primary focus of the examination. Using clinician experience and the best available evidence, a qualitative examination for determining the presence or absence of a scapular contribution to shoulder dysfunction is currently the best option widely available to clinicians. Future investigations should attempt to standardize methodological approaches to perform better comparisons between studies and generate higher quality results. Finally, rehabilitation approaches should be reconsidered where enhancing motor control becomes the primary focus rather than increasing strength.

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Figure 7. Conscious correction of scapula begins with the patient standing (a) and being instructed to actively “squeeze your shoulder blades together” (b). Utilization of mirrors or mobile devices can assist patients with visualizing correct scapular positioning.

Figure 8. The Low Row begins in the starting position of standing and knees slightly bent (a). The patient performs extension of the hips and trunk to facilitate scapular retraction (b).
Figure 9. Lawnmower with arm close to body begins with the patient standing and the arm close to the body as if supported by a sling (a). The patient is instructed to extend the hips and trunk followed by rotation of the trunk to facilitate scapular medial translation and retraction (b).

Figure 10. The Robbery maneuver requires instructions to the patient to “place the elbows in the back pockets” moving from a trunk and hip slightly flexed position (a) and moving to an extended position (b).
Figure 11. Lawnmower with arm away from body is the advancement of the previous lawnmower exercise with the arm in a slightly flexed position to begin (a) but the same hip extension and trunk rotation components (b).

Figure 12. The Fencing exercise begins with the arm elevated to 90° in the frontal plane (a) and performed by side stepping and simultaneously retracting the scapula and adducting the arm (b).
REFERENCES


Systematic Review/Meta-Analysis

Effective Interventions for Improving Functional Movement Screen Scores Among “High-Risk” Athletes: A Systematic Review

Sean C. Clark, MS1, Nicholas D. Rowe, BA1, Mohamed Adnan, BA1, Symone M. Brown, MPH2, Mary K. Mulcahey, MD2

1 Tulane University School of Medicine, 2 Department of Orthopaedic Surgery, Tulane University School of Medicine

Keywords: intervention program, injury prevention, injury risk reduction, functional movement screen, movement system

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Background
The Functional Movement Screen™ (FMS™) is a tool designed to screen a series of movements that aids in the identification of compensatory fundamental movement patterns, functional limitations, and asymmetrical movement patterns. A previous systematic review and meta-analysis has shown that athletes with an FMS™ score <13-14 are considered "high-risk" and are more likely to be injured. There are discrepancies regarding the efficacy of physical intervention programs in improving FMS™ scores.

Purpose
The aim of this systematic review was to assess the role of physical intervention programs in increasing functional movement in "high-risk" athletes as measured by the FMS™.

Study Design
Systematic Review

Methods
A computerized search was performed in 2019 according to PRISMA guidelines searching Embase, Science Direct, Ovid, and PubMed. The studies were assessed for quality and risk of bias using the Modified Downs and Black checklist. Participant demographics, intervention routines, and FMS™ scores were extracted from the included studies.

Results
Six studies met the inclusion criteria and demonstrated a fair methodological quality. Comparisons across all studies revealed significant improvement in FMS™ scores following implementation of a variety of physical intervention programs. These programs included those that utilized functional training, foot muscle strengthening, Pilates, core stability training, and resistance movements. Despite variations in the corrective exercises performed, the number of training sessions, and the length of the intervention program, all studies demonstrated an increase in the total FMS™ score following program implementation.

Conclusion
The included intervention programs significantly improved total FMS™ scores in "high-risk" athletes. Despite variations in the corrective exercises (interventions) performed, the number of training sessions, and the length of the program, all studies demonstrated a significant increase in the total FMS™ score following program implementation.

Corresponding Author:
Sean C. Clark, MS
1430 Tulane Avenue
New Orleans, LA 70112
Phone: 610-731-1300
Email: sclark19@tulane.edu
Effective Interventions for Improving Functional Movement Screen Scores Among "High-Risk" Athletes: A Systematic Review

INTRODUCTION

The Functional Movement Screen™ (FMS™) is a tool designed to screen a series of movements that aids in the identification of compensatory fundamental movement patterns, functional limitations, and asymmetrical movement patterns. The FMS™ includes seven screening tests: active straight leg raise, deep squat, hurdle step, in-line lunge, rotary stability, shoulder mobility, and trunk stability push-up. With a maximum total FMS™ score of 21 points, each test is rated on a three-point scale ranging from zero (pain during the action) to three (correctly performed action).

Athletic injuries hamper the ability of athletes to compete at all levels. Sheu et al. estimates that 8.6 million sports and recreation related injuries occur each year in the United States, translating into 54.1 injuries per 1000 people. The development and execution of preventative exercise programs could reduce the severity and occurrence of athletic injuries. The FMS™ has become a popular tool to identify athletes with a higher likelihood of developing a sports related injury. Kiesel et al., noted that athletes with total FMS scores ≤14 had an 11 times increased risk of serious injury and a 51% probability of sustaining a serious injury over the course of one competitive season. Since the FMS™ has been proposed to identify muscular imbalance, interventional prophylactic strengthening programs targeting muscular imbalances can be implemented. Identifying "high-risk" athletes in pre-season screening with a low cost, time efficient, and low physical risk screening tool could decrease medical costs, the number of serious injuries, and time lost to injury. The FMS™ may provide coaches, athletic trainers, physical therapists, and other healthcare providers with valuable information needed for early detection of injury-prone athletes who may benefit from intervention. After determining that an athlete could be at risk for injury (FMS™ score ≤14), a six-to-eight-week long intervention program consisting of corrective exercises aimed at improving functional movements could be implemented. Recently, authors have demonstrated that incorporating an intervention program can improve symmetry, core strength, flexibility, and general strength, all of which help reduce the risk of injury. A systematic review and meta-analysis by Bunn et al. demonstrated that those defined as having a "high-risk" FMS™ score (<13-14) were 51% more likely to be injured than individuals with FMS™ scores >14. The aim of this systematic review was to assess the role of physical intervention programs in increasing functional movement in "high-risk" athletes as measured by the FMS™.

METHODS

This study was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and was prospectively registered with PROSPERO (121425).

RESULTS

The literature searches identified 361 potential studies. After the removal of 118 duplicates and 172 studies that did not meet inclusion criteria, 71 articles were available for full-text review. Following thorough review of these articles and their references, a total of six studies were included in this study (Figure 1). Six studies with a total of 256 patients were analyzed. Three of the included studies (50%) were Level 2 evidence,
Table 1. Modified Downs and Black scores for included studies

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<td>Laws et al.</td>
<td>9</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>Sulowska et al.</td>
<td>9</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>Yildiz et al.</td>
<td>8</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>16</td>
</tr>
</tbody>
</table>

Figure 1. Flow diagram summarizing the literature search, screening, and review.

while the remaining three were Level 3. The studies included demonstrated a fair methodological quality, with a range of 16-18 (Table 1). The majority of patients were males (n = 184), although two studies included females (n = 32) and one study did not provide participant gender (n = 40). Athletes played a variety of sports including basketball (n = 78), futsal (n = 40), mixed martial arts (n = 33), running (n = 65), tennis (n = 28) and volleyball (n = 12). The level of sport included 66 youth participants (25.8%), 65 recreational level participants (25.4%), 100 collegiate athletes (39.1%) and 25 semi-professional athletes (9.8%) (Table 2).

All six studies provided a mean pre-intervention FMS score, which ranged from 11.8 to 14.4 (Table 3). Length of intervention varied between studies, with a range of six to eight weeks. Post-intervention FMS scores were reported in all studies and significantly increased, with a range of 14.8 to 19.5 (p-values 0.001 – 0.017). The mean improvement in FMS scores following an intervention program across all studies was 3.28 points. FMS score improvement ranged from 2.09 to 5.3 points following an intervention program.

Intervention programs included core stability training, clinical Pilates, resistance training, functional training, and foot muscle strengthening exercises (Table 4). Each pro-
Table 2. Summary of included studied and patient demographics

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>LOE</th>
<th>n</th>
<th>Age (Mean ± SD)</th>
<th>Gender</th>
<th>Sport</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagherian et al.16</td>
<td>2018</td>
<td>3</td>
<td>100</td>
<td>18.1 ± 0.9</td>
<td>Male</td>
<td>Basketball (n = 40), futsal (n = 40), volleyball (n = 12), mixed martial arts (n = 8)</td>
<td>Collegiate</td>
</tr>
<tr>
<td>Bodden et al.17</td>
<td>2015</td>
<td>2</td>
<td>25</td>
<td>24.31 ± 4.46</td>
<td>Male</td>
<td>Mixed martial arts</td>
<td>Semi-Professional</td>
</tr>
<tr>
<td>Kluseman et al.18</td>
<td>2012</td>
<td>3</td>
<td>38</td>
<td>14.5 ± 1</td>
<td>Male (n = 17), Female (n = 21)</td>
<td>Basketball</td>
<td>Youth</td>
</tr>
<tr>
<td>Laws et al.19</td>
<td>2017</td>
<td>2</td>
<td>40</td>
<td>Not reported</td>
<td>Male (n = 14), Female (n = 11)</td>
<td>Runners</td>
<td>Recreational</td>
</tr>
<tr>
<td>Sulowska et al.20</td>
<td>2016</td>
<td>2</td>
<td>25</td>
<td>28 ± 3.86</td>
<td>Male (n = 14), Female (n = 11)</td>
<td>Runners</td>
<td>Recreational</td>
</tr>
<tr>
<td>Yildiz et al.21</td>
<td>2019</td>
<td>3</td>
<td>28</td>
<td>9.6 ± 0.7</td>
<td>Male</td>
<td>Tennis</td>
<td>Youth</td>
</tr>
</tbody>
</table>

LOE = Level of Evidence

Table 3. FMS™ data

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>n</th>
<th>Length of Intervention (weeks)</th>
<th>Baseline FMS™ (Mean ± SD)</th>
<th>Post-intervention FMS™ (Mean ± SD)</th>
<th>p-value</th>
<th>Average FMS™ Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagherian et al.16</td>
<td>2018</td>
<td>100</td>
<td>8</td>
<td>14.4 ± 2.02</td>
<td>17.8 ± 1.7</td>
<td>0.001</td>
<td>3.4</td>
</tr>
<tr>
<td>Bodden et al.17</td>
<td>2015</td>
<td>25</td>
<td>8</td>
<td>13.25 ± 0.87</td>
<td>15.17 ± 1.21</td>
<td>0.006</td>
<td>2.08</td>
</tr>
<tr>
<td>Kluseman et al.18a</td>
<td>2012</td>
<td>38</td>
<td>6</td>
<td>14 ± 1</td>
<td>16 ± 2</td>
<td>&lt;0.05</td>
<td>2</td>
</tr>
<tr>
<td>Laws et al.19</td>
<td>2017</td>
<td>40</td>
<td>6</td>
<td>13.4 ± 2.4</td>
<td>17.0 ± 1.96</td>
<td>&lt;0.01</td>
<td>3.6</td>
</tr>
<tr>
<td>Sulowska et al.20b</td>
<td>2016</td>
<td>25</td>
<td>6</td>
<td>13 ± 4.91</td>
<td>17 ± 1.96</td>
<td>0.002</td>
<td>4</td>
</tr>
<tr>
<td>Yildiz et al.21c</td>
<td>2019</td>
<td>28</td>
<td>8</td>
<td>14.0 ± 1.8</td>
<td>19.3 ± 0.8</td>
<td>0.017</td>
<td>5.3</td>
</tr>
</tbody>
</table>

a) Kluseman, two intervention groups in study, data provided for supervised group
b) Sulowska, two intervention groups in study, data provided for group 1
c) Yildiz, two intervention groups in study, data provided for functional training group

programs had their own unique set of exercises, some examples included the front plank, squats, and a medicine ball throw.

**DISCUSSION**

The main finding of this systematic review was that despite variations in the corrective exercises performed, the number of training sessions, and the length of the intervention program, all studies demonstrated a significant increase in the total FMS™ score following program implementation (Table 3). These programs included those that utilized functional training, foot muscle strengthening, Pilates, core stability training, and resistance movements.

Bagherian et al. evaluated FMS™ scores following an intervention program focused on improving core strength in 100 male collegiate athletes participating in various sports. This eight-week core stability training program increased the total FMS™ scores among athletes by 3.4 ± 1.7 points on average (p = 0.001). These authors also noted that there total FMS™ score improvement was dependent upon
Table 4. Comparison of included studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Intervention</th>
<th>Corrective Movements</th>
<th>Main Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagherian et al.16</td>
<td>Core stability training program, 3 times per week for 8 weeks</td>
<td>Front plank, back bridge, side bridge, sit ups, back extensions, lateral step down, Y-balance test</td>
<td>Increase in total FMSTM scores by 3.4 points on average. The baseline FMSTM scores &gt;14 increased by 2.4 points on average.</td>
</tr>
<tr>
<td>Bodden et al.17</td>
<td>Resistance training movements, 4 times per week for 8 weeks</td>
<td>Half-kneeling chops, kettlebell halos tall-kneeling chops, half get-ups, deadlifts, single-leg opposite-arm deadlifts, bottom-up kettlebell cleans, squats, overhead press</td>
<td>Increase in total FMSTM scores by 2.08 points on average. Limited difference between average FMSTM scores at week 4 (1.92) and week 8 (2.08)</td>
</tr>
<tr>
<td>Kluseman et al.18</td>
<td>Resistance training movements, 2 times per week for 6 weeks</td>
<td>Speed (20m sprint), vertical jump, line drill test, aerobic capacity countermovement, jump height, overhead squat, hurdle step, in-line lunge, shoulder mobility, straight leg raises, push up</td>
<td>Increase in total FMSTM scores by 2 points on average. The supervised group is the only group to experience a deviation from baseline in FMSTM score calculations.</td>
</tr>
<tr>
<td>Laws et al.19</td>
<td>Clinical Pilates regimen, 1 time per week for 6 weeks</td>
<td>Hip twists, single leg stretches, double leg stretches, clams, shoulders bridges, scissors, arm openings, breast strokes</td>
<td>Increase in total FMSTM scores by 3.5 points on average.</td>
</tr>
<tr>
<td>Sulowska et al.20</td>
<td>Foot muscle strengthening exercises, 7 times per week for 6 weeks</td>
<td>Vele's forward lean exercise and reverse tandem gait (group 1). Short-foot exercise (group 2).</td>
<td>Increase in total FMSTM score by 4 points on average in group 2. Group 2’s results were not statistically significant.</td>
</tr>
<tr>
<td>Yildiz et al.21</td>
<td>Functional training, 3 times per week for 8 weeks</td>
<td>Squat, dead bug, climbing man, plank, bridge, chop, lift, push up, pull up, medicine ball throw</td>
<td>Increase in total FMSTM scores by 5.3 points on average. Participants in the traditional training group experienced a decrease in FMSTM scores by an average of 1.6 points.</td>
</tr>
</tbody>
</table>

the participant’s baseline FMSTM score. Those with a baseline FMSTM total score <14 improved by 4.4 ± 2.3 points on average, while those with a baseline FMSTM total score >14 only improved by 2.4 ± 1.8 points on average. This may have been due to a ceiling effect as there is less potential for improvement for those with a baseline FMSTM total score >14. Core stability and neuromuscular control are important intrinsic factors that can impact an athlete’s risk of injury.22,23

Bodden et al. evaluated FMSTM scores following an intervention program that focused on resistance training in semiprofessional mixed martial arts (MMA) athletes. Their eight-week program increased the total FMSTM scores among athletes by 2.08 ± 1.21 points on average (p = 0.006). In addition to calculating an FMSTM score at the completion of the intervention program, the authors calculated a score mid-way through the program. There was an increase in FMSTM scores of 1.92 points between week zero and week four (p = 0.00); however, between weeks four and eight, the scores only increased by 0.16 points (p = 1.00). This may indicate that the duration of intervention programs could be examined, and shortening a program to four weeks be considered.

Laws et al. evaluated FMSTM scores following an intervention program that focused on Clinical Pilates, specifically the Australian Physiotherapy & Pilates Institute (APPi) Clinical Pilates method, in recreational runners. The underlying concept of Pilates is that compensatory movements, muscle imbalance, and poor habitual patterns of movement are the leading causes of injury and could be avoided through core strengthening. Clinical Pilates focuses on developing the core proximal stability muscles, which contribute to normal movement control. This six-week Clinical Pilates program increased total FMSTM scores by 3.5 ± 1.7 points on average (p < 0.01). These findings support the concept that improving functional movement control through core strengthening can potentially reduce the risk of injury. Klusemann et al. evaluated FMSTM scores following an intervention program that focused on resistance training movements in youth basketball players. In this study, participants were placed into two intervention groups that performed the same regimen; a fully supervised group and an online instructional video-based group. The six-week supervised resistance training program raised total FMSTM scores by 2 ± 2 points on average (p < 0.05). The online in-
structional video-based group did not demonstrate an increase in total FMS™ scores despite performing the same routine as the supervised group. Participant lack of compliance with the prescribed regimen or improper execution may be responsible for this variation. Supervised training appears to be the more effective method of program delivery.\textsuperscript{18}

Sulowska et al. evaluated FMS™ scores following an intervention program focused on improving foot muscle strength in long distance runners.\textsuperscript{20} In this study, participants were placed into two intervention groups with Group 1 performing Vele’s forward lean exercise (feet separated at shoulder distance and flat on ground while leaning upper body forward) and reverse tandem gait (walking heel-to-toe backwards), while Group 2 performed short-foot exercise (pulling the head of first metatarsal toward the calcaneus without curling the toes). Group 1 had an increase in total FMS™ score of 4 ± 1.96 points on average (p = 0.002). Group 2 had an increase in total FMS™ score of 2 ± 2.4 points on average, but the results were not statistically significant (p = 0.063). Some studies have examined the relationship between increased risk of acute injury or repetitive strain injury and excessive foot pronation.\textsuperscript{26,27} It has been reported that individuals with flat-arched feet have more prominent pronation in stance than high-arched individuals.\textsuperscript{28} The authors assessed foot posture using the Foot Posture Index (FPI-6) and noticed a change towards the neutral foot.\textsuperscript{20} Specifically, Group 1 had a significant improvement in talus head palpation, while Group 2 had a significant improvement in inversion/eversion of the calcaneus. The higher total score in the FMS™ test indicates that the applied exercises may improve the quality of overall movement patterns.\textsuperscript{20}

Yildiz et al. evaluated FMS™ scores following an intervention program in youth tennis players that focused either on functional training (consisting of movements that improved mobility and utilized the kinetic chain), or traditional training, which involved single-joint movements and a focus on local muscle groups.\textsuperscript{21} This eight-week functional training intervention program increased total Group 1 FMS™ scores by 5.3 points on average (p < 0.01) while traditional training decreased total Group 2 FMS™ scores by an average of 1.6 points (p < 0.01). Functional training is a form of training whereby a target movement is performed rather than focusing on a specific muscle. This approach has commonly been used in elderly, stroke, and postoperative patients.\textsuperscript{21} The results of Yildiz et al. suggest that interventions should focus on enhancing basic functional mobility rather than on isolated muscle strengthening in order to improve FMS™ scores.

There were several limitations to this study. First, many of the studies did not include control groups, making the interpretation of the intervention group results difficult. Second, there was a large disparity in the age ranges of the participants. It is possible that age influences the degree of improvement in FMS™ scores following an intervention program. Third, this review included a wide variety of sports. It is possible that an intervention that was successful for athletes participating in one particular sport may not have the same results for athletes in another sport. Future studies should seek to determine what may constitute clinically significant improvements in FMS™ scores.

CONCLUSION

The results of this systematic review indicate that intervention programs can improve total FMS™ scores in “high-risk” athletes. Despite variations in the corrective exercises performed, the number of training sessions, and the length of the intervention program, all studies demonstrated an increase in the total FMS™ scores following program implementation in the athletes that participated.

CONFLICTS OF INTEREST

The authors have no conflicts of interest.

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REFERENCES


Background
Excessive frontal plane motion of the trunk and/or pelvis has been implicated in numerous clinical conditions. To date, it is unclear whether 2D video is an appropriate surrogate for assessing frontal plane trunk and pelvis motion as a comprehensive validity study across a wide range of movements using a consistent methodology has not been performed.

Hypothesis/Purpose
The purpose of the current study was to assess the concurrent validity and agreement of frontal plane pelvis and trunk motion obtained with 2D video against the respective 3D angles during stepping, landing, and change in direction tasks.

Design
Crossover Study Design.

Methods
3D kinematics and 2D frontal plane video were obtained from 39 healthy participants (15 males and 24 females) during five athletic tasks (step down, lateral shuffle, deceleration, triple hop, side-step-cut). Data were extracted at peak knee flexion. Pearson's correlation analysis was used to assess the association between the 2D and 3D frontal plane angles at the trunk and pelvis. Bland Altman plots were used to assess the level of agreement between the 2D and 3D frontal plane angles at the trunk and pelvis.

Results
2D and 3D frontal plane angles for all tasks were correlated in a positive direction at the pelvis ($r = 0.54$ to $0.73$, all $p < 0.001$) and trunk ($r = 0.81$ to $0.92$, all $p < 0.001$). Absolute agreement in the frontal plane for all tasks and angles was below 5°. However, the 95% limits of agreement across tasks ranged from -12.8° to 21.3° for the pelvis and -11.8° to 9.4° for the trunk.

Conclusions
The use of 2D video to assess frontal plane trunk and pelvis motion is appropriate during stepping, landing, and change of direction tasks, however caution is advised when high levels of agreement or accuracy is required.

Corresponding Author:
Christopher M. Powers, PT, PhD, FACSM, FAPTA
USC Division of Biokinesiology & Physical Therapy
1540 E. Alcazar St. CHP-155
Los Angeles, CA 90089-9006
Phone: 323.442.1928
Fax: 323.442.1515
Email: powers@usc.edu
Utility of 2D Video Analysis for Assessing Frontal Plane Trunk and Pelvis Motion during Stepping, Landing, and Change in...
Table 2. Description of the Tasks Evaluated

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step Down</td>
<td>Participants were instructed to lower themselves from a 0.22 m step, tap the opposite heel to the floor, then return to the starting position. This motion was repeated five times without stopping.</td>
</tr>
<tr>
<td>Lateral Shuffle</td>
<td>Participants were instructed to shuffle to the side as quickly as possible (4.6 m runway), plant only the tested limb on the force plate, then switch directions and shuffle back to the start. This motion was repeated two times without stopping.</td>
</tr>
<tr>
<td>Deceleration</td>
<td>Participants were instructed to run forward as quickly as possible (4.6 m runway), plant only the tested limb on the force plate, then backpedal to the starting position. This motion was repeated two times without stopping.</td>
</tr>
<tr>
<td>Triple Hop</td>
<td>Participants were instructed to perform three consecutive maximal forward hops on the tested limb and stick the landing on the force plate. The starting distance was 90% of the maximal hop length, measured from the center of the force plate. Maximal hop length was established prior to biomechanical testing.</td>
</tr>
<tr>
<td>Side-Step-Cut</td>
<td>Participants were instructed to run forward as quickly as possible (4.6 m runway), plant only the tested limb on the force plate, then turn 90°.</td>
</tr>
</tbody>
</table>

Participants warmed up on a stationary bike for 5–10 minutes. Participants were instrumented with 21 reflective markers (10 mm diameter) on the right lower extremity. Semi-rigid plastic plates with mounted markers were used for the thigh, tibia, and heel clusters. In addition, markers were placed on the following bony landmarks: distal aspect of the 2nd toe, 1st and 5th metatarsal heads, medial and lateral malleoli, medial and lateral femoral epicondyles, bilateral greater trochanters (most prominent point), bilateral iliac crests (most superior aspect), and bilateral anterior superior iliac spines. For the torso, markers were placed on the L5–S1 junction, C7, sternal notch, and acromioclavicular joints (bilateral). A standing static calibration trial was obtained to determine the local segment coordinate system and joint axes. Ankle and knee joint centers were defined as the points 50% between the malleoli and femoral epicondyle markers, respectively. The hip joint centers were defined as the points located 25% of the distance between the greater trochanter markers. The ankle markers (medial and lateral malleolus), knee markers (medial and lateral epicondyles), toe markers (distal aspect of the 2nd toe, 1st and 5th metatarsal heads), greater trochanters, and anterior superior iliac spines (ASIS) were removed prior to the dynamic trials.

Two-dimensional video and 3D motion analysis were collected during the following tasks in the following order: 1) Step Down, 2) Lateral Shuffle, 3) Deceleration, 4) Triple Hop, and 5) Side-Step-Cut. Details regarding the instructions provided to participants for each of the tasks can be found in Table 2. These tasks were selected based on current knowledge of movements thought to be associated with various sport injuries. Participants were permitted to practice until comfortable with the performance of each task and could rest between trials as needed. One to two trials were obtained for each of the tasks above. As only a single repetition within a trial was needed for statistical analysis, two trials were obtained from some tasks to ensure that sufficient data were available in the case of technical errors (i.e., marker occlusion, etc.).

DATA ANALYSIS

The first successful trial was selected for each task and used for data analysis. A trial was successful if the participant performed the task as instructed with no marker occlusion. Marker position data were labeled in Simi Motion and then exported to Visual3D software (C-Motion, Inc, Germantown, MD, USA). Marker trajectory data were low-pass filtered at 12 Hz, using a fourth-order Butterworth filter. Joint angles were calculated using a X–Y–Z (sagittal–frontal–transverse) Cardan sequence. The trunk was modeled as a single rigid segment, defined proximally by two iliac crest markers and distally by two acromion markers. The 3D kinematic variables of interest were the frontal plane trunk and pelvis angles at peak knee flexion, which were calculated relative to the global reference frame.

For the 2D video analysis, the frame at peak knee flexion was visually identified. For the step down, the frame at which the contralateral heel touched the ground was used for analysis. Images were uploaded into ImageJ software (Version 1.50i, National Institute of Health, USA) for 2D angle assessments. Pelvis tilt was measured as the angle between the line connecting the ASIS’s and a horizontal line starting at the ASIS of the stance limb. A positive value represented contralateral pelvis drop and a negative represented contralateral pelvic rise (Figure 1). Trunk lean was measured as the angle between a vertical line starting at the umbilicus and a line through the umbilicus and sternum. A positive value represented an ipsilateral lean (towards stance limb) and a negative value represented a contralateral lean (away from stance limb) (Figure 1). All 2D measurements were obtained by a single investigator who demonstrated acceptable intra-rater reliability for all pelvis (ICCs ranging from 0.74 to 0.99) and trunk angles (ICCs ranging from 0.77 to 0.98).

STATISTICAL ANALYSIS

Data were assessed for normality using the Shapiro-Wilk’s test. Out of the 20 variables, 15 satisfied normality. Given that the majority of the data met normality and that Pear-
Table 3. Frontal Plane Angles for Pelvis and Trunk using 2D Video and 3D Motion Analysis, Mean (SD)

<table>
<thead>
<tr>
<th></th>
<th>Step Down</th>
<th>Lateral Shuffle</th>
<th>Deceleration</th>
<th>Triple Hop</th>
<th>Side-Step-Cut</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D Trunk Lean (deg)</td>
<td>3.4 (6.1)</td>
<td>-6.8 (9.0)</td>
<td>1.6 (5.3)</td>
<td>9.2 (8.6)</td>
<td>-4.7 (10.0)</td>
</tr>
<tr>
<td>3D Trunk Lean (deg)</td>
<td>3.5 (4.8)</td>
<td>-3.8 (7.0)</td>
<td>-1.4 (5.1)</td>
<td>6.6 (6.4)</td>
<td>-8.6 (9.9)</td>
</tr>
<tr>
<td>2D Pelvis Tilt (deg)</td>
<td>6.5 (4.4)</td>
<td>4.4 (5.2)</td>
<td>2.0 (4.8)</td>
<td>-3.3 (4.7)</td>
<td>10.3 (8.7)</td>
</tr>
<tr>
<td>3D Pelvis Tilt (deg)</td>
<td>1.9 (4.6)</td>
<td>7.7 (6.2)</td>
<td>3.0 (5.1)</td>
<td>-2.9 (5.3)</td>
<td>14.5 (10.5)</td>
</tr>
</tbody>
</table>

Positive values for trunk lean indicate ipsilateral lean. Positive values for pelvis tilt indicate pelvic drop.

RESULTS
DESCRIPTIVE DATA
Descriptive statistics for the 2D and 3D frontal plane trunk and pelvis angles are presented in Table 3.

CORRELATION AND AGREEMENT BETWEEN 2D AND 3D FRONTAL PLANE PELVIS ANGLES
The initial correlation analysis contained 1 outlier (deceleration), which was removed. Pearson’s correlation analysis indicated that all 2D and 3D frontal plane pelvis angles were significantly correlated in a positive direction (r = 0.54 to 0.73, all p < 0.001) (Figure 2).

The initial Bland Altman plot analysis contained two outliers (deceleration and triple hop), which were removed. The mean difference (MD) between the 3D and 2D pelvis angles ranged from -4.6° (step down) to 4.2° (side-step-cut). The 95% LOA ranged from MD ± 7.2° (step down) to MD ± 17.1° (side-step-cut). The 95% LOA ranged from -12.8° to 21.3° across tasks (Figure 3). In all tasks, the 95% LOA included 0.

CORRELATION AND AGREEMENT BETWEEN 2D AND 3D FRONTAL PLANE TRUNK ANGLES
The initial correlation analysis contained one outlier (triple hop), which was removed. Pearson’s correlation analysis indicated that all 2D and 3D frontal plane trunk angles were significantly correlated in a positive direction (r = 0.81 to 0.92, all p < 0.001) (Figure 4).

The initial Bland Altman plot analysis contained two outliers (shuffle and triple hop), which were removed. The mean difference (MD) between the 3D and 2D pelvis angles ranged from -4° (side-step-cut) to 2.6° (shuffle). The 95% LOA ranged from MD ± 5.5° (step down) to MD ± 7.8° (side-step-cut). The 95% LOA ranged from -11.8° to 9.4° across tasks (Figure 5). In all tasks, the 95% LOA included 0.

Figure 1. Measurement of 2D trunk and pelvis motion
Positive values for trunk lean indicate ipsilateral lean. Positive values for pelvis tilt indicate pelvic drop.
Figure 2. Correlation models for the 2D and 3D frontal plane pelvis angles for each task

Figure 3. Bland Altman plots comparing 2D vs. 3D frontal plane pelvis angles for each task

DISCUSSION

The purpose of the current study was to assess the concurrent validity and agreement of 2D frontal plane angles for the pelvis and trunk with the respective 3D angles across a wide range of tasks. The current findings revealed that 2D frontal plane angles were correlated with the corresponding 3D angles for both the trunk (strong to very strong) and pelvis (moderate to strong). In addition, the Bland Altman plots indicated no systematic bias, high agreement, but wide 95% LOA. These results suggest that the use of 2D video to assess trunk and pelvis angles is appropriate, how-
ever caution is advised when high levels of agreement or accuracy is required.

In terms of the Pearson correlation coefficients related to the validation of 2D trunk motion, all were strong to very strong. In addition, absolute agreement for all tasks was below 5° and there was no systematic bias (as 0 was within the 95% LOA) (Figure 5). However, inspection of the LOA indicated that the 95% confidence interval around the bias was generally large. The tightest 95% LOA occurred during the step down (-5.3°, 5.6°), while the widest 95% LOA occurred during cutting (-11.8° to 3.9°). The spread in data during cutting may have been the result of the body rotation that

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naturally occurs during this task. Out of plane motion during tasks that involve a change in direction would be expected to affect the accuracy of the 2D measures of trunk motion.

The validity results for 2D trunk motion are consistent, in part, with previous literature in this area. The current findings for the triple hop (r = 0.92) are in general agreement with Kingston et al. who reported a moderate absolute correlation coefficient (r = 0.65) during a similar task. However, our results for the step down (r = 0.90) conflict with the results of Kingston et al. and Schurr et al. who reported no significant correlations between 2D and 3D measures of trunk motion during single limb squatting. It should be noted however that Kingston et al. reported a weak absolute correlation coefficient (r = 0.42) with borderline significance (p = 0.087). In addition, Schurr et al. examined trunk motion displacement while the current study examined trunk position at a singular time point (i.e., peak knee flexion). As such, caution should be taken in making direct comparison among studies.

The Pearson correlation coefficients related to the validation of 2D pelvis motion ranged from moderate to strong, with the smallest values being observed during deceleration and largest for the triple hop (Figure 2). In addition, absolute agreement for all tasks was below 5° and there was no systematic bias (as 0 was within the 95% LOA) (Figure 3). As found with the trunk however, the 95% confidence interval around the bias was generally large. The tightest 95% LOA occurred during the triple hop (-6.3°, 6.4°), while the widest 95% LOA occurred during cutting (-12.8° to 21.3°).

As noted above for the trunk, the lower correlation coefficients and/or wider 95% LOA may be explained by trunk rotation that naturally occurs during change of direction tasks such as cutting and deceleration.

To date, previous validation studies for kinematic measures related to pelvis motion have only evaluated running. So direct comparisons of the current study findings to existing literature is limited. The current positive associations between 2D and 3D frontal pelvis motion for all tasks evaluated coincide with the findings of Dingenen et al. who reported that 2D and 3D pelvis drop were correlated during the stance phase during running. However, these findings conflict with Maykut et al., who reported that 2D and 3D pelvis motion during running were not correlated. Maykut et al. suggest that the differing frame rates for the 2D and 3D motion capture (60 Hz and 240 Hz, respectively) may have been responsible for their finding of a lack of agreement.

The findings of the current study have clinical implications. First, 2D measures of trunk and pelvis motion provide reasonable estimates of 3D motion across a wide range of functional tasks. Importantly, the current results indicate that 2D video methods may be appropriate for tasks that involve a change in direction. However, when high agreement or accuracy is required with 3D angles, 2D measures of the pelvis and trunk should be used with caution, particularly when there is body rotation. Nonetheless, 2D video may be useful for screening of persons who may be at risk for lower extremity injury. Future research is needed to determine if 2D measures of pelvis and trunk motion during high demand tasks has predictive value with respect to lower extremity injury.

There are several limitations of the current study that should be acknowledged. First, only healthy participants were evaluated. As such, the current findings cannot be generalized to various patient populations. Second, only 2D associations with 5 kinematic variables were assessed, using univariate analysis. It is possible that a multivariate regression approach with the addition of other 2D measurements (such as trunk or pelvis rotation) may have resulted in higher predictability. Third, this was a cross-sectional study, so the results do not make any assumptions of what 2D angles constitute increased injury risk. Fourth, although all reported correlations were statistically significant with moderate to very strong effect sizes, the clinical relevance of the current findings remain unknown and should be the focus of future investigations in this area. Fifth, despite the fact that measurement reliability was established for our 2D pelvis and trunk measures, the reliability of the corresponding 3D measures was not evaluated in the current study. This could have led to diminished agreement between the 2D and 3D measures for some tasks. Lastly, pelvis or trunk displacement was not evaluated. As such, the current findings are only applicable to singular measurements at peak knee flexion.

CONCLUSION

The results of the current study revealed that 2D frontal plane measures at the trunk and pelvis were moderately to strongly correlated with their respective 3D angle across a wide range of tasks. These findings suggest that 2D video analysis can be used as an alternative to 3D motion analysis to assess frontal plane motion of the trunk and pelvis. However, the ability of 2D trunk and pelvis angles to measure the corresponding 3D angles with high degrees of accuracy is limited, suggesting that 2D measurements should be used cautiously when high levels of agreement or accuracy are required.

CONFLICT OF INTEREST

The authors have no conflicts of interest to disclose

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REFERENCES


Original Research

Concurrent Validity and Reliability of Two-dimensional Frontal Plane Knee Measurements during Multi-directional Cutting Maneuvers

Dimas Sondang Irawan, Chantheng Huoth, Komsak Sinsurin, Pongthanayos Kiratisin, Roongtiwa Vachalathiti, Jim Richards

1 Biomechanics and Sports Research unit, Faculty of Physical Therapy, Mahidol University, 2 Musculoskeletal Physical Therapy Research unit, Faculty of Physical Therapy, Mahidol University, 3 Allied Health Research unit, University of Central Lancashire

Keywords: side-step cutting, knee valgus, injury risk screening, sport clinical tool, acl injury

Background
Excessive knee valgus has been strongly suggested as a contributing key factor for anterior cruciate ligament (ACL) injuries. Three-dimensional (3D) motion analysis is considered the "gold standard" to assess joint kinematics, however, this is difficult for on-field assessments and for clinical setting.

Purpose
To investigate the concurrent validity of 2D measurements of knee valgus angle during cutting in different directions and to explore intra-rater and inter-rater reliability of the 2D measurements.

Study Design
Descriptive laboratory study

Method
Seven recreational soccer players participated in this study. Participants performed three trials of cutting maneuvers in three different directions (30º, 60º, and 90º) with the dominant leg. Cutting maneuvers were recorded simultaneously with a video camera and a Vicon™ motion capture system. Knee valgus angle from 2D and 3D measurements at initial contact and at peak vertical ground reaction force (vGRF) were extracted. The Pearson's correlation was used to explore the relationship between the 2D and 3D measurements, and reliability of the 2D measurements were performed using intraclass correlation coefficients (ICC).

Result
Significant correlations between 2D and 3D knee valgus measurements were noted for 60º (r = 0.45) and 90º (r = 0.77) cutting maneuvers at initial contact. At peak vGRF, significant correlations between 2D and 3D knee valgus measurements were noted for 30º, 60º, and 90º cutting maneuvers (r=0.45, r=0.74, r=0.78), respectively. Good-to-excellent intra-rater and inter-rater reliability of the 2D knee valgus measurements was observed during cutting in all directions (ICCs: 0.821-0.997).

Conclusion
Moderate-to-strong correlation between 2D and 3D knee valgus measurements during
INTRODUCTION

ACL injury is a common and serious problem in sports and requires a long period of rehabilitation. A rate of 6.5 ACL injuries per 100,000 athlete exposures throughout various athletic activities was reported in high school level. Approximately 76% of ACL injuries require surgery, which consumes time and money for recovery and may ultimately reduce the quality of life by increasing the risk of subsequent injuries or impairments, resulting in financial hardship. After ACL reconstruction, 55% of injured athletes can return to competitive level. However, athletes with ACL deficiency have greater risk of early-onset osteoarthritis of the knee. Therefore, ACL injury prevention and risk screening are important.

Excessive knee valgus has been strongly suggested as a contributing factor to anterior cruciate ligament (ACL) injuries. Seventy to eighty-four percent of ACL injuries occur during non-contact while decelerating or rapidly changing direction in sporting activities. In addition, the combination of knee valgus with poor trunk or hip control has been identified as a key predictor of ACL strain in hip abduction, hip internal rotation, and ipsilateral trunk leaning.

Observation of the knee valgus angle is considered a critical component for injury risk assessment and often performed during functional tasks such as single-leg squat and landing tasks which are typically carried out in clinical and sports settings. Three-dimensional (3D) motion capture is considered as the "gold standard" to determine the quality of human movement. Such a system is able to evaluate multi-planar kinematics across joints and has been shown to be reliable in the assessment of many functional tasks such as landing tasks and cutting maneuvers. However, a 3D motion system is not practical within field and clinical settings due to cost, complexity, and time required to perform the analysis.

Previous studies have developed alternative two-dimensional (2D) methods and compared these with 3D methods for use in clinical settings. 2D measurement using commercial cameras is one method which is relatively inexpensive and easy to apply in field and clinical settings. 2D measurements have been used to examine dynamic knee valgus using the frontal plane projection angle (FPFA), which has shown good reliability in performance test such as running, drop jump, and single leg landing, which can provide biomechanical measurements to assess injury risk and progression through treatment. However, the use of 2D methods to assess cutting maneuvers in various directions has not been reported.

Cutting maneuvers are frequently performed during sports training sessions. Previous studies have demonstrated that different knee valgus angles were noted with different directions of cutting, which are important to consider for injury risk in sporting settings. Therefore, the potential to apply 2D measurements to determine knee valgus angle during cutting maneuvers in various directions is worthy of investigation.

To the best of authors' knowledge, the use of 2D analysis to explore knee valgus angle during side-step cutting maneuvers in multi-directions has yet to be reported. Therefore, the purpose of the present study was to investigate the concurrent validity of 2D measurements of knee valgus angle during cutting in different directions, and to explore intra-rater and inter-rater reliability of the 2D measurements. The hypothesis of the study was that 2D frontal knee measurement would have good validity and reliability in multidirectional cutting maneuvers.

METHODS

PARTICIPANTS

All participants were university students who volunteered to participate in the study. The inclusion criteria were: aged between 18- to 25-years, and regularly participated in sports involving cutting maneuvers. Participants were excluded from the study if they reported a history of lower extremity surgery or a history of serious injury of lower extremity within a year prior to testing. The research protocol was approved by the Mahidol University Central Institutional Review Board for Human Research (COA.No. 2020/062.2704). Before testing, all participants signed an informed consent form and the protocol was explained in detail.

SIDE-STEP CUTTING MANEUVERS

Athletes performed side-step cutting maneuvers in the three different directions: 50°, 60°, and 90° (Figure 1). The participants were instructed to stand at the starting point, run forward five meters and perform a side-step cutting task with the dominant leg. The standardized verbal command for all participants was "keep looking forward and perform a side-step cutting at maximum speed". The participants performed a five-minute warm up of lower limb dynamic stretching and practiced five trials of side-step cutting before actual testing in each direction. Three completed trials of each directional session were then measured and analyzed, and the knee valgus angles from the 2D and 3D measurements were extracted at initial contact and at peak vertical ground reaction force (vGRF).
2D MEASUREMENTS

A commercially available digital camera (Canon EOS 1200D, Canon USA Inc, Melville, USA) with a 18-55 mm lens, was positioned 2 m away from the force plate at a height of 60 cm and recorded at 60 Hz. Digital video footage was recorded with no optical zoom to standardize the camera image between participants. Video footage was imported to Kinovea software (Version 0.9.3, Kinovea Open Source Project, www.kinovea.org) and 2D knee measurement was processed. The frontal plane projection angle (FPPA) was used to estimate the knee valgus angle by measuring the angle between the line from ASIS to the center of patella, and the line from the ASIS to the center of the ankle joints, which was then subtracted from 180° (Figure 2). Two raters assessed the FPPA in the study. They are physical therapists who have experience in 2D measurement and in ten years of orthopedic and sports physical therapy. Each rater measured knee valgus angle of a data set which the information regarding cutting directions was encrypted by code. In order to determine intra-rater reliability, the first rater measured the FPPA twice, two weeks apart.

3D MEASUREMENTS

A 10 camera ViconTM motion analysis system (Vicon nexus 2.10, Oxford Metrics, Oxford, UK) was used to record three-dimensional marker coordinates at 200 Hz. Force data was collected synchronously using an AMTI force platform at 1,000 Hz (AMTI-OR67, Advance Mechanical Technologies Inc., Watertown, USA) which was used to identify stance phase during the cutting maneuvers. Twenty-six reflective markers were attached on the bony prominences of both sides, including anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), iliac crest, greater trochanter, medial and lateral femoral epicondyles, medial and lateral malleoli, distal head of the first metatarsals, distal head of the fifth metatarsals, proximal head of the fifth metatarsals, and heels. In addition, four rigid clusters of four markers were placed on the lateral thigh and lateral shank (Figure 3 and 4).

Kinematic and kinetic data were imported into Visual 3D software (C-Motion Inc, Germantown, USA), and digitally filtered using a low pass, fourth-order Butterworth filter with cut-off frequencies of 6 Hz and 35 Hz, respectively. Right-hand 3-dimensional Cartesian coordinate systems were used for global and segmental axes. The pelvis segment was measured relative to the global (laboratory) coordinate system, and the hip joint center was estimated using method reported by Bell et al. Knee and ankle joint centers were estimated as the midpoint between the medial and lateral femoral epicondyles and malleoli, respectively, and the knee joint angle was calculated between the shank relative to the thigh segment. Kinetics and kinematics data were extracted and normalized into 101 data points in order to represent 100% of the stance phase during side-step cutting maneuver.

STATISTICAL ANALYSIS

Three completed trials of cutting tests in each direction were processed from the seven soccer players in the study. Then, a total of 21 data sets were statistically analyzed. To determine the concurrent validity, Pearson product-moment correlation was used to assess the linear relationships between the 2D and 3D measurements of the knee valgus
angle at initial contact and at peak vGRF. The strength of the correlation \( r \) was interpreted as poor (0 to 0.49), moderate (0.50 to 0.75), and strong (> 0.75).\textsuperscript{30} Reliability analysis of the 2D measurements was performed using intraclass correlation coefficient (ICC). The ICC(3,1) and ICC(2,1) models were used for statistical analysis of intra-rater and inter-rater reliabilities, respectively. Reliability index of ICC were interpreted as poor (less than 0.5), moderate (0.5-0.75), good (0.76-0.9), and excellent (> 0.9).\textsuperscript{31}

RESULTS

Seven male soccer players, all with more than four years experience in soccer playing voluntarily participated. The characteristics of the participants are shown in Table 1. The Pearson’s correlation coefficients between 2D and 3D measurements of the FPPA at initial contact showed a significant strong correlation during 90° cutting \( r = 0.77, 95\% \text{ CI: } 0.34 - 0.89 \), with 60° cutting showing a significant but poor correlation \( r = 0.45, 95\% \text{ CI: } -0.07 - 0.83 \), and 30° cutting showing no significant correlation. For the FPPA at peak vGRF a significant correlation was seen between 2D and 3D analyses in all directions of cutting, with 90° cutting showing a strong correlation \( r = 0.78, 95\% \text{ CI: } 0.19 - 0.87 \), 60° cutting showing a moderate correlation \( r = 0.74, 95\% \text{ CI: } 0.31 - 0.89 \), and 30° cutting showing a poor correlation \( r = 0.45, 95\% \text{ CI: } -0.14 - 0.81 \), Table 2. The FPPA measurements demonstrated good-to-excellent intra-rater reliability at initial contact (ICC: 0.821-0.937) and at peak vGRF (ICCs: 0.970-0.987). In addition, the inter-rater reliability index showed excellent reliability at initial contact (ICCs: 0.974-0.987) and at peak vGRF (ICCs: 0.989-0.997), Table 3.

DISCUSSION

The purpose of this study was to determine the concurrent validity and reliability of 2D frontal knee measurements during multi-directional cutting maneuvers. To explore the concurrent validity, knee valgus angles at initial contact and at peak vGRF were captured with 2D and 3D measurements, simultaneously. Moreover, the intra-rater and inter-rater reliabilities of the 2D measurements of knee valgus were determined. The findings of the present study showed that there were statistically significant correlations between most 2D and 3D measurements, and the reliability indices of 2D measurement showed good-to-excellent intra- and inter-rater reliability at both initial contact and peak vGRF.

Cutting maneuvers require a sudden change of direction after running and involves translation and reorientation into new direction of travel.\textsuperscript{32} This study used the frontal plane projection angle (FPPA) from 2D measurement which has been reported to be highly influenced by hip and knee joint rotations in the transverse plane.\textsuperscript{33} The present findings confirmed a poor correlation of 2D and 3D knee valgus measurements at initial contact during cutting maneuvers at 30° and 60° and peak vGRF at 30°. This further supported by Schurr et al.\textsuperscript{34} who found a poor correlation \( r = 0.31 \) in the frontal plane knee angle between 2D and 3D analyses during a single-leg squat. In addition, Maykut et al.\textsuperscript{20} considered knee valgus angles during running on treadmill and also showed a poor correlation between 2D and 3D analyses \( r = 0.158 \). Maykut et al. suggested that the difference of sampling frequencies may explain the non-significant correlation between the 2D and 3D measurements, when using...
Table 1. Characteristics of participants (n = 7)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Mean (±SD) or number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (male / female)</td>
<td>7 / 0</td>
</tr>
<tr>
<td>Age (years)</td>
<td>23 (0.81)</td>
</tr>
<tr>
<td>Experience (years)</td>
<td>4</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>169.25 (4.57)</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>57 (7.75)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>20.54 (1.5)</td>
</tr>
<tr>
<td>Leg dominance (% Right)</td>
<td>100</td>
</tr>
</tbody>
</table>

SD: standard deviation; BMI: Body Mass Index

Table 2. Pearson's correlation coefficients of 2D and 3D knee valgus measurements at initial contact and at peak vGRF phases

<table>
<thead>
<tr>
<th>Time event</th>
<th>Angle of cutting direction</th>
<th>r</th>
<th>95% CI</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC</td>
<td>30º</td>
<td>-0.02</td>
<td>-1.56, 0.58</td>
<td>0.533</td>
</tr>
<tr>
<td></td>
<td>60º</td>
<td>0.45</td>
<td>-0.07, 0.83</td>
<td>0.034*</td>
</tr>
<tr>
<td></td>
<td>90º</td>
<td>0.77</td>
<td>0.34, 0.89</td>
<td>0.002*</td>
</tr>
<tr>
<td>Peak vGRF</td>
<td>30º</td>
<td>0.45</td>
<td>-0.14, 0.81</td>
<td>0.046*</td>
</tr>
<tr>
<td></td>
<td>60º</td>
<td>0.74</td>
<td>0.31, 0.89</td>
<td>0.003*</td>
</tr>
<tr>
<td></td>
<td>90º</td>
<td>0.78</td>
<td>0.19, 0.87</td>
<td>0.008*</td>
</tr>
</tbody>
</table>

* Statistically significant correlation (p ≤ 0.05); IC: initial contact; vGRF: vertical ground reaction force

Table 3. Intra-rater and inter-rater reliabilities of 2D knee valgus measurements at initial contact and at peak vGRF phases.

<table>
<thead>
<tr>
<th>Time event</th>
<th>Cutting direction</th>
<th>Intra-rater ICC (95% CI)</th>
<th>Inter-rater ICC (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC</td>
<td>30º</td>
<td>0.937 (0.631 – 0.989)</td>
<td>0.974 (0.847 – 0.995)</td>
</tr>
<tr>
<td></td>
<td>60º</td>
<td>0.821 (-0.04 – 0.969)</td>
<td>0.983 (0.899 – 0.997)</td>
</tr>
<tr>
<td></td>
<td>90º</td>
<td>0.925 (0.564 – 0.987)</td>
<td>0.987 (0.926 – 0.988)</td>
</tr>
<tr>
<td>Peak vGRF</td>
<td>30º</td>
<td>0.987 (0.926 – 0.998)</td>
<td>0.994 (0.968 – 0.999)</td>
</tr>
<tr>
<td></td>
<td>60º</td>
<td>0.970 (0.828 – 0.995)</td>
<td>0.989 (0.934 – 0.998)</td>
</tr>
<tr>
<td></td>
<td>90º</td>
<td>0.978 (0.875 – 0.996)</td>
<td>0.997 (0.981 – 0.999)</td>
</tr>
</tbody>
</table>

IC: initial contact; vGRF: vertical ground reaction force

60 Hz for the 2D measurement and 240 Hz for the 3D measurement.

However, the current study did show some significant correlations at initial contact and at peak vGRF during cutting maneuvers. At peak vGRF the correlations were strong (r=0.78), moderate (r=0.74), and poor (r=0.45) for cutting maneuvers at 90º, 60º, and 30º, respectively, with correlation at initial contact being strong (r=0.77), moderate (r=0.45), and very poor (r=0.02) for 90º, 60º, and 30º, respectively. Both Maykut et al.20 and Schurr et al.34 reported peak knee abduction angles and knee angle displacements in frontal plane, respectively, while the current study reported values at initial contact and peak vGRF. Therefore, the different time events could be a possible reason for differences seen with previous studies.

McLean et al.33 demonstrated a moderate correlation between 2D and 3D measurements. McLean et al. investigated 35º and 55º cutting and side-jump tasks in healthy male and
female collegiate basketball players, and reported moderate correlations $r = 0.58$ and $r = 0.64$ for the 35° and 55° cutting tasks and side jump, respectively. Havens et al. demonstrated 35° greater pelvic rotation to the intended direction during 90° cutting compared with 45° cutting. The current study showed strong correlations in 90° cutting, moderate correlations at 60°, and poor correlation at 30° cuttings (Table 2). The difference seen could be due to the difference in tasks explored. Schurr et al. and Maykut et al. studied single-leg squat and running, respectively.

Regarding multi-directional cutting maneuvers, Dos Santos et al. stated that there was a relationship between directions and biomechanical demands. Greater hip abduction and knee valgus angles were observed as the angle of directional change increases. The current findings indicate that knee valgus screening using 2D measurements for 60° and 90° cutting tasks could be considered as a suitable assessment for use in clinical settings, and may be useful as an injury screening tool to help health professionals observe frontal knee projection during cutting. The possible explanation of poor correlation in 30° cutting might due to the athlete's pelvic rotation to the intended direction prior to initial contact. Rotational movement could lead to a bit of difficulty of maker capture for 2D measurement. Comparing results of 2D knee valgus between studies should be interpreted with caution due to previous limitations reported when examining 2D measurements, and further work is required to explore the clinical utility of such measures in term of knee valgus magnitude.

In addition, 2D knee valgus measurements in this study showed good-to-excellent intra-rater and excellent inter-rater reliabilities. This suggests that 2D knee valgus measurement of the current study is fit for repeated measurements in clinical evaluation. The method of 2D testing used in this study is highly reliable and is therefore acceptable for assessing before and after provision of targeted intervention such as neuromuscular training and corrected cutting training.

Application of the findings to other sport tasks and to female athletes should be performed carefully. It would be interesting to perform a future study in which more participants are recruited to investigate limb dominance.

CONCLUSION

The current study demonstrated that concurrent validity of 2D and 3D knee valgus measurements is moderate-to-strong when considering 60° and 90° cutting maneuvers. Poor correlation was observed in 30° cutting maneuver. The 2D measurement of the FPPA demonstrated good-to-excellent intra-rater and excellent inter-rater reliabilities. This suggests that 2D knee valgus measurements could be used as an easy and inexpensive screening tool for injury risk identification and evaluation of change after targeted interventions such as neuromuscular training and corrected cutting training. In clinical application, knee valgus screening using 2D measurements for 60° and 90° cuttings could be performed and considered as a suitable assessment.

CONFLICT OF INTEREST

No conflict of interest

ACKNOWLEDGMENTS

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REFERENCES


Background
Low back pain is a condition present during both adulthood and adolescence. Adolescents with low back pain may benefit from treatment focused on improving abdominal muscle performance and motor control. The supine double leg lowering test (SDLTT) may be a reliable measure to assess core stability in adults, but adolescent performance on the SDLTT has not yet been established in the literature.

Purpose
To examine performance on the SDLTT in healthy adolescents ages 13 to 18 years and describe influences of gender, age, body mass index, and participation in sport.

Study Design
Cross-Sectional Study

Methods
Four licensed physical therapists administered the SDLTT with a Stabilizer pressure biofeedback cuff and inclinometer in 90 adolescents without low back pain (females = 41, males = 49) from three schools in a mid-western metropolitan area. Descriptive statistics, independent sample t-tests, two-way analysis of variance, and Pearson correlation coefficients were utilized to analyze the data.

Results
Average SDLTT score was 72.36 +/- 12.54 degrees. A significant difference between SDLTT score was present between genders with males performing better than females. No interactions between performance and involvement in sport were demonstrated.

Conclusions
Female and male adolescents appear to perform differently on the SDLTT with a stabilizer and appear to perform worse than scores recorded for adults. The SDLTT may be used to measure motor control in adolescents, but clinicians should utilize age-appropriate data for clinical decision making.

Levels of Evidence
Level 2c
INTRODUCTION

Low back pain (LBP) is no longer a condition that begins in middle age, with recent literature suggesting increased frequency of back pain in individuals under the age of 20 in both athletes and non-athletes.¹⁻⁵ The increasing prevalence of adolescent LBP supports the need to optimize care for this population. In order to improve the care for this population, appropriate measures must be utilized for examination and assessment.

Previous authors have proposed a subgroup of adult patients benefiting from motor control exercises in the treatment of LBP.⁶⁻⁸ The core includes structures of the spine, hips, and pelvis and consists of both local and global musculature at the trunk and pelvis.⁹,¹⁰ Local musculature includes muscles with an insertion or origin at the vertebræ and include the transversus abdominis and multifid.¹⁰ Global musculature includes the muscles that "transfer load between the thoracic cage and the pelvis" and include muscles such as the external obliques, internal obliques, rectus abdominis, erector spinae, and psoas.¹⁰(p20) These muscles may be responsible for the skill acquisition of dissociating or coordinating lumbar spine movements from adjacent regions.⁸ While researchers have slight variations in their definition of the core, greater discrepancy exists in defining core stability. Core stability may be achieved through the interdependence of the passive ligamentous subsystem, active musculoskeletal subsystem, and neural feedback subsystem to match various demands due to changes in posture and load and may include proprioception, strength, power, and endurance.¹¹,¹²

A clinical prediction rule exists for this subgroup of patients benefiting from core stabilization in the treatment of LBP, and recent findings suggest children and adolescents with LBP present with findings that often classify them as potentially benefiting from stabilization interventions.⁵,⁷,¹³ It is likely that adolescent patients present with deficits in core stability, however, no gold standard for measuring this impairment currently exists in the literature.¹¹ One tool used to assess lumbo pelvic motor control is the supine double leg lowering test (SDLLT), and previous authors have suggested that it may be a reliable measure of lumbo pelvic motor control in adults.¹⁴⁻¹⁸

The SDLLT was originally described as an abdominal muscle strength measurement, but based on dynamometry studies, Ladeira et al. suggested that the test is more likely exploring pelvic tilt motor control required to maintain lumbar functional stability versus true abdominal strength..¹⁴,¹⁷,¹⁹,²⁰ However, electromyographic (EMG) studies have reported moderate to high levels of abdominal muscle activation with the SDLLT, specifically the rectus abdominis, external obliques, internal obliques, and transversus abdominis. The results of these studies also indicate that the SDLLT does not isolate the lower abdominals, but rather requires high levels of abdominal co-contraction.¹⁵,²¹,²² Therefore, the muscle activity related to the SDLLT may be more indicative of assessing lumbo pelvic motor control versus strength.¹¹,¹⁴,¹⁷,²¹ However, motor control has recently been defined as "the way in which the nervous system controls posture and movement to perform a given task" through motor, sensory and integrative processes.²⁵(p380) It is possible the SDLLT assesses the ability of an individual to control sagittal plane lumbar spine motion and manage the associated internal lumbar extension moment produced while performing the SDLLT. It is therefore suggested the SDLLT may be a more appropriate test of an individual’s motor control rather than core stability.

Performance on the SDLLT in young adult and adult populations are reported in the literature but has not been investigated in the adolescent population.¹¹,¹⁴,¹⁹,²² It is therefore imperative that performance on the SDLLT is examined in this population in order to allow clinicians to reliably assess deficits and improvements in motor control in order to improve clinical examination, evaluation, and treatment of low back pain in this population. The purpose of this study was to examine performance on the SDLLT in healthy adolescents ages 13 to 18 years and describe influences of gender, age, body mass index, and participation in sport.

METHODS

PARTICIPANTS

Adolescents between the ages of 13-18 years were recruited from physical education classes at three schools in a midwestern metropolitan area between April 2017 and April 2018. Each parent or 18-year-old participant signed a written informed consent and adolescents under the age of 18 years signed a written informed assent. Exclusion criteria for this study included: (1) being younger than 13 years and/or older than 18 years, (2) a current diagnosis or previous history of low back pain, scoliosis, spondylolisthesis, and/or spondylolysis, (3) current musculoskeletal complaints in the upper or lower extremity including pain, radiating symptoms, or impairment, (4) previous history of spine, upper extremity, or lower extremity surgery, or (5) pain-related to acute fracture, tumor, infection, or systemic illness. This study had approval from the Cincinnati Children’s Hospital Medical Center Institutional Review Board.

PARTICIPANT CHARACTERISTICS DATA

Participants self-reported age in years, gender, height, weight, and athletic participation prior to performing the SDLLT. Body mass index (BMI) was calculated utilizing participant’s self-reported height and weight and then categorized based on recommendations from the Centers for Disease Control and Prevention (CDC).²⁴ Athletic participation was first categorized by participation in any activity and then further categorized by type of organized sport.

PROCEDURE

All adolescents were tested during their physical education class period. Four licensed physical therapists trained in performing and measuring the SDLLT using a standardized protocol administered the test to participants. (Figure 1).¹¹,¹⁶ A stabilizer pressure biofeedback unit (Chattanooga Group Inc, Vista, CA) is a small pressure biofeedback device typically used by physical therapists during examination and treatment of patients with low back pain. The stabilizer
was used to determine when to terminate the SDLLT (Figure 2). A single inclinometer (Baseline AccuAngle Goniometer, Japan) was used to record the hip flexion angle of the SDLLT. One examiner was blinded from the inclinometer measurement in order to eliminate the potential for intrarater bias while measuring.

After providing verbal consent, each participant took off their shoes and lay supine on a standard, portable treatment table with arms across their chest. The stabilizer was placed under the participant’s lumbar spine and their legs were passively elevated to 90 degrees of hip flexion from the horizontal (Figure 1A). To account for hamstring tightness, 5-10 degrees of knee flexion was considered acceptable. They were instructed to keep their legs at 90 degrees without assistance while the stabilizer was inflated to 40 mmHg. The following statement was given to each participant prior to completing the test: “Press your back down into the stabilizer while keeping your legs straight. Keep pressing your back into the stabilizer as you slowly lower both your legs towards the table keeping your knees straight. Don’t let your back come up from the stabilizer under you.”

The test was ended when the pressure reading from the stabilizer fell below 30 mmHg. At this point, Examiner one passively supported the participant’s legs while Examiner two utilized the single inclinometer to record the angle of their legs from the horizontal. When the SDLLT is ended, a hip flexion angle closer to 0 degrees of hip flexion indicates better performance whereas a hip flexion angle closer to 90 degrees of hip flexion indicates worse performance. (Figures 1B and 1C). Each participant received one practice trial with the stabilizer in place followed by a one-minute rest break. They then performed two recorded trials of the SDLLT with another one-minute rest break in between the trials. The above protocol was determined based on previous research published in the literature.2,3 A previous pilot study using the same protocol was used to determine reliability and found the SDLLT to have high intra-rater reliability (0.885, p<0.001) as well as high inter-rater reliability (0.832, p<0.001).18

**DATA ANALYSIS**

SDLLT scores were recorded in Microsoft Excel 2013 (Microsoft Corporation, Redmond, WA). Data were analyzed using Microsoft Excel 2013 and IBM SPSS Statistics Version 25 (IBM Corporation, Armonk, NY). Descriptive statistics were utilized to characterize the sample with regard to: age in years, gender, body mass index, height, weight, athletic participation, and performance on the SDLLT. Average SDLTT score was calculated from the two trials and categorized by gender, age in years, athletic participation, height, weight, and BMI. Independent sample t-tests and two-way analysis of variance (ANOVA) were utilized to determine whether significant differences were present between subgroups with a priori significance set to 0.05. Pearson correlation coefficients were analyzed to further determine a correlation between age and SDLLT score, age and BMI, and BMI and SDLLT score.

**RESULTS**

**SAMPLE DESCRIPTION**

A total of 142 adolescents volunteered to participate in this study and 90 met eligibility criteria (41 females, 49 males). Additional information on participant selection is presented in Figure 3. The mean age was 15.88 years +/- 1.51 years (range 13.00-18.00 years). The average height of participants was 67.93 +/- 4.12 inches (range 59.00-77.00 inches) and the average weight was 148.12 +/- 37.41 pounds (range 70.00-334.60 pounds). The average BMI of all participants was 22.45 +/- 5.01 (range 8.52-49.41). Out of the 90 participants, height information was not available for two, weight information was not available for one, and BMI information was not available for two. Additional sample characteristic information is presented in Table 1.

Based on CDC classifications for BMI, 10% of the sample in this study was underweight, 72% were a healthy weight, 11% were overweight, and 4% were obese.24 Of all participants included in the study, 56 reported they were involved in a type of organized sport whereas 34 reported they were not involved in any type of organized sport. Thirty-six participants were involved in a single sport and 20 participants were involved in two or more sports. Soccer, track and field,
Table 1. Sample Demographics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Females (n=41)</th>
<th>Males (n=49)</th>
<th>Total (n=90)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>15.51</td>
<td>16.18</td>
<td>15.88</td>
</tr>
<tr>
<td>Mean</td>
<td>1.19 (13-18)</td>
<td>1.33 (14-18)</td>
<td>1.31 (13-18)</td>
</tr>
<tr>
<td>Standard Deviation (range)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (inches)</td>
<td>64.95</td>
<td>70.43</td>
<td>67.93</td>
</tr>
<tr>
<td>Mean</td>
<td>3.05 (59-76)</td>
<td>3.12 (64-77)</td>
<td>4.12 (59-77)</td>
</tr>
<tr>
<td>Standard Deviation (range)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (pounds)</td>
<td>128.33</td>
<td>164.42</td>
<td>148.12</td>
</tr>
<tr>
<td>Mean</td>
<td>24.06 (70-200)</td>
<td>38.72 (111-334.6)</td>
<td>37.41 (70-334)</td>
</tr>
<tr>
<td>Standard Deviation (range)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI</td>
<td>21.47</td>
<td>23.28</td>
<td>22.45</td>
</tr>
<tr>
<td>Mean</td>
<td>3.90 (8.52-32.28)</td>
<td>5.68 (17.70-49.41)</td>
<td>5.01 (8.52-49.41)</td>
</tr>
<tr>
<td>Standard Deviation (range)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

and football were the most commonly represented sports with each having greater than or equal to 10 participants.

SDLLT PERFORMANCE

Healthy adolescents without pain scored an average of 72.56 +/- 12.54 degrees on the SDLTT. SDLTT scores for the entire group and for males and females are presented in Figure 4.

There was a significant difference in SDLTT score between females (76.99 +/- 6.98 degrees) and males (68.49 +/- 14.74 degrees) suggesting females and males perform differently on the SDLTT (p=0.001). There was no significant difference between participants who were involved in organized sports and participants who were not involved in organized sports (p=0.849).

A two-way analysis of variance was used to assess interaction between gender, participation in an organized sport, and SDLTT score. No interaction was found between participation in an organized sport and SDLTT score (p=0.849) or between gender and participation in organized sport (p=0.587).

Correlations were assessed between age and SDLTT score, BMI and age, and BMI and SDLTT score. There was a significant weak negative correlation between age and SDLTT score (r=-0.218, p=0.04) and a significant weak positive correlation between BMI and age (r=0.229, p=0.05). No significant correlation was found between BMI and performance on the SDLTT (r=-0.113, p=0.30).

DISCUSSION

The purpose of this study was to describe SDLTT performance as measured using a stabilizer in healthy adolescents without pain using a previously established standardized protocol. Previous authors have suggested that female and male adults perform differently on the SDLTT and results of this study demonstrate a difference in adolescent performance on the SDLTT between gender, suggesting that adolescent females and males also perform differently on the SDLTT.11,14,22 As age increased, BMI also increased with no relationship between BMI and performance on the SDLTT.

Compared to previously published studies, the results of this study indicate adolescents may not perform as well as...
adults on the SDLTT. Literature assessing adults over 18 years of age suggests normal scores for the SDLTT to be between 15 degrees and 55 degrees. Youdas et al. described normal scores on the SDLTT in adults ages 40 to 69 years of 49.6 degrees for females and 39.0 degrees for males, Krause et al. described normal on the SDLTT in adults ages 18 to 29 years as 36.9 degrees for females and 15.4 degrees for males, and Sharrock et al. described normal values in adults ages 18 to 22 years of 54.8 degrees for females and 47.4 degrees for males. In contrast, adolescents ages 13 to 18 years in this study performed an average of 77.0 degrees females and an average of 68.5 degrees for males. Poorer performance on the SDLTT in this study as compared to previously published studies may be due to differences in maturation, cognition, and neuromuscular control in the adolescent population compared to adults. Future directions should further evaluate any differences in SDLTT score between specific ages due to potential differences in maturation and peak height velocity which can lead to variable performances.

Differences in SDLTT performance may also be due to protocol. Kendall first described the SDLTT and used a hand under the lumbar spine to determine lumbopelvic motion and when to decide the end of the test. Krause et al. also used an examiner’s hand to assess for an increase in lumbar lordosis indicating the end of the test. The protocol in this study utilized a stabilizer similar to that described by Sharrock et al. to determine the end of the test. The stabilizer is likely a more objective measure and more sensitive and reliable than an examiner’s hand in detecting changes in lumbar lordosis, which may contribute to the poorer scores on the SDLTT in this study compared to previous studies. The large number of participants who performed between 80 and 90 degrees on the SDLTT may indicate excessive sensitivity and responsiveness of the stabilizer to movement in the pelvis/lumbar spine, based on this study’s protocol. This study also utilized a single inclinometer instead of a goniometer which may contribute to differences in the measurement of the performance in this study compared to previous studies.

There were no significant differences between participants who were involved in sports and those who did not. Previous work has reported differences in prevalence of low back pain in adolescent athletes participating in combat sports or sports requiring repetitive translation or rotation forces. With increasing evidence emerging on the relationship of motor control to athletic performance, it is possible that athletes participating in sports requiring skills similar to the SDLTT or demanding repetitive rotational forces and high impact may perform differently on the SDLTT compared to other athletes. Further, adolescent athletes may require greater amounts of motor control for sports performance and the SDLTT may assist clinicians in assessing motor control. Future studies investigating performance by sport may further clarify the potential impact of specific sports on SDLTT performance.

Adolescents present with unique characteristics related to physical and cognitive development that contribute to differences in movement compared to adults. Despite differences between adults and adolescents, clinicians often utilize clinical measures studied in adults with established normative values based on adult performance in the pediatric and adolescent population. As previously mentioned, studies on the prevalence of low back pain suggest differences exist in adolescents compared to adults. While repetitive microtrauma can lead to low back pain within both the adult and adolescent populations, low back pain in adolescents may also be due to insufficiency within the muscle-tendon complex due to decreased neuromuscular control and impaired posture. Due to the demands of the SDLTT, it is possible that the SDLTT requires both strength and neuromuscular control to dissociate hip extension from lumbar extension and anterior pelvic tilt. With the mean SDLTT score of adolescents ages 13 to 18 years appearing worse than values seen in adults, it is important that clinicians utilize values on performance specific to the population they are treating in order to determine whether an impairment in motor control is present, assess meaningful changes in performance, and set reasonable and achievable goals. While no reference values currently exist for SDLTT performance in the adolescent population, the findings from this study may assist clinicians in determining a patient’s progress as they return to their prior level of function or optimize their current level of function.

LIMITATIONS

Several limitations may exist in this study. First, the relatively small sample size of this study may limit the generalizability of the findings to the general population. Second, this study did not account for leg length which may change the findings of this study. Although it does not appear that weight, height, and BMI influence performance on the SDLTT, the length of the lower extremities may affect the amount of muscle recruitment and motor control required to perform the SDLTT. Third, while this study allowed up to 10 degrees of knee flexion to account for hamstring tightness, hamstring flexibility was not formally assessed and excessive hamstring tightness may impact the generalizability of the results. In addition, decreased hamstring length in the starting testing position may cause a passive posterior pelvic tilt which may have affected performance and clinicians should be mindful of this when utilizing the SDLTT. Fourth, this study relied on verbal reports of height and weight which may also alter the relationship between these variables and performance on the SDLTT. Fifth, while students were pulled from physical education class randomly and at different times during class to perform the SDLTT, fatigue from physical education class was not controlled for. Lastly, for several participants, performance on the second trial was improved compared to the first trial. This may be due to a learning effect on the SDLTT or it is possible that the SDLTT is a more novel task to adolescents compared to adults. This may explain differences in performance between adolescents and adults as well as the improved performance between trials in some participants. It is also possible that adolescents utilized different movement strategies to maintain pressure on the stabilizer.

Additional work is needed to further examine the reliability and validity of the SDLTT in the adolescent population. Future directions may include establishing normative values for performance on the SDLTT in a larger sample size.
performance on the SDLLT utilizing the standardized protocol described in this study. It is recommended that future studies account for leg length in order to determine whether the length of the lower extremities influence performance on the SDLLT. Due to the large number of participants performing between 80 and 90 degrees on the SDLLT, future research should consider utilizing a different pressure reading on the stabilizer to determine the end of the SDLLT. Future work should also focus on comparing performance on other trunk motor control tests between adults and adolescents in order to determine whether a trend in poorer performance is present in other tests besides the SDLLT. It is important that future work also examine performance on the SDLLT in relation to maturation status and/or cognition since these factors may have affected performance on the SDLLT. Lastly, future studies should compare performance on the SDLLT in adolescents with low back pain to adolescents without low back pain. In this study, none of the participants reported back pain while administering the SDLLT. However, the onset of pain during the SDLLT may impact performance on this test. Clinically, the SDLLT is often terminated or modified with the onset of back pain and performance may be reported as 90 degrees with pain in the starting position.

CONCLUSION

To the author’s knowledge, this is the first study to examine performance on the SDLLT utilizing a standardized methodology involving a stabilizer in adolescents ages 13 to 18 years. The results of this study indicate that female and male adolescents appear to perform differently on the SDLLT, but it does not appear that there is a relationship between SDLLT score and BMI. Performance on the SDLLT in adolescents also appears to be worse than in performance by adults reported in previous studies. The SDLLT is simple to use in a clinic setting, requires minimal equipment, and seems to have minimal to no adverse effects. The SDLLT may be a useful measure for physical therapists to assess motor control in adolescents and compare performance to that of healthy adolescents without pain or impairment to assist in clinical decision making.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

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REFERENCES


Background

The Lower Quarter Y-Balance Test (YBT-LQ) has been shown to be reliable for assessing dynamic balance in children and adolescents. However, limited research is available about the effects of leg dominance on YBT-LQ performance in adolescents. In addition, there is no consensus on the use of maximum reach or mean reach distance being a better measure of YBT-LQ performance.

Hypothesis/Purpose

The purposes of this study were to determine if there is a difference in the YBT-LQ performance between the dominant and non-dominant limbs in non-athlete adolescents, and to compare the reliability of the maximum reach scores to that of the mean reach scores in this population.

Study Design

Prospective cohort study

Methods

Twenty-six healthy non-athlete adolescents (13.6 ± 1.0 years, 22 girls, 4 boys) performed the YBT-LQ on two separate days while the same investigator scored their performance. Paired t-tests were used to compare reach distances on dominant and non-dominant stance limbs. Intraclass correlation coefficients (ICC$^{3,1}$) were calculated for the maximum and mean reach distances for three directions (anterior, posterolateral, posteromedial) and the composite scores on each limb.

Results

There was no significant difference in YBT-LQ performance between dominant and non-dominant stance limbs ($p > 0.05$). Overall, the between-day intra-rater reliability for maximum reach and mean reach scores was moderate-to-good for both limbs (ICC$^{3,1} = 0.59 - 0.83$), but was poor for the composite score on the dominant limb (ICC$^{3,1} = 0.42$) and maximum anterior reach on non-dominant limb (ICC$^{3,1} = 0.48$).

Conclusion

Limb dominance does not seem to be a factor for YBT-LQ performance in this population. The YBT-LQ appears to be a reliable tool for dynamic balance assessment in non-athlete adolescents using the individual score of each direction. The use of mean reach measures seems to slightly improve reliability, specifically the anterior reach direction, in this population.
population.

**Level of Evidence**

Level 2b

**INTRODUCTION**

Postural stability is considered to be an important indicator of neuromusculoskeletal health. Specifically, postural stability in children and adolescents is influenced by physiological functions such as muscular strength and neuromuscular development in childhood. Dynamic postural control is an important prerequisite to the development of fundamental movement skills and activities of daily living in children and is usually established in the first decade of life, whereas proficiency is acquired as children age, develop, and interact with their environment. Without mastery of balance abilities in the early years of childhood, children’s performance in more complex movements associated with development and sports may be diminished, and they may be at a higher risk for injury during activity participation as adolescents or adults. It is known that decreased balance and dynamic postural control are associated with lower extremity injuries among adolescent athletes and adult athletes, and that adolescents have a higher risk of sport-related injury than younger children. Therefore, assessment of dynamic postural stability and balance is important in identifying musculoskeletal impairments, risk for injury, and monitoring recovery from injury.

Tests such as the Lower Quarter Y-Balance Test (YBT-LQ) are often used to predict injuries in high school and college athletes. They are also used to assess dynamic balance and postural control in various populations, including healthy, recreationally active adults, college and professional athletes, and adolescents recovering from injury. The YBT-LQ is an instrumented tool that was developed using components of the Star Excursion Balance test to standardize performance of dynamic balance and postural stability. To perform the YBT-LQ, a participant must maintain single limb stance on a stationary platform while pushing a movable target with the opposite foot in the anterior (ANT), posterior-medial (PM) and posterior-lateral (PL) reach directions (Figure 1).

The reliability of the YBT-LQ has been extensively researched in populations of various ages. For adult populations, the YBT-LQ was found to have good-to-excellent inter-rater reliability (ICC2,1 = 0.80 - 1.00) and intra-rater reliability (ICC3,1 = 0.85-0.91). For adolescents, the within-day inter-rater reliability was reported to be excellent (ICC2,1 = 0.96 - 0.99), whereas the within-day and between-day intra-rater reliability was found only to be fair-to-good (ICC3,1 = 0.57-0.91). Lastly, for pre-adolescent children, both the within-day (ICC2,1 ≥ 0.995) and between-day (ICC2,1 = 0.91 - 0.97) inter-rater reliability were excellent. The between-day inter-rater reliability was less than excellent, but the ICC values (0.71 - 0.84) still showed moderate-to-good reliability. In addition, although many studies reported reliability outcomes using maximum reach distances for data analysis, other studies suggested using mean reach for YBT-LQ performance analysis. No consensus has been reached regarding which measure is superior, specifically among adolescent populations.

Leg dominance has been reported to be a risk factor associated with non-contact lower extremity injury among athletes. Clinicians often compare performance outcomes on functional balance tests between limbs to determine risk of injury, to evaluate presence of instabilities, to assess progress, or to consider readiness for return-to-sport activities. However, this assumes that both limbs are functionally equal and symmetrical prior to injury. Hoffman et al. measured center of pressure excursion (measure of dynamic balance) while a group of healthy adults were performing a static unipedal stance on a force platform. They found no significant differences between dominant and non-dominant limbs. Similarly, two other studies found symmetry between dominant and non-dominant limbs in healthy adults during a single limb stance on a movable platform. However, Promsri et al. reported significant differences in postural control when investigating single leg stance on a firm surface and on a multiaxial unstable board between preferred and non-preferred limbs of healthy adults.

Furthermore, literature suggests no effects of leg dominance on a single limb stance in adolescent and teen populations. Mala et al. and Bigoni et al. found that limb preference had no significant effect on postural stability during a static single leg stance on a pressure mat among elite teenage soccer players and in pre-pubescent male soccer players, respectively. To date, few studies have used the YBT-LQ to compare limb differences in young adolescent populations. Muehlbauer et al. assessed dynamic balance in young soccer players using the YBT-LQ. Similar to the results of the Mala et al. and Bigoni et al. studies, Muehlbauer et al. did not find differences between dominant and non-dominant limbs. In contrast, Breen et al. assessed performance of the YBT-LQ in children and adolescent athletes and found a significant asymmetry between limbs in the posterior-medial and posterior-lateral reach directions among children aged 10-12 years compared to teens aged 16-18 years, although limb dominance was not reported. The populations of the above-mentioned studies were sub-elite or elite athletes, thus limiting the generalizability of...
results to other populations. To date, no other studies have examined effects of leg dominance on postural stability in untrained or non-athletic adolescents. Specifically, it is not clear if leg dominance would affect YBT-LQ performance in this population.

Young adolescents are at higher risk for lower extremity injury compared to older teens and adults,\textsuperscript{4,27,39–41} in part due to the rapid rate of growth occurring during adolescence,\textsuperscript{2,40,42} which could affect dynamic balance significantly. As competitive athletes were the populations of interest in the previous studies that examined leg dominance effects on dynamic balance, the target participants in this study were adolescents with a variety of body types and those who did not participate in organized or elite sport training. In addition, as discussed earlier, it is difficult to compare the YBT-LQ study results because both maximum and mean reach distances were used interchangeably. Therefore, the primary purpose of this study was to determine whether or not the YBT-LQ scores would be different between the dominant and non-dominant limbs in non-athlete adolescents aged 12-16 years. The secondary purpose of this study was to compare the between-day intra-rater reliability of the maximum reach performance to that of mean reach performance on YBT-LQ in non-athlete adolescents. The reliability using these two outcome measures was anticipated to be in agreement with other studies performed on this age group.\textsuperscript{27–29}

METHODS

SUBJECTS

Using G*Power version 3.1,\textsuperscript{43} an \textit{a priori} power analysis was performed to calculate the sample size needed to detect a significant difference between dominant and non-dominant limbs. A total of 26 participants was required to achieve a power of 0.80 using an \textit{α} of 0.05 and a medium effect size of 0.50. The effect size of 0.50 was chosen based on the limb difference findings of a previous YBT-LQ study in healthy adults.\textsuperscript{30}

The study was approved by the Institutional Review Board at Texas Woman’s University. Healthy adolescents aged 12-16 years who did not actively participate in organized sports or in elite sport training were recruited for participation in the study from a local junior/senior high school. Eligible participants were excluded from the study if they reported: lower extremity injury or surgery within the prior six months, current or recent vestibular disorder within the prior three months, currently being treated for inner ear, sinus, upper respiratory infection or head cold, concussion within the prior three months, pregnancy, or musculoskeletal or neuromuscular pathology/diseases that could affect dynamic balance. Once the participant was determined to be eligible for the study, the participants and their parent or legal guardian read and signed the informed consent form.

INSTRUMENT

The Y-Balance Test Kit\textsuperscript{TM} was used to assess dynamic balance in this study. The kit consists of a stance platform to which three pieces of PVC pipe are attached in the ANT, PM, and PL directions.\textsuperscript{11} The posterior pipes are positioned 135 degrees from the anterior pipe, with 90 degrees between the posterior pipes. Each pipe is marked in 5-millimeter increments for measurement. A reach indicator slides on each pipe so that the participant pushes it with one limb while maintaining a single leg stance on the center stance platform (Figure 2). The distance that the indicator traveled was recorded as reach distance.

PROCEDURES

Prior to the YBT-LQ testing, participants completed an intake form and self-reported their height, weight, and dominant limb. Dominant limb was defined as the preferred leg used to kick a ball.\textsuperscript{32,54,44} Leg length was measured for each lower extremity on each participant while lying in the supine position with hips and knees extended. The investigator measured the distance from the most inferior aspect of the anterior superior iliac spine to the most distal portion of the medial malleolus with a tape measure. Leg length was used to normalize the reach distances collected during the YBT-LQ testing.

The YBT-LQ testing protocol was performed as described by Plisky and Gorman.\textsuperscript{11} All participants were instructed with the YBT-LQ test and given a demonstration of proper performance of the YBT-LQ by the by a single rater (i.e., principal investigator). Each participant stood on one leg in the center of the stance platform with the most distal aspect of their athletic shoe at the starting line. While maintaining a single-leg stance, the participant was asked to push the reach indicator along the pipe with the free limb in the ANT, PM, and PL directions in relation to the stance foot. Each participant was allowed up to six practice trials on each leg.
The maximum reach or mean reach for all three directions was calculated by averaging the reach distances of three trials: \[
(\text{R each } 1 + \text{R each } 2 + \text{R each } 3) / 3.
\]

The greatest successful reach distance from three trials in a single direction until a successful trial was completed. If a participant was unable to perform a successful trial in six attempts, the participant failed that direction.

Testing was administered and scored by the principal investigator, a licensed physical therapist with greater than two years’ experience in YBT-LQ, who repeated the YBT-LQ a second time the next day on the same participants in order to determine between-day intra-rater reliability. Although the same investigator scored the YBT-LQ the same day, each participant’s scores of the first YBT-LQ were not available to the testing investigator during the second testing. The greatest successful reach distance from three trials in a single direction was used as maximum reach. Mean reach was also calculated for each direction by averaging the reach distances of three trials: \[
(\text{Reach } 1 + \text{Reach } 2 + \text{Reach } 3) / 3.
\]

In each reach direction prior to formal testing,\textsuperscript{11,29} Testing occurred within 20 minutes after completion of practice trials.\textsuperscript{11} Each participant performed three reach trials\textsuperscript{29} in each direction for both limbs in the standardized testing order described by Plisky and Gorman.\textsuperscript{11} Each participant started in the ANT direction with the left foot while standing on the right leg, followed by standing on the left leg and reaching in the ANT direction with the right foot. This procedure was repeated for the PM reach direction followed by the PL reach directions.\textsuperscript{11} Additional testing trials were added if the first three trials were deemed unsuccessful. Unsuccessful trials were discarded and repeated if the participant 1) failed to maintain unilateral stance on the platform, 2) failed to maintain the reach foot contact with the reach indicator in the target direction while in motion, 3) used the reach indicator for stance support, or 4) failed to return the reach foot to the starting position under control. The starting position for the reach foot is defined by the area immediately between the standing platform and the pipe opposite the stance foot.\textsuperscript{11} If a successful testing trial was not completed within three reaches, additional trials were performed up to six reaches in a single direction until a successful trial was completed. If a participant was unable to perform a successful trial in six attempts, the participant failed that direction.

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(\text{Reach } 1 + \text{Reach } 2 + \text{Reach } 3) / 3.
\]

Maximum reach and mean reach distance in each direction were normalized as a percentage of leg length to allow for comparison across participants in this and other studies. The following formula was used to calculate normalized reach score: \[
[\text{maximum or mean reach/limb length)} \times 100.
\]

In each reach direction prior to formal testing,\textsuperscript{11,29} Testing occurred within 20 minutes after completion of practice trials.\textsuperscript{11} Each participant performed three reach trials\textsuperscript{29} in each direction for both limbs in the standardized testing order described by Plisky and Gorman.\textsuperscript{11} Each participant started in the ANT direction with the left foot while standing on the right leg, followed by standing on the left leg and reaching in the ANT direction with the right foot. This procedure was repeated for the PM reach direction followed by the PL reach directions.\textsuperscript{11} Additional testing trials were added if the first three trials were deemed unsuccessful. Unsuccessful trials were discarded and repeated if the participant 1) failed to maintain unilateral stance on the platform, 2) failed to maintain the reach foot contact with the reach indicator in the target direction while in motion, 3) used the reach indicator for stance support, or 4) failed to return the reach foot to the starting position under control. The starting position for the reach foot is defined by the area immediately between the standing platform and the pipe opposite the stance foot.\textsuperscript{11} If a successful testing trial was not completed within three reaches, additional trials were performed up to six reaches in a single direction until a successful trial was completed. If a participant was unable to perform a successful trial in six attempts, the participant failed that direction.

Testing was administered and scored by the principal investigator, a licensed physical therapist with greater than two years’ experience in YBT-LQ, who repeated the YBT-LQ a second time the next day on the same participants in order to determine between-day intra-rater reliability. Although the same investigator scored the YBT-LQ both times, each participant’s scores of the first YBT-LQ were not available to the testing investigator during the second testing. The greatest successful reach distance from three trials in a single direction was used as maximum reach. Mean reach was also calculated for each direction by averaging the reach distances of three trials: \[
(\text{Reach } 1 + \text{Reach } 2 + \text{Reach } 3) / 3.
\]

Maximum reach and mean reach distance in each direction were normalized as a percentage of leg length to allow for comparison across participants in this and other studies. The following formula was used to calculate normalized reach score: \[
[\text{maximum or mean reach/limb length)} \times 100.
\]

The maximum reach or mean reach for all three directions was calculated by averaging the reach distances of three trials: \[
(\text{R each } 1 + \text{R each } 2 + \text{R each } 3) / 3.
\]

The greatest successful reach distance from three trials in a single direction until a successful trial was completed. If a participant was unable to perform a successful trial in six attempts, the participant failed that direction.

Means and standard deviations were calculated for participants’ demographics, as well as the reach distances of all three directions and composite score for each limb. Paired t-tests were used to compare the reach distances in all three directions and the composite scores between the dominant and non-dominant limbs. Intraclass correlation coefficients (ICC\textsubscript{3,1}) were calculated to determine the between-day intra-rater reliability with a 95% confidence interval (CI). Interpretation of ICC values were as follows: ICC < 0.50: poor reliability, ICC = 0.50-0.74: moderate or fair reliability, ICC = 0.75-0.89: good reliability, and ICC > 0.90: excellent reliability.\textsuperscript{45} Standard error of measurements (SEMs) were calculated to estimate the amount of error using the formula: \[
\text{SEM} = \text{SD} \times \sqrt{1 - \text{ICC}^2}.
\]

Minimal detectable changes (MDCs) also were computed for clinical interpretation using the equation: \[
\text{MDC}_{95\%} = \text{SEM} \times 1.96 \times \sqrt{2}.
\]

All statistical analyses were completed using IBM SPSS statistics for Macintosh, version 25 (IBM Corp., Armonk, NY), and the α level was set at 0.05 for all statistical analyses.

RESULTS

Twenty-six healthy adolescents (22 girls, 4 boys) with an average age of 13.6 ± 1.0 years were enrolled in the study. Two participants (girls) did not return for the second day testing, resulting in data analysis of 26 subjects for comparisons between dominant and non-dominant stance limbs and 24 subjects for the between-day intra-rater reliability. Demographic data of all participants is presented in Table 1.

Table 2 presents the maximum and mean reach distances from the data collected from 26 participants during Session 1, corresponding normalized values in all three directions, and the composite scores for the dominant and non-dominant limb. Two participants (girls) were not able to complete any ANT reach for both limbs, two additional participants (girls) only completed the ANT reach on the dominant limb, two different participants (a girl and a boy) only completed the ANT reach on the non-dominant limb, and one participant (girl) only completed a single trial on the dominant limb. These participants were unsuccessful at completing the ANT reach because they failed to main-
Table 2. The Maximum and Mean Reach Distances of the Y-Balance Test-Lower Quarter (YBT-LQ) presented as mean (SD) (n=26)

<table>
<thead>
<tr>
<th>Dominant Limb</th>
<th>Maximum Reach Distance (cm)</th>
<th>Normalized Maximum Reach Distance (%)</th>
<th>Mean Reach Distance (cm)</th>
<th>Normalized Mean Reach Distance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANT*</td>
<td>45.35 (20.53)</td>
<td>53.27 (24.24)</td>
<td>43.88 (19.92)</td>
<td>51.56 (23.53)</td>
</tr>
<tr>
<td>PM</td>
<td>85.08 (11.89)</td>
<td>99.44 (13.26)</td>
<td>82.79 (11.27)</td>
<td>96.77 (12.58)</td>
</tr>
<tr>
<td>PL</td>
<td>79.81 (20.68)</td>
<td>93.34 (24.28)</td>
<td>76.09 (20.50)</td>
<td>88.99 (24.21)</td>
</tr>
<tr>
<td>COMP</td>
<td>82.01 (15.08)</td>
<td>94.16 (15.97)</td>
<td>79.11 (14.70)</td>
<td>79.11 (14.70)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Non-Dominant Limb</th>
<th>Maximum Reach Distance (cm)</th>
<th>Normalized Maximum Reach Distance (%)</th>
<th>Mean Reach Distance (cm)</th>
<th>Normalized Mean Reach Distance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANT†</td>
<td>44.54 (20.82)</td>
<td>51.95 (24.30)</td>
<td>42.59 (19.7)</td>
<td>49.68 (23.0)</td>
</tr>
<tr>
<td>PM</td>
<td>85.96 (12.21)</td>
<td>100.58 (14.40)</td>
<td>84.15 (12.63)</td>
<td>98.48 (14.97)</td>
</tr>
<tr>
<td>PL</td>
<td>79.08 (20.34)</td>
<td>92.50 (23.99)</td>
<td>76.76 (19.83)</td>
<td>89.79 (23.35)</td>
</tr>
<tr>
<td>COMP</td>
<td>81.68 (13.00)</td>
<td>92.54 (16.51)</td>
<td>79.32 (12.81)</td>
<td>79.32 (12.81)</td>
</tr>
</tbody>
</table>

ANT = anterior; PM = posteromedial; PL = posterolateral; COMP = composite score.
*n = 21; †n = 22

Table 3. Intraclass Correlation Coefficients (ICCs), Standard Error of Measurement (SEM), Minimal Detectable Change (MDC) of the YBT-LQ in Non-athlete Adolescents (n=24)

<table>
<thead>
<tr>
<th></th>
<th>Using Maximum Reach Distance</th>
<th>Using Mean Reach Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC 3,1 (95% CI)</td>
<td>SEM (cm)</td>
</tr>
<tr>
<td>Dominant Limb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANT*</td>
<td>0.73 (0.44-0.88)</td>
<td>3.87</td>
</tr>
<tr>
<td>PM</td>
<td>0.81 (0.60-0.91)</td>
<td>5.58</td>
</tr>
<tr>
<td>PL</td>
<td>0.74 (0.47-0.86)</td>
<td>6.82</td>
</tr>
<tr>
<td>COMP</td>
<td>0.42 (0.03-0.70)</td>
<td>9.13</td>
</tr>
<tr>
<td>Non-Dominant Limb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANT†</td>
<td>0.48 (0.06-0.75)</td>
<td>6.22</td>
</tr>
<tr>
<td>PM</td>
<td>0.70 (0.42-0.86)</td>
<td>7.73</td>
</tr>
<tr>
<td>PL</td>
<td>0.80 (0.58-0.91)</td>
<td>6.31</td>
</tr>
<tr>
<td>COMP</td>
<td>0.75 (0.51-0.88)</td>
<td>5.93</td>
</tr>
</tbody>
</table>

CI=confidence interval; ANT = anterior; PM = posteromedial; PL = posterolateral; COMP = composite score.
*n = 19; †n = 20

DISCUSSION

The results of this study indicate that healthy, non-athlete adolescents had similar performance in the YBT-LQ either...
performing on the dominant limb or on the non-dominant limb. These results are in agreement with the previous studies regarding effects of limb dominance during balance and postural stability tasks among adult and athletic populations. It has been hypothesized that the use of modern training regimens focusing on bilateral exercises during sport is a possible reason for no significant differences being found between limbs during YBT-LQ performance among athletes.38 Subjects in the present study were identified to be recreationally active, so they may also participate in bilateral physical activities, although specifics were not tracked and these were not controlled for during analysis. There have also been reports that the YBT-LQ may not be sensitive enough to detect reach distance differences between limbs in young athletes.38,39

Further comparison of mean reach distances among adolescent participants in the present study showed normalized mean reach performance to be similar to that reported by Bulow et al.41 who demonstrated that physically active healthy adolescent females had mean reach distances from 57.0 (4.5) cm to 103.6 (8.8) cm. However, Linek et al.29 reported higher normalized mean reach distances for a cohort of male adolescent football players from 67.7 (8.6) cm to 112.1 (10.4) cm. Similarly, the normalized maximum reach distances reported by Muehlbauer et al.38 were higher for a cohort of young male adolescent soccer players, reporting 72.8 (7.4) cm to 121.8 (12.1) cm, compared to the maximum reach distances of participants in the study. The differences among the studies may be due to different levels of training and physical activity between the study populations. Participants in this study were of similar adolescent age but were untrained and only recreationally active compared to sub-elite or elite athletes described by Linek at al.29 and Muehlbauer et al.38 Higher maximum reach distances reported among adult studies32–34 compared to those of the adolescents in this present study could be attributed to differences in age of subjects as this has been reported to have a significant effect on performance with older, more experienced individuals having a greater reach distance on the YBT-LQ.38

The results of this present study demonstrated moderate or good between-day reliability (ICC3,1 = 0.70-0.81) for maximum reach in all three directions except the ANT reach on the non-dominant limb and the composite score on the dominant limb, which resulted in lower reliability values (ICC3,1 = 0.42-0.48). These results are similar to other studies that investigated the between-day reliability of YBT-LQ in adolescent populations.27–29 Schwiertz et al.28 reported moderate-to-excellent reliability (ICC3,1 = 0.69-0.96) for the PL and PM reach directions among healthy adolescents in sixth to tenth grade (equivalent to 11-16 years of age), and poor-to-fair reliability (ICC3,1 = 0.40-0.69) for the ANT reach on the right leg among the seventh and ninth graders. However, Schwiertz et al.28 reported overall good reliability (ICC3,1 = 0.83-0.96) for the composite score. Similarly, Greenberg et al.27 reported moderate-to-excellent reliability (ICC3,1 = 0.68-0.91) for YBT-LQ in adolescent female athletes, whereas Linek et al.29 reported fair-to-excellent reliability (ICC3,1 = 0.57-0.82) among male adolescent and teenage semi-professional athletes. ICC values of the current study were observed to be within the range of ICCs reported by Schwietz et al. in the three individual directions,28 however, the reliability was slightly lower than that reported by Greenberg et al.27 and Linek et al.29 This could be in part due to the participants in the present study wearing shoes to perform the YBT-LQ, rather than barefoot testing, thus contributing to the slightly lower reliability values.

It is well documented in the literature that ANT reach distance is generally lower than reach distance in other directions and an ANT reach direction asymmetry between limbs on the YBT-LQ is associated with non-contact lower extremity injury prediction among adult athletes.7–10 It was observed that 25% (n=6) of the participants were unable to successfully complete the ANT reach trial on either their dominant or non-dominant limb, or both, and one additional participant completed only one successful trial on their non-dominant limb. The unsuccessful trials were primarily due to the participants failure to maintain unilateral stance on the platform or failure to return the reach foot to the starting position under control. In addition, 27% (n=7) of the participants had a between-limb ANT reach differences greater than the recommended cut-off (> 4 cm) used to predict risk of non-contact lower extremity injury.7 Muehlbauer et al.38 also reported a significant ANT reach asymmetry between limbs in the elite male athletes of adolescent age. These findings suggest there may be significant variability of ANT reach performance among young adolescents, including ability to achieve a successful reach trial, irrespective of activity level or sport training. Further research is needed to identify contributing factors to ANT reach asymmetry in this age group. Therefore, caution should be taken when interpreting ANT reach results for the purposes of lower extremity injury prediction in adolescents.

Previous studies on reliability of YBT-LQ predominantly have used maximum reach distance to evaluate YBT-LQ performance,3,11,27,28 but two studies26,29 reported both maximum reach and the mean reach of the YBT-LQ performance. Schaffer et al.26 reported superior ICC, SEM, and MDC values with the mean reach. The present study also showed that the use of mean reach had improved reliability for the ANT and PL directions on the non-dominant limb and composite scores for both limbs. Although the ICC value of the ANT reach on the non-dominant limb was not high (ICC3,1 = 0.59) when using mean reach distances, the reliability improved compared to the lower reliability (ICC3,1 = 0.48) when maximum reach was used. Consequently, lower SEMs and smaller MDCs were found when mean reach was used for scoring. These findings reflect reports in previous literature26 with noted variability likely due to the effects of puberty and growth on adolescent performance compared to skeletally mature adults. Linek et al.29 reasoned that fluctuating postures among adolescents resulted in less uniformity of results during individual attempts and reported this as a possible reason for larger deviations found in reliability of young male athletes compared to adult studies. Therefore, Linek et al. suggested that the average of three measurements be used for reliability in the adolescent population.29 Likewise, authors of the current study recommend future studies and clinicians consider use of mean reach (of the three trials) during perfor-
Conduct a performance analysis of YBT-LQ in this population, as this could reduce variation resulting in improved reliability.

Limitations of this study included variability of baseline activity levels among participants and allowing participants to wear preferred athletic shoes during the YBT-LQ. Both may limit direct comparison of the results of this present study to those of other YBT-LQ studies performed in adolescent populations. However, this study was intended for the outcomes to be more generalizable to the typical adolescent population, and did not control for any activities the subjects may have engaged in prior to testing sessions which may have affected a subject’s performance during testing. It is also unknown how motivation could have an impact on subject performance, as this study was done on healthy adolescents who were not training for sport participation or recovering from injury. Attempts to reduce the effects of these limitations were made by testing subjects only one day apart at approximately the same time and by providing all subjects with consistent directions on both days of testing. Caution should be used when generalizing the results of this study to other populations or conditions. In addition, although the results of this study indicated mean reach to be a better measure of performance than maximum reach on the YBT-LQ in this population, the ANT reliability data was based on a smaller sample size due to participants being unable to complete this part of the test. Future studies are recommended on larger sample sizes, specifically to examine whether mean or maximum value of the ANT reach is optimal for this young adolescent population. Lastly, there was a significant difference between the number of boys and girls in this study. This discrepancy may limit the generalization of the results of the study, as the literature suggests differences in YBT-LQ performance between boys and girls. However, the gender factor was not the intended study variable of the study.

CONCLUSION

The results of this study suggest that leg dominance does not affect YBT-LQ performance in young non-athlete adolescents. In addition, the YBT-LQ, specifically the two posterior reaches, appears to be reliable for dynamic balance assessment in this population, whereas the composite score demonstrated poor reliability. Therefore, clinicians are advised to report the three reach scores separately. Use of the mean reach rather than maximum reach in each direction appears to have a better reliability for this population.

CONFLICTS OF INTEREST

The authors have nothing to disclose nor any conflicts of interest.

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REFERENCES


Original Research

Patellofemoral Joint Loading During the Performance of the Forward and Side Lunge with Step Height Variations

Rafael Escamilla, Naiquan Zheng, Toran D MacLeod, Rodney Imamura, Kevin E. Wilk, Shangcheng Wang, Irv Rubenstein, Kyle Yamashiro, Glenn S. Fleisig

1 Department of Physical Therapy, California State University, Sacramento, USA; Results Physical Therapy and Training Center, Sacramento, CA USA, 2 The Center for Biomedical Engineering and Science, Department of Mechanical Engineering and Engineering Science, University of North Carolina, Charlotte, NC, 3 Department of Physical Therapy, California State University, Sacramento, USA, 4 Kinesiology and Health Science Department, California State University, Sacramento, USA, 5 Champion Sports Medicine, Birmingham, AL, USA, 6 STEPS, Inc., USA, 7 Results Physical Therapy and Training Center, Sacramento, CA USA, 8 American Sports Medicine Institute, Birmingham, AL, USA

Keywords: Anterior knee pain, knee kinetics, lunge, movement system, patella, rehabilitation

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Background
Forward and side lunge exercises strengthen hip and thigh musculature, enhance patellofemoral joint stability, and are commonly used during patellofemoral rehabilitation and training for sport.

Hypothesis/Purpose
The purpose was to quantify, via calculated estimates, patellofemoral force and stress between two lunge type variations (forward lunge versus side lunge) and between two step height variations (ground level versus 10 cm platform). The hypotheses were that patellofemoral force and stress would be greater at all knee angles performing the bodyweight side lunge compared to the bodyweight forward lunge, and greater when performing the forward and side lunge at ground level compared to up a 10cm platform.

Study Design
Controlled laboratory biomechanics repeated measures, counterbalanced design.

Methods
Sixteen participants performed a forward and side lunge at ground level and up a 10cm platform. Electromyographic, ground reaction force, and kinematic variables were collected and input into a biomechanical optimization model, and patellofemoral joint force and stress were calculated as a function of knee angle during the lunge descent and ascent and assessed with a repeated measures 2-way ANOVA (p<0.05).

Results
At 10° (p=0.003) knee angle (0° = full knee extension) during lunge descent and 10° and 30° (p<0.001) knee angles during lunge ascent patellofemoral joint force and stress were greater in forward lunge than side lunge. At 40°(p=0.005), 50°(p=0.002), 60°(p<0.001), 70°(p=0.006), 80°(p=0.005), 90°(p=0.002), and 100°(p<0.001) knee angles during lunge descent and 50°(p=0.002), 60°(p<0.001), 70°(p<0.001), 80°(p<0.001), and 90°(p<0.001) knee angles during lunge ascent patellofemoral joint force and stress were greater in side lunge than forward lunge. At 60°(p=0.009) knee angle during lunge descent and 40°(p=0.008), 50°(p=0.009), and 60°(p=0.007) knee angles during lunge ascent.

Corresponding author:
Rafael Escamilla, PhD, PT, CSCS, FACSM
California State University, Sacramento
Department of Physical Therapy
6000 J Street; Sacramento, CA 95819-6020
916-278-6930 (office); 916-278-5053 (fax)
rescamil@csus.edu (e-mail)
Patellofemoral joint force and stress were greater lunging at ground level than up a 10cm platform.

**Conclusions**

Patellofemoral joint loading changed according to lunge type, step height, and knee angle. Patellofemoral compressive force and stress were greater while lunging at ground level compared to lunging up to a 10 cm platform between 40° - 60° knee angles, and greater while performing the side lunge compared to the forward lunge between 40° - 100° knee angles.

**Level of Evidence**

**INTRODUCTION**

The high and repetitive patellofemoral forces that occur during sport often results in high patellofemoral joint stress (patellofemoral force/patella contact area), which over time can lead to patellofemoral pain syndrome (PFPS). Lunging exercises, such as the side lunge and forward lunge, strengthen both hip and thigh musculature and are important rehabilitation and training exercises to enhance patellofemoral joint stability and improve optimal interaction between the femur and patella during activity and sport.1,2 Understanding what patellofemoral force and stress magnitudes are generated and how they vary while employing the forward and side lunge with step height variations may help clinicians better prescribe and progress lunging exercises to individuals with PFPS.

Although a few studies have examined patellofemoral biomechanics during the lunge exercise,3-5 patellofemoral force and stress has been examined only once in the literature during the side lunge exercise6 and only twice in the literature during the forward lunge exercise.7,8 Escamilla and colleagues7 employed a 12 repetition maximum (12 RM) weight to assess patellofemoral force and stress while performing the forward lunge using a long step and short step. In addition, Escamilla and colleagues8 employed a 12 repetition maximum (12 RM) weight to assess patellofemoral force and stress between the forward lunge and the side lunge, and both patellofemoral force and stress were greater in the side lunge compared to the forward lunge. Hofmann and colleagues8 examined patellofemoral force and stress for both the lead and trail limb while performing the forward lunge with no external resistance between forward and vertical trunk and shank positions.

In patellofemoral rehabilitation progression, lunging exercises are initially performed with no external resistance (bodyweight only) and progressed to using weights (dumbbells or barbells) or other external resistance, such as resistance bands, and this progression increases both hip and thigh muscle recruitment and patellofemoral force and stress.2,6,7 Moreover, both forward and side lunge exercises are commonly performed and progressed in knee rehabilitation settings using different step heights (ground level versus elevated platform). However, there are currently no studies in the literature that have examined patellofemoral force and stress during the bodyweight forward lunge and the bodyweight side lunge, or while lunging with step height variations. Therefore, the purpose of this study was to quantify, via calculated estimates, patellofemoral force and stress between two lunge type variations (forward lunge versus side lunge) and between two step height variations (ground level versus 10 cm platform). The hypotheses were that patellofemoral force and stress would be significantly greater throughout the knee range of motion when performing the bodyweight side lunge compared to the bodyweight forward lunge, and significantly greater when performing the forward and side lunge at ground level compared to up to a 10 cm platform.

**METHODS**

**SUBJECTS**

Sixteen healthy participants (eight males and eight females) without a history of patellofemoral pathology participated with a mean (±SD) age, mass, and height of 28.9±7.9 y, 77.5±6.6 kg, and 175.9±2.3 cm, respectively, for males, and 30.6±9.8 y, 61.2±6.8 kg, and 166.4±8.5 cm, respectively, for females. Inclusion criteria included all participants being able to perform forward and side lunge pain-free with proper technique for 12 repetitions using bodyweight and having at least five years’ experience in performing the forward and side lunge, and exclusion criteria included not achieving a 0°-20° forward trunk tilt or 0°-20° forward tilt of the tibia (which keeps the knee over the foot) at the lowest position of the forward and side lunge. All participants provided written informed consent in accordance with the Institutional Review Board at California State University, Sacramento.

**EXERCISE DESCRIPTION**

Each participant attended a pre-test session one week prior to testing and practiced performing the forward and side lunges at ground level (Figures 1A, B) and up a 10cm platform (Figures 1C, D). The starting position all four forward and side lunge variations were standing upright with both feet together. From the starting position, the participant lunged forward (forward lunge) or to the side (side lunge) with the right lower extremity towards a securely mounted force platform at ground level (Figures 1A, B) and to a securely mounted force platform 10 cm above ground level (Figures 1C,D), and then pushed back to the starting position. A metronome was used to help ensure the right knee flexed and extended at approximately 45°/s. The mean (±SD) step length (measured from left toe to right heel and
based on participant preference) was 91.7±5.2 cm for males and 89.3±7.1 cm for females for the forward lunge and 99.5±4.9 cm for males and 98.4±5.8 cm for females for the side lunge. Each participant's preferred step length measurement was used during data collection.

DATA COLLECTION

Blue Sensor (Ambu Inc., Linthicum, MD) disposable surface electrodes (type M-00-S; 22 mm wide and 30 mm long) were used to collect EMG data and were placed in a bipolar configuration along the longitudinal axis of each muscle, with a center-to-center distance of approximately 3 cm between electrodes.

Prior to applying the electrodes, the skin was prepared by shaving, abrading, and cleaning with isopropyl alcohol wipes to reduce skin impedance. Electrode pairs were then placed on the participant's right side using previously described locations,6,7 for the following muscles: a) rectus femoris; b) vastus lateralis; c) vastus medialis; d) medial hamstrings (semimembranosus and semitendinosus); e) lateral hamstrings (biceps femoris); and f) gastrocnemius (middle portion between medial and lateral bellies).

For three-dimensional (3D) motion capture, spheres (3.8 cm in diameter) covered with reflective tape were attached to the following bony landmarks as previously described:6,7 a) third metatarsal head of the right foot; b) medial and lateral malleoli of the right leg; c) upper edges of the medial and lateral tibial plateaus of the right knee; d) posterosuperior greater trochanters of the left and right femurs; and e) lateral acromion of the right shoulder.

Once the electrodes and spheres were positioned, the participant warmed up and practiced the exercises as needed, and data collection commenced. An eight camera Vicon-Peak Performance motion analysis system (Vicon-Peak Performance Technologies, Inc., Englewood, CO) was used to collect 60 Hz video data. Force data were collected at 960 Hz using an AMTI force platform (Model OR6-6-2000, Advanced Mechanical Technologies, Inc.). EMG data were collected at 960 Hz using a Noraxon Myosystem unit (Noraxon USA, Inc., Scottsdale, AZ). The EMG amplifier bandwidth frequency was 10-500 Hz with an input impedance of 20,000 kΩ, and the common-mode rejection ratio was 130 dB. Video, EMG, and force data were electronically synchronized and simultaneously collected as each participant performed one set of three repetitions of the forward and side lunge at ground level and up a 10 cm platform, assigned in a random order.

Subsequent to completing all four lunge type and step height variations, EMG data were collected during maximum voluntary isometric contractions (MVIC) to normalize the EMG data collected during each lunge type and step height variation, as previously described.6,7 The MVIC for the rectus femoris, vastus lateralis, and vastus medialis were collected in a seated position at 90° knee and hip flexion during a maximum effort knee extension. The MVIC for the lateral and medial hamstrings were collected in the same seated position during a maximum effort knee flexion. MVIC for the gastrocnemius was collected during a maximum effort standing unilateral stance toe raise with the ankle positioned approximately halfway between neutral and full plantar flexion. Two trials (five second each) were collected for each MVIC of each muscle in a randomized order for the three muscle groups.

DATA REDUCTION

Video images for each reflective marker were tracked and digitized in 3D space with Vicon-Peak Performance software, utilizing the direct linear transformation method. Testing of the accuracy of the calibration system resulted in reflective markers that could be located in 3D space with an error less than 0.3 cm. The raw position data were smoothed using a double-pass fourth order Butterworth low-pass filter with a cut-off frequency of 6 Hz.6,7,9 Joint angles, linear and angular velocities, and linear and angular accelerations were calculated in a 2D sagittal plane of the knee utilizing appropriate kinematic equations, as previously described.6,7,9

Raw EMG signals were full-wave rectified, smoothed using a 10 ms moving average window, and linear enveloped throughout the knee range of motion for each repetition.6,7,9 EMG data were then normalized for each muscle and expressed as a percentage of each participant's highest corresponding MVIC trial. The MVIC was calculated using the highest EMG signal over a one second time interval throughout the five second MVIC trials, as previously described.6,7,9 Normalized EMG data for the three repetitions (trials) were then averaged at corresponding knee angles between 0-100° with 0° defining full knee extension, 0-100° defining the lunge descent, and 100-0° defining the lunge ascent. The EMG data were used only to calculate patellofemoral force and stress in a biomechanical knee model (see Appendix) and were not analyzed separately.
Table 1. Mean (± SD) patellofemoral joint force (N) values while performing the forward lunge and side lunge with step height variations.

<table>
<thead>
<tr>
<th>Knee Angles for Descent Phase</th>
<th>Lunge Type Variations</th>
<th>Step Height Variations</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Forward Lunge</td>
<td>Side Lunge</td>
<td></td>
</tr>
<tr>
<td>10°</td>
<td>64±38</td>
<td>37±21</td>
<td>0.003*</td>
</tr>
<tr>
<td>20°</td>
<td>113±62</td>
<td>104±62</td>
<td>0.357</td>
</tr>
<tr>
<td>30°</td>
<td>148±74</td>
<td>156±94</td>
<td>0.761</td>
</tr>
<tr>
<td>40°</td>
<td>167±87</td>
<td>252±115</td>
<td>0.005*</td>
</tr>
<tr>
<td>50°</td>
<td>201±115</td>
<td>374±176</td>
<td>0.002*</td>
</tr>
<tr>
<td>60°</td>
<td>297±170</td>
<td>581±323</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>70°</td>
<td>393±230</td>
<td>728±417</td>
<td>0.006*</td>
</tr>
<tr>
<td>80°</td>
<td>521±301</td>
<td>958±489</td>
<td>0.005*</td>
</tr>
<tr>
<td>90°</td>
<td>619±319</td>
<td>1054±523</td>
<td>0.002*</td>
</tr>
<tr>
<td>100°</td>
<td>615±305</td>
<td>973±434</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Knee Angles for Ascent Phase</th>
<th>Lunge Type Variations</th>
<th>Step Height Variations</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>10°</td>
<td>104±469</td>
<td>943±507</td>
<td>0.979</td>
</tr>
<tr>
<td>90°</td>
<td>1218±464</td>
<td>1011±550</td>
<td>0.909</td>
</tr>
<tr>
<td>80°</td>
<td>1302±499</td>
<td>1021±576</td>
<td>0.792</td>
</tr>
<tr>
<td>70°</td>
<td>1204±472</td>
<td>858±506</td>
<td>0.188</td>
</tr>
<tr>
<td>60°</td>
<td>881±417</td>
<td>603±368</td>
<td>0.007**</td>
</tr>
<tr>
<td>50°</td>
<td>573±338</td>
<td>404±237</td>
<td>0.009**</td>
</tr>
<tr>
<td>40°</td>
<td>230±112</td>
<td>226±109</td>
<td>0.008**</td>
</tr>
<tr>
<td>30°</td>
<td>124±73</td>
<td>154±92</td>
<td>0.244</td>
</tr>
<tr>
<td>20°</td>
<td>92±55</td>
<td>100±60</td>
<td>0.978</td>
</tr>
<tr>
<td>10°</td>
<td>29±17</td>
<td>44±27</td>
<td>0.622</td>
</tr>
</tbody>
</table>

Note: The mean values given for the two lunge type conditions (forward lunge and side lunge) were collapsed across the two step height conditions (lunging at ground level and lunging up to 10 cm platform), while the mean values given for the 2 step height conditions were collapsed across the two lunge type conditions. The p-values shown for lunge type conditions and step height conditions represent the main effects of the ANOVA.

DATA ANALYSIS

A repeated measures 2-way analysis of variance (ANOVA) was initially employed (p < 0.05) for each 10° knee angle (from 10° to 100°) during the lunge descent and each 10° knee angle (from 100° to 10°) during the lunge ascent to assess the effects of lunge type (forward versus side lunge) and step height (ground level versus 10 cm platform) on patellofemoral compressive force and stress. Subsequently, the Holm-Bonferroni sequential correction was employed to adjust the significance level secondary to multiple ANOVA’s being tested. Bonferroni t-tests were used to assess pairwise comparisons among the lunging conditions.

RESULTS

Descriptive data for calculated patellofemoral joint force and stress for each lunge type and step height condition are provided in Figures 2A-2B. Visual observation of the data suggest that patellofemoral joint force and stress generally increased progressively as knee flexion increased during the descent phase and decreased progressively as knee flexion decreased during the ascent phase. Moreover, for a given knee angle, patellofemoral joint force and stress were generally slightly greater during the ascent phases compared to the descent phases.

Tables 1 and 2 and Figures 2A and 2B provide patellofemoral joint force and stress values between the two lunge type conditions (forward versus side lunge) collapsed across the two step height conditions. The p-values shown for the lunge type conditions represent the main effects of the ANOVA, with the results of the Holm-Bonferroni sequential correction showing significant differences for p-values less than or equal to 0.006.

At 10° knee angle during the lunge descent and at 10° and 30° knee angles during the lunge ascent patellofemoral force and stress were significantly greater in the forward lunge compared to the side lunge. In contrast, at 40°, 50°, 60°, 70°, 80°, 90°, and 100° knee angles during the lunge descent and at 50°, 60°, 70°, 80°, and 90° knee angles during the lunge ascent patellofemoral joint force and stress were significantly greater in the side lunge compared to the forward lunge.
Table 2. Mean (± SD) patellofemoral joint stress (MPa) values while performing the forward lunge and side lunge with step height variations.

<table>
<thead>
<tr>
<th>Knee Angles for Descent Phase</th>
<th>Lunge Type Variations</th>
<th>Step Height Variations</th>
<th>p-value</th>
<th>Lunge at Ground Level</th>
<th>Lunge up to 10 cm Platform</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Forward Lunge</td>
<td>Side Lunge</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10°</td>
<td>0.37±0.22</td>
<td>0.22±0.12</td>
<td>0.003*</td>
<td>0.32±0.19</td>
<td>0.27±0.16</td>
<td>0.102</td>
</tr>
<tr>
<td>20°</td>
<td>0.61±0.34</td>
<td>0.56±0.34</td>
<td>0.357</td>
<td>0.60±0.37</td>
<td>0.57±0.32</td>
<td>0.511</td>
</tr>
<tr>
<td>30°</td>
<td>0.61±0.31</td>
<td>0.65±0.39</td>
<td>0.761</td>
<td>0.63±0.37</td>
<td>0.63±0.33</td>
<td>0.805</td>
</tr>
<tr>
<td>40°</td>
<td>0.58±0.30</td>
<td>0.87±0.40</td>
<td>0.005*</td>
<td>0.76±0.40</td>
<td>0.67±0.35</td>
<td>0.210</td>
</tr>
<tr>
<td>50°</td>
<td>0.64±0.37</td>
<td>1.20±0.56</td>
<td>0.002*</td>
<td>0.99±0.58</td>
<td>0.85±0.52</td>
<td>0.174</td>
</tr>
</tbody>
</table>

*Significant difference (p < 0.006) between lunge type conditions
**Significant difference (p < 0.009) between step height conditions

Note: The mean values given for the two lunge type conditions (forward lunge and side lunge) were collapsed across the two step height conditions (lunging at ground level and lunging up to 10 cm platform), while the mean values given for the 2 step height conditions were collapsed across the two lunge type conditions. The p-values shown for lunge type conditions and step height conditions represent the main effects of the ANOVA.

Tables 1 and 2 and Figures 3A and 3B show patellofemoral joint force and stress values between the two step height conditions (ground level versus 10 cm platform) collapsed across the two lunge type conditions. The p-values shown for the step height conditions represent the main effects of the ANOVA, with the results of the Holm-Bonferroni sequential correction showing significant differences for p-values less than or equal to 0.009. At 60° knee angle during the lunge descent and at 40°, 50°, and 60° knee angles during the lunge ascent patellofemoral joint force and stress were significantly greater lunging at ground level compared to lunging up to 10 cm platform. There were no significant interactions between lunge type and step height.

**DISCUSSION**

This is the only known study that has examined the effects of lunging with various step heights on patellofemoral joint loading (compressive force and stress). Key findings include that there were greater patellofemoral force and stress at 1) lower knee angles (0° - 30°) for the forward lunge; 2) higher knee angles (40° - 100°) for the side lunge; and 3)
middle knee angles (40° - 60°) lunging at ground level com-
pared to lunging up a 10 cm platform. These findings pro-
vide insights to how the patellofemoral joint can be loaded
and progressed in PFPS rehabilitation as a function of knee
angle and step height. Early in PFPS rehabilitation where
the initial goal is to minimize patellofemoral joint loading
in order to minimize patellofemoral pain, performing
“mini” lunges with lower knee angles between 0° - 40° may
be appropriate given patellofemoral joint loading is rela-
tively low (Figures 3A and 3B). Lunging within this lower knee
angle range either at ground level or up to a 10 cm
platform may both be appropriate given during this knee
range patellofemoral joint loading was similar between step
heights. As lunging progression moves beyond 40° knee an-
gle towards higher knee angles, patellofemoral joint force
and stress progressively increases exponentially (Figures
3A and 3B), and is greater lunging at ground level compared to
up to a 10 cm platform, and is greater during the side lunge
than the forward lunge. The lack of significant interactions
implies the effects of step height variations were not af-
fected by lunge type variations. Therefore, lunging progres-
sion as a function of knee angle and step height during PFPS
rehabilitation may proceed as follows: 1) forward lunge at
lower knee angles (0° - 30°) both at ground level and up to a
10 cm platform; 2) forward lunge at middle knee angle (0° -
60°) up to a 10 cm platform; 3) forward lunge at middle knee
angle (0° - 60°) at ground level; 4) side lunge at middle knee
angle (0° - 60°) up to a 10 cm platform; 5) side lunge at mid-
dle knee angle (0° - 60°) at ground level; 6) forward lunge at
higher knee angle (0° - 100°) up to a 10 cm platform; 7) for-
dward lunge at higher knee angle (0° - 100°) at ground level;
8) side lunge at higher knee angle (0° - 100°) up to a 10 cm
platform; and 9) side lunge at higher knee angle (0° - 100°)
at ground level.

In spite of lunging exercises being performed in training
for sport and during PFPS rehabilitation, this is the first
study to examine patellofemoral joint loading during the
bodyweight lunge. Escamilla and colleagues\textsuperscript{6} did examine
patellofemoral joint loading during the forward and side
lunge, but these authors used a 12 RM external load, which
is more appropriate in the latter stages of PFPS rehabilita-
tion. In contrast, the bodyweight lunge, as studied herein
is more appropriate earlier in PFPS rehabilitation. Like the
current study, Escamilla et al.\textsuperscript{6} also reported significantly
greater patellofemoral joint force and stress at higher knee
angles (80° and higher) for the side lunge compared to the
forward lunge, but unlike the current study these authors
reported no significant differences in patellofemoral joint
force and stress at middle knee angles between 40° - 70°,
which in the current study were greater in the side lunge
compared to the forward lunge. Moreover, in Escamilla et
al.\textsuperscript{6} there were no significant differences in patellofemoral
joint force and stress between side and forward lunging
at low knee angles between 0° - 30°, while in the current
study patellofemoral joint force and stress was greater in
the forward lunge compared to the side lunge at 10° and 30°
knee angles. Using external resistance versus bodyweight
only not surprisingly increases patellofemoral joint force
and stress, which at similar knee angles were two to three
times greater in Escamilla et al.,\textsuperscript{6,7} who used a 12 RM lunging
intensity, compared to the current study, which used the
bodyweight lunge. Interestingly, the magnitudes of
patellofemoral joint loading from Hofmann and col-
leagues,\textsuperscript{8} who also examined the bodyweight lunge, were
more similar to patellofemoral joint loading of the 12 RM
lunging intensity employed by Escamilla et al.\textsuperscript{6} compared to
the patellofemoral joint force and stress magnitudes of approxi-
mately 2400 N and 15 MPa, respectively, for the barbell
squat using a 35% bodyweight external load, and approx-
imately 1700 N and 9.5 MPa, respectively, for the body-
weight squat occurring at 90° knee angle. The approximate
1700 N peak patellofemoral compressive force during the
bodyweight squat is similar although slightly more than
the approximate 1500 N peak patellofemoral compressive
force during the bodyweight side lunge in the current study.
Peak patellofemoral joint force and stress in healthy partic-
pants during fast walking reportedly are approximately 900
N and 3.15 MPa, respectively,19 which is approximately 50%
lower than the peak patellofemoral joint force for the side
lunge in the current study and approximately 15% higher
than the peak patellofemoral joint force for the forward
lunge in the current study. However, the peak patellofemoral stress of 3.13 MPa during fast walking is
similar to the peak patellofemoral stress of 3.25 MPa in the
side lunge from the current study, but 55-40% higher than
the patellofemoral peak force of 1.91 MPa in the forward
lunge in the current study. Peak patellofemoral joint force
and stress magnitudes in healthy participants going up and
down stairs are approximately 2500 N and 7 MPa, respec-
tively,19 which are similar to the peak patellofemoral joint
force and stress magnitudes measured in the 12 RM forward
lunge reported by Escamilla et al.,6,7 but approximately two
to three times as great as the peak force and stress magni-
tudes for the bodyweight side and forward lunge in the cur-
rent study.

Unfortunately, it is currently unknown what
patellofemoral joint force or stress magnitudes, and over
what time duration, can ultimately lead to patellofemoral
pathology. There are many factors that may contribute to
patellofemoral pathology, such as overuse or trauma, dys-
functional extensor mechanism, weakness in the quadri-
ceps or hip external rotators, tight quadriceps, hamstrings,
or iliobial band, lower extremity malalignment, and ex-
cessive rear-foot pronation. Nevertheless, clinicians can use
information regarding patellofemoral joint force and stress
magnitudes among different weight bearing exercises, tech-
nique variations, and functional activities to be able to
make informed decisions regarding which exercise they
choose to employ during patellofemoral rehabilitation.

There are limitations in the current study. Firstly, MRI
knee kinematic data have shown during the weight bearing
squat that the femur moves and rotates underneath a rel-
atively stationary patella, and excessive femoral rotation
may increase patellofemoral joint stress on the contralat-
eral patellar facets.20 Unfortunately, MRI knee kinematic
data do not currently exist while performing the forward or
side lunge exercises. Therefore, it is unknown how much
femoral rotation occurs during the forward and side lunge
and how this rotation varies among healthy individuals
and those with pathologies. Secondly, all biomechanical models
also have limitations (see Appendix for biomechanical
model and its limitations). Thirdly, patellofemoral joint
stress magnitudes were measured using patellar contact
area values from MRI data from the literature and were not
measured directly for the included subjects. However, the
contact areas used from the literature were determined dur-
ing loaded weight bearing exercise in healthy male and fe-
male participants, similar to the current study. Moreover,
the near linear and direct relationship between contact area and knee angle has been shown to be similar among studies.\textsuperscript{14,21,22} This implies that the patellofemoral joint stress curve patterns shown in Figures 2B and 3B using contact areas from the literature will be similar to patellofemoral joint stress curve patterns if contact areas were measured directly using MRI. The patellofemoral joint stress patterns are important to clinicians in determining what knee range of motions that patellofemoral joint stress increases or decreases.

CONCLUSIONS

Patellofemoral joint loading during lunging changes according to lunge type, step height, and knee angle. Patellofemoral compressive force and stress were greater while lunging at ground level compared to lunging up to a 10 cm platform between 40° - 60° knee angles, and greater while performing the side lunge compared to the forward lunge between 40° - 100° knee angles. The current findings can be used to help guide patellofemoral rehabilitation regarding the selection of forward and side lunge techniques involving lunging with different step heights. Furthermore, the results will assist exercise specialists who prescribe and progress forward and side lunge exercises in order to optimize hip and thigh strengthening and patellofemoral joint loading. These results may benefit athletes who employ sport specific lunging movements to enhance their return to sport and performance while optimally loading the patellofemoral joint.

CONFLICT OF INTEREST

The authors of this manuscript affirm we have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript. The authors of this manuscript also affirm they have no conflict of interest of any kind.

Protocol used in current study was approved by Institutional Review Board at Sacramento State.

Submitted: November 26, 2020 CST, Accepted: December 09, 2021 CST
REFERENCES


SUPPLEMENTARY MATERIALS

Appendix 1


Do Individuals with History of Patellofemoral Pain Walk and Squat Similarly to Healthy Controls? A 3D Kinematic Analysis During Pain Remission Phase.

Diego Martins, PT, MSc, Marcelo Peduzzi de Castro, PT, PhD, Caroline Ruschel, PE, PhD, Carlos Alberto Atherinos Pierri, MD, Heiliane de Brito Fontana, PT PhD, Gilmar Moraes Santos, PT, PhD

1 Center of Health and Sports Science, University of the State of Santa Catarina; 2 Center of Health and Sports Science, University of the State of Santa Catarina; Labclin - Neuromuscularskeletal Rehabilitation and Clinical Biomechanics Laboratory, 3 Core Centre of Orthopedics and Rehabilitation, 4 Morphological Sciences Department, Federal University of Santa Catarina

Keywords: patellofemoral pain syndrome, lower extremity, knee, biomechanical phenomena

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Background
Patellofemoral pain (PFP) is typically accompanied by changes in movement pattern. However, it is unclear if these changes persist in the remission phase of symptoms. Investigating movement patterns in individuals in remission phase of PFP may help to further guide the rehabilitation process and to understand whether changes are due to high levels of pain or related to other factors.

Purpose
To compare 3D kinematics during walking and the single leg squat (SLS) between individuals with history of PFP in remission phase and a control group without history of lower limb injuries and PFP.

Study Design
Cross-sectional case-control study.

Methods
Individuals with onset of PFP for at least one year and in phase of remission of symptoms (experimental group [EG]; n=13, 30±8 years) were compared to a control group (CG, n=13, 28±7 years). A 10-camera motion analysis system (Vicon-Nexus®) was used to record 3D ankle, knee, hip and trunk angles during walking and SLS.

Results
The EG presented less ankle dorsiflexion, knee and hip flexion during the stance phase of walking compared to the CG (p=0.005, large effect size ηp2 = 0.141). During the SLS, no between-group differences were observed for the ankle, knee and hip angles at the peak of knee flexion (p>0.05). A trend for increased trunk range of movement in the EG compared to the CG was observed (p=0.075, medium effect size ηp2 = 0.127).

Conclusion
The results of this study indicate less movement in the sagittal plane during walking, and a trend towards more movement of the trunk during SLS in the EG compared to the CG. The participants of the EG had minimal symptoms, to the point of not classifying them as pathological. However, the between-group differences suggest that even in the remission
INTRODUCTION

Level of Evidence

Patellofemoral pain (PFP) is characterized by retro, anteropatellar or diffuse peripatellar knee pain during activities such as walking, running, squatting, climbing and descending stairs. The annual prevalence of PFP is 22.7% and 28.9% for the general population and adolescents, respectively, with most patients being young, physically active women.

For most patients, PFP consists of a chronic musculoskeletal condition with periods of remission of symptoms. Long-term cohort studies showed that most individuals with idiopathic knee pain or PFP have persistent symptoms several years after the onset of condition. This recurrence of PFP has been associated with the development of knee osteoarthritis, with subjects undergoing total knee arthroplasty often reporting history of PFP during adolescence. It has been hypothesized that PFP and patellofemoral osteoarthritis form a continuum of disease.

The factors associated with the reoccurrence of PFP are mostly unknown. Previous studies have identified biomechanical changes in subjects with PFP such as decreased knee flexion, increased hip adduction and internal rotation, and increased ipsilateral trunk inclination during walking, running and squatting. These changes, however, have been found in individuals currently experiencing pain and it is unclear whether changes have emerged from pain or were present before the onset of PFP. Additionally, it is not known whether the observed changes in kinematics disappear in the remission phase of PFP. The investigation of movement patterns in individuals in remission phase of PFP may help in the understanding of pain reoccurrence in PFP and help clinicians to manage this chronic musculoskeletal condition and set goals in rehabilitation process.

The aim of this study was to compare 3D kinematics during walking and the SLS between individuals with history of PFP in remission phase and a control group without history of lower limb injuries and PFP. It was hypothesized that individuals in the remission phase of PFP would show different kinematic movement patterns compared to the control group. Specifically, it was expected that decreased knee flexion, increased knee abduction, increased hip adduction and internal rotation, and increased ipsilateral trunk inclination would be observed in the PFP group compared to control.

MATERIAL AND METHODS

This was a cross-sectional case control study with a convenience sample. This study was approved by the Ethics and Research Committee with Human Beings of the University of the State of Santa Catarina (Florianopolis, Brazil) and all the individuals consented to participate voluntarily. This study was conducted between the years 2017 and 2018.

Participants

The participants were recruited from the database of a local rehabilitation facility and from the local community. Individuals of both sexes aged between 18 and 50 years old participated in this study. The experimental group (EG) was composed by individuals with onset of PFP for at least one year and in phase of remission of symptoms (presenting knee pain less than 5 on visual analogue scale - VAS). Cutoff for pain was based on the most commonly used classification for PFP: presence of pain equal or greater than 5 on a VAS during functional tasks such as squatting, climbing and descending stairs, walking, jumping, running or sitting for a long time with a knee flexed. Subjects were excluded if they presented (i) pain equal to or greater than 3 on VAS scale during the execution of the SLS or walking, (ii) reported any perceived functional limitation in the execution of their daily activities or that limited their practice of regular physical activity, or (iii) reported lower limb surgeries in the last year, chronic articular (rheumatologic) diseases, signs or symptoms of another pathology in the knee, pregnancy, and/or diagnosis of cancer. A control group (CG) paired by sex, age (± 2 years) and body mass index (± 0.5 kg.m⁻²) and had never presented history of PFP or any other knee condition was also included. All the previously mentioned exclusion criteria for the EG were also considered for the CG.

Only the limb that presented history of PFP was considered in the analysis. In cases of bilateral PFP, the knee referred to present more symptoms at the time of the last occurrence of PFP was included. In the case of similar bilateral symptoms, the selection was random. PFP individuals were matched to the CG according to limb dominance.

Thirteen participants were included in both EG and CG. Table 1 shows the summary of demographic information of participants.

Instruments

For the kinematic data collection, a 10-camera Vicon Bonita MX motion analysis system (Oxford Metrics, Oxford, UK) sampling at 100 Hz was used. Two AMTI OR6-7 force platforms (Advanced Mechanical Technology, Watertown, USA) were used to record ground reaction forces at a frequency of 1000 Hz. Data processing and analysis were performed in Visual 3D® (C-Motion Inc., MA, US).

For measuring the participants' physical activity level, the short form of the International Physical Activity Questionnaire (IPAQ) – Portuguese version was used. The IPAQ classifies individuals by levels of physical activity, based on both the total volume and the number of day/sessions...
Table 1. Mean (standard deviation) of participants age, height, mass and BMI.

<table>
<thead>
<tr>
<th></th>
<th>EG (n=13)</th>
<th>CG (n=13)</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>30 (8)</td>
<td>28 (7)</td>
<td>59.0</td>
<td>0.12</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.71 (0.05)</td>
<td>1.66 (0.08)</td>
<td>67.4</td>
<td>0.092</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>70.4 (9.2)</td>
<td>68.5 (10.0)</td>
<td>71.25</td>
<td>0.08</td>
</tr>
<tr>
<td>BMI (kg.m⁻²)</td>
<td>24.0 (3.2)</td>
<td>24.3 (3.1)</td>
<td>19.87</td>
<td>0.4</td>
</tr>
</tbody>
</table>

EG: experimental group; CG: control group; BMI: body mass index.

of practice as follows: of practice as follows 'high' (performing vigorous-intensity activity on at least 3 days per week, achieving a minimum total physical activity of 1500 metabolic equivalents-minutes per week (MET-min/week) or seven or more days per week of any combination of walking, moderate-intensity or vigorous-intensity activities achieving a minimum total physical activity of 3000 MET-minutes/week; ‘moderate’ (performing three or more days per week of vigorous-intensity activity during at least 20 minutes per day or five or more days per week of moderate-intensity activity and/or walking for at least 30 minutes per day or five or more days per week of any combination of walking, moderate-intensity or vigorous intensity activities, achieving a minimum total physical activity of 600 MET-minutes/week. Individuals who do not fit into any of these categories are considered to have a 'low' physical activity level. The combined total physical activity as a continuous score (which corresponds to the weighted sum of walking, moderate- and vigorous-intensity activities scores) was calculated for all participants and expressed in MET-minutes/week.

Participants' knee functional level was assessed through the Lysholm Questionnaire - Portuguese version. The Lysholm score is based in eight domains: limp (5 points), support (5 points), pain (25 points), instability (25 points), locking (15 points), swelling (10 points), stair-climbing (10 points), and squatting (5 points), with a final score ranging from 95 to 100 points being classified as 'excellent'; 84 to 94 points as 'good'; 65 to 83 as 'fair' and values equal or below 64 points as 'poor'.

DATA COLLECTION

The participants were contacted by phone or email with preliminary information to schedule the data collection. Upon arrival at the laboratory, participants answered questions regarding personal information required to assess inclusion and exclusion criteria. Subjects that met the criteria responded to the Lysholm and IPAQ questionnaires. Then 32 reflective markers of 20 mm in diameter each were placed in the following landmarks: first and fifth metatarsal head, calcaneus, medial and lateral malleoli, tibial tuberosity, fibular head, medial and lateral condyles of femur, lateral thigh, greater trochanter of femur, anterior superior iliac spine, posterior superior iliac spine, the tenth thoracic (T10) spinal process, the seventh cervical (C7) spinal process, acromion, jugular notch and xiphoid process. Markers of the appendicular skeleton were placed bilaterally. All participants wore elastic (lycra) swimsuits to increase skin adhesion and not disrupt the location of the markers, and they remained barefoot during data collection.

Afterwards, the familiarization with the SLS started. First, the participant was asked to perform a squat up to 60° of knee flexion with the researcher using a manual goniometer to confirm the position. At this position, the distance from the gluteal fold to the ground was measured and a tripod was positioned behind the participant to touch the participant buttocks informing the end of the descent phase during the experimental trials. Participants were asked to perform two sets of four squats and five SLS with both lower limbs with last set including the use of a metronome to control cadence at 45 beats per minute (bpm). If the participant still had difficulty in performing the movement at the required amplitude and cadence, additional repetitions were performed until reaching the appropriate performance. The trial was composed of five SLSs with 60° of maximum knee flexion at 45 bpm, with the arms resting on the waist and the non-stance limb held in line with the stance limb and the knee flexed at approximately 90°. The trial was not considered valid in cases where the participant touched the floor with the contralateral limb. Before and at the end of each trial, participants were asked whether any pain was felt, and the VAS was used if pain was present. Three trials consisting of five SLSs were performed for each lower limb.

After the SLS trials, walking analysis was initiated. Participants were instructed to walk at a self-selected speed on a 5-m walkway. At mid-distance of the walkway, two force platforms were located. The participants were instructed to walk at a cadence of 100 bpm and when they naturally reached the proposed cadence, six walking trials were recorded. In three of six trials, the participant stepped on the force platform with the right foot and, in the other three, with the left foot. The trial was not considered valid in case the participant stepped with part of the foot outside the force platform. Three trials for each side were used for analysis. Before and at the end of each trial, it was asked about the eventual presence of pain in the same way we did during the SLS trials.

Within-trial reliability of the SLS and walking variables for each joint/segment and plane of movement was assessed using the intraclass correlation coefficient (ICC, absolute agreement). ICC values higher than 0.8 were considered as excellent, between 0.6 and 0.8 as good, between 0.4 to 0.6 as moderate and below 0.4 as poor. The within-trial reliability for the kinematic variables of SLS and walking was generally excellent. Of the 51 variables analyzed, 45 presented excellent reliability and six presented good reliability.
DATA ANALYSIS

Kinematic data were processed through Visual 3D® (C-Motion Inc., MA, US) using a 6-degree of freedom model. For the calculation of the joint angles, it was used the Cardan X-Y-Z angles sequence, representing, respectively, flexion/extension, adduction/abduction, and axial rotation. For the ankle, knee and hip joints, the local coordinate system was used, and for the trunk the global coordinate system was used. Results are shown with positive values for angular position indicating flexion, adduction, and internal rotation in the sagittal, frontal and transverse plane respectively. Kinematic data were filtered using a fourth-order zero-lag Butterworth low-pass filter with a cut-off frequency of 12 Hz.

The instant of interest for the SLS was the peak of knee flexion (PK60). Then joint angles for the ankle, knee and hip were extracted at this event. For the trunk, the range of movement (ROM) was calculated for each repetition of the SLS The values of the three central repetitions from each of the three trials included in the analysis were extracted and averaged. Thus, a grand mean of the three trials was calculated. For walking trials, kinematics of ankle, knee and hip were extracted at the first peak (Fy1), the valley (Fymin) and at the second peak (Fy2) of the vertical component of the ground reaction force. The three trials were used to compose the mean using the limb of interest.

STATISTICS

Demographic data and level of functionality were treated by descriptive statistics (mean and standard deviation) and compared by unpaired T-Test. Median and interquartile ranges were computed for the combined total physical activity score17 and Mann-Whitney’s U test was used to compare groups. The physical activity level of participants, as a categorical variable (low, moderate and high), was compared between CG an EG groups by using the Fisher’s Exact test. For the analysis of walking, a multivariate analysis of variance (MANOVA) was conducted with events (Fy1, Fymin and Fy2), joint (ankle, knee and hip) and plane of movement (sagittal, frontal and transverse) as repeated measure factors, group (CG and EG) as independent factor and joint position as dependent variable. For SLS two MANOVAs were used. In the first MANOVA, joint (ankle, knee and hip) and plane of movement (sagittal, frontal and transverse) were used as repeated measure factors, group (CG and EG) as independent factor and joint position as dependent variable. In the second MANOVA, plane of movement (sagittal, frontal and transverse) was used as repeated measure factors, group (CG and EG) as independent factor and trunk ROM as dependent variable. Tukey post-hoc test was applied for multiple comparisons. The partial Eta square ($\eta^2$) was used to measure the effect sizes considering that an $\eta^2$ between 0.01 and 0.06 was considered small, between 0.061 and 0.14 was considered medium, and above 0.14 large.21 Statistical software v.8 (StatSoft, USA) was used with an alpha of 0.05 for all tests.

RESULTS

The Lysholm scores for knee function and symptoms were lower ($t = 209.9$, $p = 0.004$) in the EG (78±10 points, classified as regular) compared to the CG (93±5 points, classified as excellent). All participants of the EG referred the presence of pain in the ‘pain domain’ of the Lysholm questionnaire. For most of them, such pain (lower than 3 onVAS) was inconstant (n=11) with only two individuals reporting constant pain. Most of the individuals that reported inconstant pain (10 out of 11), informed that pain was triggered during heavy exercises.

The median [interquartile range] of the total physical activity score was similar for the EG (1708[1196] MET-minutes/week) and CG (1914[1319] MET-minutes/week), and no difference was found between them ($U = 79.0$, $p = 0.801$). Both groups were similar with regards to the physical activity level ($p = 0.480$). All participants in CG and most in EG (n=11) were classified as having a moderate physical activity level and two EG participants as having a high physical activity level.

WALKING KINEMATICS

There were no interactions for the factors (i) event, joint, plane of movement and group $[F (8,192) = 0.54; p = 0.825; \eta^2_p = 0.022]$, (ii) event, joint, and group, $[F (4,96) = 1.70; p = 0.156; \eta^2_p = 0.066]$, and (iii) event, joint and group $[F (4,96) = 1.05; p = 0.394; \eta^2_p = 0.041]$. There was interaction with a large effect size between event, plane of movement and group factors $[F (4,96) = 3.95; p = 0.0051; \eta^2_p = 0.141]$. Tukey’s post hoc test showed that the EG participants presented decreased movement in the sagittal plane (less ankle dorsiflexion, knee and hip flexion) during walking at the three ground reaction force events (Fy1, Fymin and Fy2) compared to the CG (Figure 1). No differences between groups for the frontal and transverse planes were observed.
SINGLE LEG SQUAT KINEMATICS

When analyzing the joint positions at PK60 there was no interaction between the factors joint, plane of movement and group \( F(4,96) = 0.916; p = 0.458; \eta^2 = 0.036 \). No other interaction or main effects involving the factor group were observed (Figure 2).

For the trunk ROM during SLS (Figure 3), no interaction between group and plane of movement was found \( F(2,48) = 0.781; p = 0.464; \eta^2 = 0.032 \). Although not statistically significant, a trend of main effect for group with moderate effect size was observed \( F(1,24) = 3.477; p = 0.075; \eta^2 = 0.127 \). Such trend possibly occurred due to larger ROM in the transverse and frontal planes presented by the EG compared to the CG (Figure 3).

DISCUSSION

During walking and SLS, no between-groups differences were observed in the ankle, knee and hip in the frontal and transverse planes. In agreement with the hypothesis, less movement in the sagittal plane, including reduced knee flexion, in the EG compared to the CG during walking as well a trend towards more movement in the trunk in the EG compared to the CG during the SLS was observed.

The decreased knee and hip flexion found in walking for the EG is in agreement with a previous study on individuals with PFP.22 In the current study, it was shown that this kinematic pattern might also present in the remission phase of PFP. In individuals in the acute phase of PFP, this movement pattern is often considered a strategy to avoid an increase in the external knee flexion moment and patellofemoral joint stress.23 This has been called quadriceps avoidance.24 It is possible that the participants of the present study, even in the remission phase of PFP, still retain the movement pattern of the period with PFP or that this movement pattern might preclude the onset of symptoms.

Previous authors analyzing the kinematics of functional tasks (e.g., squats, stair descent and running) in individuals with PFP have reported increased hip internal rotation, hip adduction and knee abduction when comparing them to a control group.25,26 These kinematic patterns usually associated with PFP were not observed in the EG of the present study during the SLS. The EG and CG groups behaved very similarly in the analysis of this task probably because the EG subjects presented minimal pain (<3 in VAS) in their daily live. Thus, the changes in lower limb frontal and transverse planes kinematics presented by PFP individuals in comparison to healthy controls24,25 might be a compensatory pattern possibly caused by substantial pain.25,27 The results of this study indicate that individuals in the remission phase of PFP perform a typically normal pattern instead of presenting these compensatory movements.

With regard to the trunk ROM during SLS, the results of the present study indicate a trend (did not reach statistical significance) for the occurrence of a greater contralateral inclination and greater ipsilateral rotation in the EG compared to the CG. In a previous study25 investigating individuals with PFP (no specification on the degree of pain, but with subjects diagnosed), an increase in ipsilateral inclination during the execution of SLS beyond 60° of knee flexion was observed when compared to a control group. In an exploratory analysis in this study, including both lower limbs in the individuals with bilateral PFP (n = 17) versus matched controls, statistical significance was met. Changes in trunk position are known to affect the load at lower limb joints,28 including the knee29,30 and rehabilitation programs often focus on correcting the trunk movement, aiming to bring it closer to those observed and pain free subjects.

The relationship between the severity of PFP and move-
ment pattern alterations is an issue often discussed in the literature. While a movement pattern may be a contributing factor to the development of pain there is no consensus, and it is possible that changes reflect a compensatory mechanism to pain. In this study, the presence of pain in the EG was minimal to the point of characterizing a remission phase of PFP. Nevertheless, it was observed decreased movement in the sagittal plane during walking and increased movement of trunk during the SLS. It seems likely that with time and rehabilitation efforts, symptoms may improve, while some kinematic changes persist. Whether correcting these movements might protect persons with history of PFP and keep them in the remission phase is beyond the scope of this study and future studies testing such hypothesis are warranted.

Participants of both groups presented similar levels of physical activity and were considered active according to the IPAQ classification. A similar result was found in the studies with symptomatic participants, demonstrating that even with PFP, the participants are physically active. However, despite reporting no limitations in their daily routine in the interview, individuals in the EG showed a Lysholm score that indicated regular knee functionality, and not excellent as found for the control group. The similar physical activity level between groups is in line with the perceived absence of functional limitation in both groups, as set in our inclusion criteria. Previous studies have suggested that even higher-level athletes may not reach the excellent category in the Lysholm and that scores for individuals that consider their knee function as normal may range from 43 to 100. The results of the Lysholm scores, however, do seem to indicate that the participants in our EG presented with residual limitations in their knee functionality. The lower functionality score in the EG compared to the CG resulted from different combinations of knee instability, pain during heavy exercise, slightly impaired stairs execution and impaired squat execution. It is possible that the persistent kinematic alterations are related to the functional deficit observed. Interestingly, this deficit did not seem to affect physical activity level, as shown by the findings of the IPAQ.

The sample of this study was small; however, the statistical models of this study were sensitive to a medium to large effect sizes and most of the previously conducted studies focusing on the kinematics of individuals with PFP included a similar number of participants. Walking and squatting trials were not randomized; therefore it is possible that the differences observed during walking might depend on the execution of a previous set of squats. Walking analysis is a useful tool to identify movement pattern alterations in subjects with PFP, it can identify several important clinical changes might not be sensitive if tested in isolation.

CONCLUSION

The results of this study indicate that there are changes in walking and single-leg squat kinematics in subjects in the remission phase of PFP when compared to healthy controls. Specifically, the experimental group showed smaller angular changes in the sagittal plane (less ankle dorsiflexion, knee and hip flexion) during walking and greater trunk angular movement during single-leg squatting than the control participants. Therefore, differences in walking and SLS could contribute to patellofemoral pain recurrence. The recurrence of PFP is high and identifying deficits that persist in the remission phase can help provide background information needed for the design of appropriate intervention strategies and may also assist in our understanding of the relationship between pain and movement patterns alterations in individuals with PFP.

CONFLICT OF INTEREST

The authors report no conflicts of interest or bias in this work.

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REFERENCES


Original Research

Correlation Between Y-Balance Test and Balance, Functional Performance, and Outcome Measures in Patients Following ACL Reconstruction

Jin Seong Kim, PT1, Ui Jae Hwang, PhD, PT2, Moon Young Choi, MS, ATC3, Doo Hwan Kong, MS, ATC1, Kyu Sung Chung, PhD, MD1, Jeong Ku Ha, MD4, Oh Yun Kwon, PhD, PT2 a

1 Sports Medical Center and Sports Medicine Research Institute, Seoul Paik Hospital, Inje University, 2 Physical Therapy, Yonsei University, 3 Orthopedic Surgery and Sports Medicine Research Institute., Seoul Paik Hospital, Inje University, 4 Orthopedic Surgery and Sports Medicine Research Institute, Seoul Paik Hospital, Inje University

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Background
The Y-Balance test (YBT) is commonly used to evaluate balance after anterior cruciate ligament reconstruction (ACLR). However, several studies have also used it as a functional performance test (FPT).

Purpose
This study aimed to examine the relationship between YBT scores and measures of knee joint laxity, static balance, knee flexor and extensor torque and strength ratio, and FPTs.

Study Design
Retrospective cohort study.

Methods
Fifty-nine patients who underwent ACLR using hamstring autografts were retrospectively analyzed. The Pearson correlation coefficient was used to determine the strength of the association between scores on the YBT and selected outcomes including laxity measured via the KT-2000 arthrometer, static balance measured via the Biodex Balance System, isokinetic muscle torque and hamstring-to-quadriceps (HQ) ratio, and performance on the single leg hop test and the single leg vertical jump test.

Results
Forty-six men and 13 women were included. The mean age and follow-up period were 29.6 ± 9.6 years and 12.4 ± 2.1 months, respectively. The KT-2000 arthrometer measures, Biodex Balance System scores, and HQ ratio measurements were not significantly correlated with the YBT scores. All YBT scores, except the YBT-anterior score, correlated with the isokinetic extensor and flexor torques (r-values: 0.271–0.520). All the YBT scores had significant weak to moderate correlations with the single leg hop test and single leg vertical jump test: YBT-anterior (r = 0.303, r = 0.258), YBT-posteromedial (r = 0.475, r = 0.412), YBT-posterolateral (r = 0.525, r = 0.377), and YBT-composite (r = 0.520, r = 0.412).

Corresponding author:
Oh Yun Kwon, PhD, PT, Professor
Address: 234 Maeji-ri, Heungeop-Myeon, Wonju, Kangwon-Do, 220-710, Laboratory of Kinetic Ergocise based on Movement Analysis, Department of Physical Therapy, Graduate School, Yonsei University, Wonju, Republic of Korea
TEL: +82-33-760-2721
FAX: +82-33-760-2496
E-mail: kwonoy@yonsei.ac.kr
Conclusion
Post-ACLR YBT scores correlated with functional performance and muscle strength, but not with static balance, joint laxity, and HQ ratios. The YBT scores as a measure of balance are related to improved functional performance and isokinetic torque measures.

Level of evidence

INTRODUCTION

After anterior cruciate ligament reconstruction (ACLR), several clinical outcome measures, such as patient reported outcomes (Lysholm score, International Knee Documentation Committee subjective score, Tegner activity score, etc.), joint instability, muscle strength, and balance, are used to evaluate knee and functional performance. Based on the evaluation results, a milestone-based return-to-sports (RTS) program is constructed. Balance is an important factor for performance of activities of daily living and sports in patients with ACLR. However, balance is difficult to maintain after anterior cruciate ligament (ACL) injury owing to the decreased hamstring muscle activation and lack of joint position sense.

The Y-Balance test (YBT) is used to assess dynamic balance impairments associated with lower extremity injuries such as ACL injury, patellofemoral pain syndrome, and ankle instability. The YBT is commonly applied to musculoskeletal injuries because it is relatively inexpensive, portable, easy to administer, and shows good interrater test-retest reliability (intraclass correlation coefficient, 0.85–0.93). Furthermore, the YBT score is useful as a component of the criteria for RTS and as an indicator of neuromuscular training results. The YBT is commonly used to evaluate the outcome of reconstruction after ACL tear, which has a high incidence of occurrence during sports activities.

The YBT scores relate not only to balance, but also to various other factors. Previous authors have reported that the YBT scores were not correlated with the Biodex Balance System (BBS)-measured balance in healthy subjects and no correlation with the hamstring-to-quadriceps (HQ) ratio, but is correlated with knee extensor and flexor peak torque in patients who underwent ACLR. Functional movement (hurdle step, in-line lunge, shoulder mobility, and deep squat) was associated with greater anterior reach on the YBT, and the YBT scores were also a significant predictive factor of joint instability. As the YBT scores are related to various factors such as joint instability, balance, muscle strength, and functional performance, it is unlikely that this measure is solely representative of balance for ACLR patients.

Therefore, there is a need to identify the variables that are most related to YBT scores in patients who undergo ACLR. The aim of this study was to examine the relationship between YBT scores and measures of knee joint laxity, balance, knee flexor and extensor torque, HQ ratio, and functional performance tests (FPTs) after ACLR.

METHODS

SUBJECTS

This study retrospectively reviewed the medical records of patients who underwent primary ACLR by a single experienced surgeon (J.K.H.) between June 2016 and May, 2019. The inclusion criteria were as follows: (a) patients who underwent single-bundle ACLR using quadrupled semitendinosus tendon autograft from the hamstrings; (b) patients who were followed for one year or more; (c) patients aged 18–45 years; and (d) patients who completed all the required tests at the hospital. Patients with multiple concomitant ligament injuries and fractures, those who underwent meniscal root repair, cartilage repair, osteotomy to correct mechanical alignment, revision ACLR, subtotal or total meniscectomy, or those with a history of prior knee surgery were excluded. All the patients underwent the same follow-up protocol. The KT-2000 arthrometer, BBS, isokinetic muscle strength test at 60°/s for quadriceps and hamstring, single-leg hop test (SLHT), and single-leg vertical jump test (SLVJT) were all assessed by one of the authors (M.Y.C.) who were blinded to the evaluation procedures after ACLR. All tests were conducted at a sports medicine center in the hospital and at a similar time (approximately one year) postoperatively. The order of the tests was randomized using a randomization website (www.randomization.com). The study protocol was approved by the Inje University Seoul Paik Hospital Institutional Review Board (number 2020-06-002). Written informed consent was obtained from all the patients.

SURGICAL TECHNIQUES

All surgical procedures were performed using the outside-in technique. A quadrupled semitendinosus tendon autograft with remnant preservation was harvested. A single surgeon (J.K.H.) performed all the operations. The reference points of the femoral and tibial tunnels were based on the anatomical center. The femoral tunnel was drilled using a flip-cutter. After graft passage, femoral fixation was achieved using TightRope RT (Arthrex, Naples, FL, USA). A hydroxyapatite interference screw (S&N Corp., Andover, MA, USA) was used for tibial fixation. In all cases, post-tie fixation was performed using a cortical screw for additional tibial fixation.

POSTOPERATIVE REHABILITATION

All patients underwent the same rehabilitation program, which comprised home-based exercises. Range of motion (ROM) exercises were initiated three–five days after the operation. One to two days after the operation, weight-bear-
ing was initiated. The patients wore a functional knee brace held in full extension for three weeks. Full weight-bearing was allowed at three weeks, and the brace was removed after four to six weeks depending on the patient’s feeling of knee instability. Six weeks after the operation, open kinetic chain exercises for the quadriceps were allowed within a 90°–45° range of flexion. The perturbation training program was performed progressively six weeks after surgery. Three months after the operation, light running and sidecutting activities were allowed, and functional exercises emphasizing proprioception was initiated. Six months after the operation, RTS with no competition was allowed.

TESTS

All tests were conducted one year after the operation by one of the authors (M.Y.C.) who was blinded to the patients’ surgical information. The tests included the YBT, KT-2000 arthrometer testing, static balance via the BBS, isokinetic muscle torque (as a measure of strength from which HQ ratios were calculated), and the SLHT and SLVJT. The order of the tests was randomized using a randomization website (www.randomization.com).

**Y-BALANCE TEST**

The patients performed six practice trials and three measurement trials of the YBT using the YBT test kit, administered per standardized instructions for performance (Move2Perform, Evansville, IN, USA), and the average of the three measurements was used for the data analysis (in cm). The patients stood barefoot with the involved side bearing their weight and placed both hands on their chest. The patients were instructed to push the box as far as possible in the anterior (ANT), posteromedial (PM), and posterolateral (PL) directions (Figure 1). The tester provided patient feedback and proper guidance to reduce mistakes such as kicking or stepping on the box during practice trials. The YBT-ANT, PM, PL, and composite scores were used for the analyses. The YBT scores were normalized to the limb length measurement of the patients. To calculate the composite score, the sum of the maximum reaches in each of the three directions was divided by three times the leg length.

**JOINT LAXITY ASSESSMENT**

The side-to-side difference was measured (in mm) using a KT-2000 arthrometer (Med Metrics Corp., San Diego, CA, USA) with the knee at 30° flexion in the supine position. After the patients had fully relaxed, the tibia was pulled in the anterior direction as far as possible (Figure 2). The tibia was pulled with a force of 13.6 kg for three trials and the distance was recorded. The mean distance from the three trials was used for the analysis.

**BIODEX BALANCE SYSTEM**

Balance was evaluated using the BBS (Shirley, NY, USA) (Figure 3). The BBS consists of a mobile platform and 12 levels of difficulty, with Level 12 being the most stable and Level 1 as the most unstable. The test was initiated at Level 8 to measure balance. The following three indices were electronically generated by the BBS software: (1) anterior/posterior index (API), (2) medial/lateral index (MLI), and (3) overall index. These indices are unitless and calculated according to the degree of platform oscillation during one-leg standing. Higher index scores on the BBS indicate greater instability. The reported reliability coefficients were 0.77 and 0.99. The patients were instructed to stand barefoot, with the knees slightly bent and both hands placed on the chest, with the non-weight-bearing leg off the ground with the knee flexed and placed behind the weight-bearing leg. Each patient was encouraged to try to keep the platform in a neutral or stable position. The patients were instructed to maintain their balance in the smallest concentric ring (balance zone) on the BBS monitor. Each testing trial lasted for 30 s, and three testing trials were conducted to obtain reliable measurements. During the 10 s rest period between the trials, the contralateral leg was placed on the floor to prevent fatigue. During the test, the patients maintained an
Table 1. General characteristics of the included patients (n = 59)

<table>
<thead>
<tr>
<th>Patient Characteristics</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>29.6 ± 9.6</td>
</tr>
<tr>
<td>Sex, male/female (n)</td>
<td>46 / 13</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>172.9 ± 8.5</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>77.9 ± 13.2</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>25.9 ± 3.6</td>
</tr>
<tr>
<td>Follow-up period (mo)</td>
<td>12.4 ± 2.1</td>
</tr>
</tbody>
</table>

Values are expressed as mean ± standard deviation or number only.

upright position on the unstable surface of the BBS.

**ISOKINETIC MUSCLE STRENGTH TEST**

Isokinetic muscle strength was measured using the HUMAC-NORM isokinetic extremity system (Computer Sports Medicine Inc., Stoughton, MA, USA). Isokinetic muscle strength was measured at an angular velocity of 60°/s within 0°–90° of knee flexion with the patients in a sitting position. The extensor peak torque per unit of body weight (PT/BW, Nm/kg) and the flexor PT/BW and HQ ratio at angular velocities of 60°/s were calculated. For each session, the concentric quadriceps and hamstring contractions were repeated for four times, and the highest values were recorded and used for analysis.

**FUNCTIONAL PERFORMANCE TESTS**

The FPTs selected for comparison with the YBT in this study included the SLHT and SLVJT (in cm) of the involved side. The SLHT and SLVJT are commonly used tests to measure functional performance. In the SLHT, the patients stood on the involved leg and hopped as far as possible in the forward direction, landing on the same leg. Both hands were placed on iliac crests to restrict arm swing for counter movement. The distance was measured from the toe during push-off to the heel at the landing site. InBody u-Town (InBody Corp., Seoul, Korea) was used to assess SLVJT ability. The patient stood on one leg in the middle of a pressure sensitive mat (90 × 60 cm) and was asked to perform three maximal vertical jumps, with the knee extended, for as high as possible. Both hands were placed on iliac crests to restrict arm swing for counter movement. Height was automatically calculated at the highest point the patient has jumped. Jump height (cm) = 0.5 × 9.799611 × (time × 0.5)² × 100. These tests were performed for a total of three times, and the longest and highest distances were used for the data analysis.

**STATISTICAL ANALYSIS**

All statistical analyses were performed using the SPSS software for Windows (ver. 22.0; IBM Co., Armonk, NY, USA). Sex, age, height, weight, body mass index, and average final follow-up period were calculated as means and standard deviations to identify patient characteristics. The Pearson correlation coefficient was used to determine the strength of the association between YBT scores (ANT, PM, PL, and composite) and selected outcome measures. The outcome measures included the KT-2000 arthrometer, three-index BBS (overall, API, and MLI), three-component isokinetic muscle strength test at 60°/s (extensor PT/BW, flexor PT/BW, and HQ ratio), and two FPTs (SLHT and SLVJT). The r values were defined as follows: 0.00–0.19, no to slight correlation; 0.20–0.39, weak correlation; 0.40–0.69, moderate correlation; 0.70–0.89, strong correlation; and 0.90–1.00, very strong correlation. The statistical significance was set at p < 0.05.

**RESULTS**

The subjects included 46 men and 13 women (mean age 29.6 ± 9.6 years; body mass index 25.9 ± 3.6 kg/m²; and follow-up period of 12.4 ± 2.1 months) (Table 1).

Static balance, knee joint laxity, and HQ ratio did not
Table 2. Correlation coefficient between the YBT, BBS, KT-2000 arthrometer, HQ ratio

<table>
<thead>
<tr>
<th></th>
<th>BBS overall</th>
<th>BBS API</th>
<th>BBS MLI</th>
<th>KT-2000 arthrometer</th>
<th>60°/s HQ ratio</th>
</tr>
</thead>
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<tr>
<td><strong>YBT-ANT</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(n = 59)</td>
<td>r</td>
<td>-0.072</td>
<td>-0.061</td>
<td>-0.062</td>
<td>-0.034</td>
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<tr>
<td></td>
<td>p</td>
<td>0.590</td>
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<tr>
<td>(n = 59)</td>
<td>r</td>
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<td></td>
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<tr>
<td><strong>YBT-PL</strong></td>
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<tr>
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<tr>
<td></td>
<td>p</td>
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</tr>
<tr>
<td><strong>YBT-composite</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n = 59)</td>
<td>r</td>
<td>-0.034</td>
<td>-0.079</td>
<td>-0.002</td>
<td>-0.217</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.799</td>
<td>0.551</td>
<td>0.987</td>
<td>0.101</td>
</tr>
</tbody>
</table>

YBT, Y-balance test; ANT, anterior; PM, posteromedial; PL, posterolateral; BBS, Biodex Balance System; API, anterior/posterior index; MLI, medial/lateral index; HQ ratio, hamstring-to-quadriceps ratio.

Table 3. Correlation coefficient between the YBT, isokinetic strength and functional performance

<table>
<thead>
<tr>
<th></th>
<th>60°/s EPT/BW</th>
<th>60°/s FPT/BW</th>
<th>Single-leg hop test</th>
<th>Single-leg vertical jump test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>YBT-ANT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n = 59)</td>
<td>r</td>
<td>0.188</td>
<td>0.208</td>
<td>0.303*</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.155</td>
<td>0.113</td>
<td>0.020</td>
</tr>
<tr>
<td><strong>YBT-PM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n = 59)</td>
<td>r</td>
<td>0.271*</td>
<td>0.365*</td>
<td>0.475†</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.038</td>
<td>0.005</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td><strong>YBT-PL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n = 59)</td>
<td>r</td>
<td>0.273*</td>
<td>0.285*</td>
<td>0.525†</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.036</td>
<td>0.029</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td><strong>YBT-composite</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n = 59)</td>
<td>r</td>
<td>0.288*</td>
<td>0.336*</td>
<td>0.520†</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.027</td>
<td>0.009</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

YBT, Y-balance test; ANT, anterior; PM, posteromedial; PL, posterolateral; EPT/BW, extensor peak torque per body weight; FPT/BW, flexor peak torque per body weight.

*significant at p < 0.05
†significant at p < 0.01
correlate with YBT scores on the involved extremity (Table 2). The isokinetic extensor and flexor PT/BW at 60°/s had significant weak correlations with the YBT-PM, YBT-PL, and YBT-composite. YBT-PM correlated with extensor PT/BW (r = 0.271) and flexor PT/BW (r = 0.365); YBT-PL, with the extensor (r = 0.273) and flexor PT/BW (r = 0.285); and YBT-composite, with the extensor (r = 0.288) and flexor PT/BW (r = 0.336) (Table 3).

The SLHT score had significant weak-to-moderate correlations with all YBT scores, as follows: YBT-ANT (r = 0.303), YBT-PM (r = 0.475), YBT-PL (r = 0.525), and YBT-composite (r = 0.520). The SLVJT score also had significant weak to moderate correlations with all YBT scores, as follows: YBT-ANT (r = 0.258), YBT-PM (r = 0.412), YBT-PL (r = 0.577), and YBT-composite (r = 0.412) (Table 3).

DISCUSSION

The current study results indicate that the scores in YBT performed by patients one year after ACLR exhibited no significant correlation with static balance, joint laxity, and knee muscle strength ratio measures. The tester performed the examinations using the KT-2000 arthrometer to measure joint laxity, the BBS for static balance, and the HQ ratio at 60°/s for the knee muscle strength ratio. Although the YBT scores did not correlate with static balance, joint laxity, and knee muscle strength ratio, they exhibited weak correlations with knee muscle strength and weak-to-moderate correlation with functional performance tests. The YBT scores were more strongly associated with functional performance than with other outcome measures. Although the YBT is considered a balance test, based on the current results, the YBT performed after ACLR may be appropriately considered as an FPT.

Studying the correlation between the YBT and balance-related test scores in patients who underwent ACLR is a valuable point of this study, which demonstrated that the YBT scores correlated with other FPT scores and knee muscle strength. The clinical relevance of this is that the YBT is related more to physical function, such as knee muscle strength and functional performance, than it is to balance.

The YBT scores did not correlate with any index of the BBS, which are considered static balance assessments, used for patients after ACLR. Although the BBS is static and the YBT is dynamic, both are tools are used for assessing balance ability. Therefore, the authors of the current study expected a correlation between the YBT scores and BBS index.
especially BBS-API, because ACL restricts the anterior tibial translation, and the anterior-posterior stability of the knee is an important factor for successful treatment. However, Almeida et al. reported that the YBT scores had no correlation with the BBS scores in healthy subjects because the YBT required more dynamic movements than did the BBS. This was similar to the results of our study.

The HQ ratio of knee muscle strength and the KT-2000 arthrometer measures of joint laxity were also not correlated with the YBT scores. A high HQ ratio means that the hamstring restricting the anterior tibial translation functions well, but may also indicate relative quadriceps weakness. Kim et al. reported that the HQ ratio slightly increases in patients with ACL injury because quadriceps weakness is threefold greater than hamstring weakness. Therefore, a high HQ ratio was inadequate data. An appropriate HQ ratio for ideal knee muscle balance is known for 0.6, but an HQ ratio that is too high or low could mean muscle imbalance of the quadriceps and hamstrings. Since the correlation analysis is a linear relationship, the YBT scores might not be correlated with the HQ ratio, which requires an appropriate, rather than a high ratio.

Regarding joint laxity, Lee et al. reported that knee joint laxity did not correlate with dynamic standing balance in patients with chronic ACL deficiency, and Leiphart et al. reported that patients with ACL injury had no significant difference in functional performance despite the significant knee joint laxity on the involved side, because they appeared to have adopted compensatory mechanisms of increased hamstring activity to achieve functional joint stabilization. Therefore, it is difficult to believe that joint laxity, which is static ligamentous stability, is correlated with the YBT, which is dynamic movement control, influenced by the neuromuscular system.

The extensor and flexor PT/BW values in the isokinetic muscle strength test at 60°/s correlated with the scores in all the YBTs, except for the YBT-ANT. Unlike this study, a previous study reported that the YBT-ANT, YBT-PM, and YBT-PL scores were all related to the extensor and flexor PT/BW in patients with ACLR. However, the extensor PT/BW of the contralateral side was only related to the YBT-PM, and the follow-up period of the study was short at 5−12 months, which may be an insufficient time frame for ACL recovery. During the YBT, multiple joints are involved, not a single joint. However, the YBT-ANT is most affected by ankle dorsiflexion, and when performing the YBT-PM or YBT-PL, hip muscle strength is required because the trunk is farthest from the center of mass in the sagittal plane. Nevertheless, in all YBT directions, the hip muscles and hip external rotator have been reported to be less activated than the quadriceps and hamstring muscles, and as the knee angle increased in the sagittal plane, the YBT scores were higher. Therefore, although multiple joints and muscles in the lower extremity affect YBT scores, extensor and flexor PT/BW might have a significant influence.

The scores in both the SLHT and SLVJT, were significantly correlated with the YBT scores. After ACL injury, a lack of proprioception and transmission of information about joint movement occurs. Consequently, these factors are proposed to decreased balance, and thus functional performance, which may increase the risk for musculoskeletal injuries. Thus, the accurate evaluation of functional performance ability is important, for which various examinations are available. Teeyen et al. reported the correlation between the YBT and FPT scores including the crossover and 6-m timed hop test results, to verify the usefulness of the YBT. Their results were similar to that observed in this study, even though the FPT using Teeyen's study was a more advanced performance. Therefore, in the early rehabilitation stage, because the YBT scores correlate with the FPT scores and the YBT is easier to start with and hop/functional tests come later, it could be a good addition for measuring functional performance after ACLR.

Previous researchers have reported correlations between the YBT and single-leg hop test scores of 0.55, and isokinetic muscle strength ranging from 0.294 to 0.591. Those results are similar to that of this study. Furthermore, the current study found that the YBT was closer to a dynamic test than to a static test, which matches the original purpose of the YBT.

This study had some limitations. First, this was a retrospective study. Therefore, a selection bias may have been present. Second, the activity level before surgery was not considered. The results of the evaluations may have varied depending on the physical ability of the patients, as well as their sex. Thus, further studies must be conducted on the general population as well as healthy athletes for comparison. Third, the one-year follow-up period was relatively short. Fourth, this study did not consider the influence of ankle and hip ROM and strength on the YBT scores.

CONCLUSION

The results of the current study demonstrate that post-ACLR YBT scores were correlated with functional performance tests and isokinetic measures of muscle strength, but not with static balance, joint laxity, and the HQ ratio. The YBT scores as a measure of balance are related to improved functional performance and isokinetic torque measures.

ACKNOWLEDGEMENTS

We would like to thank all the patients for their time and commitment to the present study.

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CONFLICT OF INTEREST

The authors declare that they have no potential conflicts of interest with respect to the research, authorship, or publication of this article.

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REFERENCES


Modified Biering-Sorenson Protocol Changes Joint Contributions to Total Support in Individuals with a History of Anterior Cruciate Ligament Reconstruction During Drop Vertical Jump Landings

David M Werner¹ ², Maria F Mostaed², Samantha K Price², Joaquin A Barrios²

¹ Division of Physical Therapy Education, University of Nebraska Medical Center; Medical Sciences Interdepartmental Area Program, University of Nebraska Medical Center, ² Department of Physical Therapy, University of Dayton

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Background
There are persistent deficits of the proximal musculature in individuals with anterior cruciate ligament reconstruction. Previous research has shown that proximal musculature fatigue alters drop vertical jump performance in healthy individuals. It is unknown how proximal musculature fatigue will alter drop vertical jump performance in individuals who have undergone anterior cruciate ligament reconstruction.

Hypothesis/Purpose
The purpose of this study was to examine the effects of a proximal extensor musculature fatigue protocol on drop vertical jump landing biomechanics of individuals with a history of anterior cruciate ligament reconstruction using both single-joint parameters and total support moment analysis.

Study Design
Quasi-experimental pre-post laboratory experiment

Methods
Nineteen participants with a history of unilateral anterior cruciate ligament reconstruction were recruited. Three-dimensional motion analysis was performed bilaterally during a drop vertical jump. Participants then completed a proximal extensor musculature fatigue protocol and immediately repeated the drop vertical jump task. Sagittal plane kinetics and kinematics were collected. Joint contributions to peak total support moment were calculated. A condition-by-limb repeated measures analysis of variance was performed to explore the effects of the fatigue protocol, using an alpha level of 0.05.

Results
There were no interactions observed for any parameters. However, the injured limb demonstrated less vertical ground reaction force (13%, p=0.013) and reduced peak dorsiflexion angle (2°, p=0.028) both before and after the protocol. After the fatigue protocol both limbs demonstrated reduced hip extensor contribution to peak total support moment (4%, p=0.035).

Conclusions
Individuals with a history of anterior cruciate ligament reconstruction performed the drop vertical jump with an altered anti-gravity support strategy after the proximal extensor

Corresponding Author:
David Werner PT, DPT, OCS, CSCS
Division of Physical Therapy Education,
98420 Nebraska Medical Center, Omaha, NE 68198-4420, USA
dwerner@unmc.edu
musculature fatigue protocol. The significant reduction in bilateral hip extensor contribution to peak total support moment suggests evidence of targeted fatigue.

**Level of Evidence**

**III**

**INTRODUCTION**

It is estimated that up to 250,000 anterior cruciate ligament (ACL) injuries are sustained each year. Standard of care in the United States after complete ACL rupture is surgical ACL reconstruction (ACLR), with over 125,000 performed annually. Individuals after ACLR typically demonstrate persistent neuromuscular deficits at the knee joint including, but not limited to muscular weakness, reduced proprioception, and altered walking and landing patterns characterized by altered knee biomechanics. Post-operatively it is recommended to restore thigh muscle performance. However, individuals after ACLR also appear to demonstrate persistent proximal neuromuscular impairments. These include altered hip abductor activation, hip extensor strength, reduced core motor control, and trunk extension endurance deficits.

Neuromuscular fatigue can be described as the failure of a muscle to maintain a required or expected force output. Additionally, it has been suggested that experimental fatigue of a muscle may affect that muscle's contribution to a task. The effects of experimentally-induced proximal neuromuscular fatigue on lower extremity biomechanics have been explored in a growing body of literature, predominantly in healthy and able-bodied individuals. Overall, it appears that when targeting specific muscle groups with a fatigue protocol, alterations in kinematics or kinetics are mainly observed in the primary plane of movement of those muscle groups. These altered movement patterns have also been observed in joints distal to the fatigued muscle group. In a previous related study, an isometric fatigue protocol targeting the hip extensors led to an increase in gluteus maximus muscle activation with preservation of joint kinematics during bilateral jump-landings in healthy individuals. Fatigue of muscle groups proximal to the knee region overall appears to impact instrumented assessments during clinical tasks in healthy populations, but has not been tested after ACLR.

Imposing neuromuscular fatigue on proximal muscle groups may interact with persisting post-surgical deficits after ACLR to exacerbate or reveal aberrations in movement reflecting further compromise in neuromuscular control. As lower limb neuromuscular control reflects a multi-joint coordinated strategy, analysis of total support moment (TSM) may provide novel insights into whole-limb movement strategies beyond that of single-joint parameters. The TSM is a summed moment from the extensor synergy of the hip, knee, and ankle that represents the anti-gravity support of the center of mass of the body. At the instance of peak TSM, the sagittal plane moments of the hip, knee, and ankle are assessed to calculate the contribution of each individual joint to the TSM. The TSM has previously been used to characterize differences in neuromuscular strategy during single-limb landing after ACLR compared to controls.

Most previous studies involving fatigue after ACLR have utilized peripheral fatiguing tasks such as squatting and jumping to functional failure points. However, these fatiguing tasks have not directly targeted proximal neuromuscular control. With relevance to the current study, previous electromyography work has validated the ability of the isometric Biering-Sorensen test procedure to induce fatigue to the gluteus maximus, the body’s primary hip extensor muscle. While the Biering-Sorensen test has been used to assess the effects of a hip extensor fatigue protocol on landing mechanics in healthy individuals, the effects after ACLR are unknown.

Therefore, the purpose of this study was to examine the effects of a proximal extensor muscle fatigue protocol on drop vertical jump landing biomechanics of individuals with a history of anterior cruciate ligament reconstruction using both single-joint parameters and total support moment analysis. The DVJ was utilized as the landing task of interest as it has been prospectively linked to secondary ACL injury risk, and has been evaluated before and after Biering-Sorensen testing in healthy individuals. It was hypothesized that the injured limb would differentially demonstrate greater peak lower limb flexion single-joint parameters after the fatigue protocol. Instances of increased hip contributions to movements have been seen in individuals with a history of ACLR during landing and squatting. Based on this data, it was hypothesized that the within-limb TSM joint contribution profile would shift distally to reflect a decreased hip contribution, with the injured limb redistributing less to the knee than the uninjured limb.

**MATERIALS AND METHODS**

**DESIGN**

This study was a single group, pretest-posttest quasi-experimental study. Participants were recruited with electronic and paper flyers. Individuals presented to the laboratory and provided written informed consent approved by the university’s Institutional Review Board prior to testing. The same examiners conducted all testing.

**PARTICIPANTS**

A convenience sample of nineteen participants between the ages of 18-40 years old with a history of unilateral ACLR at least one year prior was recruited for this study. To be included, participants needed to have completed formal rehabilitation and been fully cleared by a physician for return to sport or previous level of activity. Participants were excluded if they had any spinal or lower extremity pain or injury within the prior six months. Participants completed the Tegner Activity Scale and the International Knee Documentation Committee Scale (IKDC) prior to motion capture.
MOTION CAPTURE

Video data were collected using an 8-camera motion capture system (VICON, Centennial, CO, USA, 150 Hz), and force data using two force plates (BERTEC Corp., Worthington, OH, USA, 1500 Hz). Individuals had 47 reflective markers placed over their bilateral lower extremities and pelvis. Marker locations included: L5-S1 interspinous space, iliac crests, anterior superior iliac crests, greater trochanters, medial and lateral femoral condyles, medial and lateral tibial plateaus, medial and lateral malleoli, first and fifth metatarsal heads, distal feet, and proximal, distal, and lateral heels. Rigid marker clusters were placed over the thigh and shank segments. Static standing and dynamic calibration trials were captured.

DROP VERTICAL JUMP

The DVJ was performed as previously described. Briefly, participants stood atop a 30 cm box. They were instructed to fall off the box, land with one foot on each force plate and immediately perform a maximal effort counter-movement jump reaching with both hands for an overhead target. For a trial to be successful the following criteria were required: participants dropped off the box without jumping, landed with each foot on a force plate, and successfully reached overhead during the jump. After successfully completing four trials, participants completed the fatigue protocol, with special care taken to prevent reflective marker placement alteration. Once the fatigue protocol was completed, participants immediately performed four additional successful drop vertical jump trials. All trials were used for analysis.

FATIGUE PROTOCOL

Participants completed three repeated efforts of a modified Biering-Sorensen extension position, held until failure, modified in that three repeated efforts were performed rather than one. Individuals had their lower extremities fastened to a plinth with two belts. Using upper extremity support, they initially positioned their torso horizontally off the plinth. To begin each effort, they were instructed to hold their torso parallel to the ground, to cross their arms, and maintain that position for as long as possible (Figure 1). Participants were provided verbal encouragement throughout the three efforts. For each effort, one verbal warning was given when positional failure was observed. The second positional failure resulted in termination of that effort. Between efforts, individuals received a 15 second rest break. After completion of the final effort, the participants were immediately unfastened from the plinth to perform the post-fatigue DVJs. The time to termination for each effort was recorded, as was the time between the end of the final effort and the start of the post-fatigue DVJ procedures.

BIOMECHANICAL DATA

Vicon Nexus was used for labelling and gap-filling of marker trajectories for the entire contact phase of the task, defined as the time in which a threshold of 20 Newtons of force was on the force plate. Trials were then exported and post-processed using Visual 3D (C-motion, Bethesda, MD, USA) and custom Labview code (National Instruments, Austin, TX, USA). Data were filtered using a low-pass Butterworth filter with a cutoff of 12 Hz. Joint angle and moment data were derived using X-Y-Z Cardan rotation sequences and traditional inverse dynamics procedures, respectively. Joint moments were normalized to body height (meters) and mass (kilograms) and reported as internal moments. Vertical ground reaction force (vGRF) was extracted and expressed normalized to body weight. For the single-joint parameters, the variables of interest were the sagittal plane peak joint angles and moments of the hip, knee and ankle, as well as peak vertical ground reaction force. For the TSM analysis, joint moment data were time normalized to ground contact, and were compared and summed at the instance of peak TSM.

STATISTICAL ANALYSIS

Statistical analysis was performed using SPSS version 25 (IBM Corp, Armonk, NY, USA). Descriptive statistics were calculated on baseline parameters. Two-factor (condition-by-limb) analyses of variance with Bonferroni correction were performed to assess for potential interactions, main effects and simple effects for peak ground reaction force, peak joint moments and angles, and joint moments at the instance of peak total support. An alpha level of 0.05 was used. Post-hoc Pearson correlations were used to examine the relationship between change in percent contribution at the knee and hip to activity level (measured by Tegner), IKDC score, and time since surgery.
### Table 1. Participant descriptive data

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex Frequency (F:M)</td>
<td></td>
<td>16:3</td>
</tr>
<tr>
<td>Injured Limb (dominant:nondominant)</td>
<td></td>
<td>10:9</td>
</tr>
<tr>
<td>Age (years)</td>
<td>24.5 (4.8)</td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>23.53 (2.3)</td>
<td></td>
</tr>
<tr>
<td>Tegner Activity Scale (0-10)</td>
<td>7.1 (2.2)</td>
<td></td>
</tr>
<tr>
<td>IKDC Score (0-100)</td>
<td>83.4 (7.4)</td>
<td></td>
</tr>
<tr>
<td>Time since surgery (months)</td>
<td>59.1 (37.2)</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2. Modified Biering-Sorensen results (seconds)

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effort 1</td>
<td>84.4 (44.0)</td>
</tr>
<tr>
<td>Effort 2</td>
<td>42.9 (19.0)</td>
</tr>
<tr>
<td>Effort 3</td>
<td>34.3 (18.0)</td>
</tr>
<tr>
<td>Cumulative Hold Time</td>
<td>161.7 (65.3)</td>
</tr>
<tr>
<td>Transition time from fatigue protocol to testing</td>
<td>24.1 (5.9)</td>
</tr>
</tbody>
</table>

### RESULTS

Descriptive data for all participants are presented in Table 1. The average participant was a young adult female with a normal body mass index, approximately five years removed from unilateral ACLR with an IKDC score slightly below age matched healthy individuals and a Tegner score indicating recreational or competitive sport participation.

All participants completed all study procedures. In regards to the modified Biering-Sorensen fatigue protocol, an average reduction in time to positional failure of approximately 50 seconds (~59%) was observed between the first and third consecutive efforts. On average, participants transitioned to the post-protocol DVJ testing in less than 25 seconds after completing the third and final modified Biering-Sorensen effort (Table 2).

The single-joint results are presented in Table 3. No interactions or main effects of condition were observed. Two main effects of limb were seen. The injured limb demonstrated less peak ankle dorsiflexion angle (2°, p=0.028), as well as less peak vGRF (13%, p=0.013).

The joint contributions and peak TSM data are presented in Figure 2. No interactions or main effects of limb were observed. However, a single main effect of condition at peak TSM was seen for the hip contribution. After the protocol, at peak TSM, the hips showed a 4% decreased contribution to TSM (p=0.035).

Post-hoc analysis revealed a significant correlation (r = 0.527, p =0.02) between percent change in knee contribution post-protocol and time since surgery. The relationship was such that as time since surgery increased, individuals had a higher percentage contribution at the knee post-protocol. Otherwise, no other significant correlations were noted (p >0.05).

### DISCUSSION

The overall purpose of this study was to examine if a proximal extensor fatigue protocol elicited differential alterations in sagittal plane lower extremity kinematics and kinetics during a DVJ in individuals with a history of ACLR. Neither the single-joint nor whole-limb results directly supported the differential effect hypothesis, as no interac-
solutions were observed. When considering single-joint parameters, the participants loaded the injured limb less, and dorsiflexed less at maximum well, which is consistent with findings in previous literature. When considering the whole-limb TSM analysis, the proximal extensor fatigue protocol generally elicited a decrease in the hip joint contribution to anti-gravity support, which provides supporting evidence that the fatigue protocol affected the targeted muscles.

Of particular relevance to the current study are the findings of Hollman et al.\textsuperscript{18} In a comparable study, healthy women performed a bilateral jump-landing task and isometric hip dynamometry before and after a modified Biering-Sorensen fatigue protocol. Hollman and colleagues measured hip and knee kinematics and gluteus maximus muscle activations, and found no change in peak hip and knee angles after the modified Biering-Sorensen fatigue protocol. However, peak isometric hip extension force was reduced and gluteus maximus electromyographic activation was increased after the fatigue protocol. The authors suggested that the kinematics may have stayed consistent due to increased neural drive to the gluteus maximus. In the current study, electromyographic data were not collected, and there was no change in single-joint kinematics or kinetics supporting the results of Hollman and colleagues\textsuperscript{18} despite the history of unilateral ACLR. In regards to whole-limb neuromuscular strategy, the proximal extensor fatigue protocol resulted in a reduction in hip extensor contribution to peak TSM. Both the increased gluteal activations seen in the Hollman study and the altered TSM seen in this study may be considered evidence of compensatory motor solutions used to preserve requisite task-level kinematics.

Two discrete parameters were suggestive of altered function in the ACLR limb, peak vGRF and ankle dorsiflexion angle. In regards to decreased vGRF during landings, a recent systematic review with meta-analysis identified that 9/10 included studies showed reduced peak vGRF in adolescents with a history of ACLR.\textsuperscript{58} This study’s pre-protocol data add to the robust literature identifying loading asymmetry in individuals after ACLR. The lack of change in peak vGRF post-protocol suggests that proximal extensor fatigue does not strongly influence the magnitude of whole-limb vertical loading after ACLR.

There was less ankle dorsiflexion observed in the injured limb compared to the uninjured limb during the DVJ. Reduced peak ankle dorsiflexion and reduced ankle dorsiflexion at initial contact has been observed in the injured limb compared to both the uninjured limb and to controls during the DVJ.\textsuperscript{39,40} However, clinical measurement of maximum ankle dorsiflexion after ACL injury has been found to not differ between limbs.\textsuperscript{41} The combination of these studies may suggest that performance of the DVJ may not consistently engage physiological end-range dorsiflexion. Therefore, the difference between limbs in peak dorsiflexion after ACLR may be largely attributable to an avoidance strategy of the injured limb.\textsuperscript{40} In the current study, the observed combination of reduced peak ankle dorsiflexion angle and vGRF in the injured limb provides supportive evidence for this avoidance phenomenon.

The fatigue protocol elicited reduced hip moment contributions to peak TSM. The reduction in hip contribution may reflect decreased muscle force output from the hip extensors after the protocol at the instance of peak anti-gravity demand. Hollman and colleagues\textsuperscript{18} previously reported a 25% reduction in isometric hip extension strength after a similar protocol. The reduced hip contribution to peak

### Table 3. Condition by limb results, presented as Mean (SD)

<table>
<thead>
<tr>
<th></th>
<th>Injured Limb</th>
<th>Uninjured Limb</th>
<th>Interaction</th>
<th>Condition Main Effect</th>
<th>Limb Main Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-fatigue</td>
<td>Post-fatigue</td>
<td>Pre-fatigue</td>
<td>Post-fatigue</td>
<td>p-value</td>
</tr>
<tr>
<td>Peak Hip Flexion Angle (degrees)</td>
<td>76.4 (12.8)</td>
<td>74.9 (13.6)</td>
<td>75.2 (13.3)</td>
<td>72.9 (14.0)</td>
<td>0.130</td>
</tr>
<tr>
<td>Peak Knee Flexion Angle (degrees)</td>
<td>86.9 (10.6)</td>
<td>86.3 (10.1)</td>
<td>86.7 (11.4)</td>
<td>85.4 (10.5)</td>
<td>0.095</td>
</tr>
<tr>
<td>Peak Ankle Dorsiflexion Angle (degrees)</td>
<td>26.9 (5.1)</td>
<td>26.8 (5.6)</td>
<td>29.2 (4.6)</td>
<td>29.3 (4.4)</td>
<td>0.709</td>
</tr>
<tr>
<td>Peak Internal Hip Extension Moment (Nm/(kg*m))</td>
<td>1.17 (0.21)</td>
<td>1.18 (0.23)</td>
<td>1.26 (0.28)</td>
<td>1.26 (0.27)</td>
<td>0.757</td>
</tr>
<tr>
<td>Peak Internal Knee Extension Moment (Nm/(kg*m))</td>
<td>1.04 (0.24)</td>
<td>1.07 (0.26)</td>
<td>1.11 (0.26)</td>
<td>1.14 (0.26)</td>
<td>0.927</td>
</tr>
<tr>
<td>Peak Internal Ankle Plantarflexion Moment (Nm/(kg*m))</td>
<td>0.71 (0.20)</td>
<td>0.74 (0.20)</td>
<td>0.78 (0.16)</td>
<td>0.79 (0.16)</td>
<td>0.366</td>
</tr>
<tr>
<td>Peak Vertical Ground Reaction Force (N)</td>
<td>1.45 (0.23)</td>
<td>1.47 (0.20)</td>
<td>1.65 (0.24)</td>
<td>1.65 (0.23)</td>
<td>0.807</td>
</tr>
<tr>
<td>Peak Total Support Moment</td>
<td>2.24 (0.44)</td>
<td>2.28 (0.45)</td>
<td>2.38 (0.36)</td>
<td>2.37 (0.29)</td>
<td>0.248</td>
</tr>
</tbody>
</table>

Bolded – statistically significant

International Journal of Sports Physical Therapy
TSM seen in the current study participants may reflect a transient reduction in hip strength from the protocol. This reduction in hip contribution may impact performance of other tasks after a proximal extensor fatigue protocol and thus be of interest to clinicians observing movement in a post-fatigued state. Interestingly, the knee contribution in the injured limb appeared to improve after the protocol. Previous studies have shown that the ACLR population demonstrates a decreased knee contribution to TSM during single limb landing. While the joint moment redistribution elicited by hip extensor fatigue would be transient, there may be potential rehabilitative and training applications to further explore.

The correlation between increasing knee contribution and time since surgery aligns with previous literature demonstrating increases in knee extensor strength over time after ACLR. Barford and colleagues found that over the course of rehabilitation a higher percentage of individuals developed adequate knee extension strength as measured by isokinetic limb symmetry index. Additionally, in a review of literature, it was recommended that it could take up to two years for knee extensor strength to recover. The average length of time since surgery of the current cohort was nearly five years, meaning they had greater opportunity to recover quadriceps strength. It is unknown if time since surgery and percent change in knee contribution would have a different relationship in those closer to surgery.

There are limitations to this study. As this is a cross-sectional study, it cannot be determined if the observed response to the hip extensor fatigue protocol would have been seen prior to injury. The sample size is relatively small and therefore prone to sampling error, a larger sample would improve the generalizability of the results to confidently characterize the ACLR population. While biomarkers of fatigue were not collected, participants performed three efforts of a validated single effort hip extensor fatiguing task. Trunk data were not collected, but could help explain the total body impact of the modified Biering-Sorensen fatigue protocol. Also, as with any study utilizing traditional motion capture techniques, skin movement artifact can affect the joint motion estimates.

CONCLUSION

The results of this study demonstrate that a hip extensor fatigue protocol elicits reduced bilateral hip extensor contribution to total support moment when anti-gravity demands are greatest in persons with ACLR. The clinical implications of this redistribution warrant further investigation.

CONFLICTS OF INTEREST

The authors have no relationships/activities/interests to disclose that are related to the content of this manuscript.

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REFERENCES


Prevalence of Risk Factors of the Female Athlete Triad among Young Elite Athletes of Pakistan

Jaweria Syed, Anam Jamil, Nazma Namroz, Madiha Shakeel, Ayesha Malik, Sumaira Kanwal, Huma Riaz

1 ShifaTameer-e-Millat University, 2 Abasyn University, 3 Riphah International University, 4 Margalla Institute of Health Sciences

Keywords: pakistan, osteoporosis, female athlete triad, bone mineral density, athlete, amenorrhea, eating disorders

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Background
Female athletes who are not vigilant about their food choices and choose extraneous physical activities may head towards negative health effects.

Purpose
The purpose was to determine the prevalence of risk factors that may lead to the Female Athlete Triad among young elite athletes in Pakistan.

Study Design & Methods
A cross sectional questionnaire-based study was conducted in 2018 at Pakistan Sports Board to investigate the risk factors of The Female Athlete Triad among young elite athletes based in national training camps of major metropolitan cities. Trained and professional female elite athletes of age 18 – 25 years, able to comprehend questionnaire in English were included. Athletes completed the questionnaire including demographics, educational qualifications, Body Mass Index, sports participation, and playing hours. The Eating Aptitude Test-26 (EAT-26) and questionnaires on risks of amenorrhea and risks of low bone mineral density were completed. Individual prevalence of the risk factors of three components was assessed. The data were analyzed using SPSS-20 and descriptive statistics applied.

Results
A sample of 60 elite athletes, (23.57 ± 2.37 years, BMI 21.97 <u‘>±1.90) who participated in various sports were included. EAT-26 results indicated that 50% of athletes were at risk of an eating disorder. Disordered Eating behaviors in need of referral were identified in 83.3%. Risks for amenorrhea were identified in 15%, and concerning low Bone Mineral Density, no risks were identified, except the intake of caffeinated beverages in 51.7%.

Conclusion
The prevalence of risk for disordered eating was found to be significant among female elite athletes of Pakistan, but risk of amenorrhea and low bone mineral density were not of major concern.

Level of evidence
3b

INTRODUCTION
In sports, amazing feats of physical, mental, and skill are common. An elite athlete strives hard and excels above their baseline level of participation, devoting their energy and time to grooming their individual talents. This helps
them become a performance perfectionist in their field. Doing more is their way of life. The operational definition of an elite athlete for this manuscript is an athlete that was a member of a national squad representing their country nationally and internationally in a team or individual sport.

When gender specificity is considered, the number of young females participating in constant physical training, athletic activities, recreational games, and elite sport competitions has increased astonishingly in last three decades. These female athletes display amazing talent all over the globe. However, such training and talent offers another challenge for sports scientists and practitioners: the need for developing unique training programs for young female athletes according to their individual sports requirements. Despite many good outcomes, there are certain associated risks with sports involvement. Young female athletes are prone to various health risks with sports related injuries. Several major medical conditions are reported in young female athletes including disordered eating, menstrual cycle disturbance, and impaired bone mineral health. The female athlete triad (FAT) was initially described by Women’s task force of the American College of Sports Medicine (ACSM) in 1992. Not only the ACSM but also the International Federation of Sports Medicine (FIMS) in collaboration with International Olympic Committee (IOC) have developed a consensus statement on the FAT.

The FATIs characterized by a negative balance of energy. Eating disorders and disordered eating are not gender specific, and includes Relative Energy Deficiency in Sport (RED-S). RED-S is related to the FAT and describes the interrelationship among low energy availability (with or without disordered eating) and various body systems. Due to energy imbalance, females are prone to menstrual disturbances and the development of low bone mineral density (BMD). The interrelated nature of these three components affects the overall health of female athletes. Restrictive eating and routine strenuous or prolonged exertion can cause energy deficits, which changes hormonal levels in the body, affecting the reproductive system and ultimately the menstrual cycle is disturbed and if balance not regained, may be followed by negative effects on bones. This multifaceted syndrome is based on insufficient balance between energy intake and energy expenditure. If not considered promptly, the triad may have irreversible health consequences, either of individual facets or all three in combination.

A review of sixty-five studies (n = 10,498, age = 21.8 ± 3.5 years, body mass index = 20.8 ± 2.6 kg/m²; mean ± SD) examined the prevalence of collective triad and individual components of the FAT. It aimed to describe the prevalence of the FAT in both lean versus non-lean sports in young athletes. Gharib et al. investigated the triad’s long-term complications and suggested that a multidisciplinary approach involving family members and coaches be employed to address health concerns. A study by Barrack et al. updated the prevalence rates of the three components of the female athlete triad present in athletes. Miller et al. investigated whether Australian exercising women were aware of the FAT and its consequences including energy deficiency, menstrual disturbances, and low BMD. A total 191 females between the ages of 18–40 completed the survey. Melin et al. recruited a population from the Danish and Swedish sport federations and aimed to examine associations between the three components and the prevalence of triad-associated conditions in endurance athletes. Forty active, exercising women participated in the study which included gynecological examination with assessment of bone health, analysis of diet, and blood analysis. Goodwin conducted a study to profile components of the FAT among elite female athletes and non-athletes in which 25 athletes and 14 non-athletes provided their data for energy availability, menstrual function, and physical activity. Dual Energy X-rays Absorptiometry (DEXA) was done to find their Bone Mineral Density (BMD) respectively. De Souza et al. and Sundgot Borgen et al. sought to discern the prevalence of severe menstrual disturbances in exercising females and disordered eating in elite athletes involved in high intensity training. Almost half of the exercising females had menstrual disturbances and suboptimal eating habits and routines and the authors suggested that suchathletes need family and team support to manage healthy eating habits. Prather et al. screened and assessed 220 elite female soccer athletes for being at risk of disordered eating attitudes, menstrual dysfunction and stress fractures and found these athletes were susceptible to stress fractures and menstrual disturbances. In female skaters, prevalence and correlation of eating disorders were studied by Voelkar et al. who discussed body dissatisfaction and concern of weight and appearance as major problem. Finally, Amrinder found that both athletes non-athletes had risk factors for the triad, hence educating the females is of utmost priority.

A significant number of studies have been conducted internationally to determine the prevalence of risk factors of the FAT in elite athletes. Authors have described the risk factors and prevalence of the triad components individually or as a whole condition. But in Pakistan, no significant work has been done, and the FAT remains underreported concerning prevalence, prevention, awareness, screening and treatment. Therefore, the purpose of this study was to determine the prevalence of risk factors that may lead to the FAT among young elite athletes in Pakistan.

METHODS

This was a cross sectional study conducted from July 2018–Jan 2019 at Pakistan Sports Board, which is the governing body to regulate the sports sector in Pakistan. The study variables consist of risk factors for disordered eating, risks for menstrual disturbances, and risk factors for low BMD in elite female athletes.

A questionnaire consisting of demographics, educational qualification, BMI, sports participation and risk factors concerning the FAT was developed by the authors under supervision. It included three parts: The Eating Aptitude Test-26 (EAT-26) for risk of eating disorders, and two self-structured questionnaires for risks of amenorrhea and low BMD (Appendix A). The World Health Organization (WHO) guidelines for tool development were followed for development of the questionnaires. After proofreading, both tools were piloted on a study sample of 20 participants, as a result both questionnaires were found to be reliable and valid for further use. The finalized version of the questionnaire the
### Table 1. Demographic details of age, height and weight

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean±SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age(years)</td>
<td>23.57±2.4</td>
</tr>
<tr>
<td>Height(inches)</td>
<td>64.43±2.2</td>
</tr>
<tr>
<td>Weight(kg)</td>
<td>55.95±9.65</td>
</tr>
</tbody>
</table>

### Table 2. Demographic details of educational qualification, BMI, type of sports and training hours of included female athletes

<table>
<thead>
<tr>
<th>Variables</th>
<th>n(%)</th>
<th>Variables</th>
<th>n(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualification</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Under matriculation</td>
<td>1(1.7%)</td>
<td>Martial arts/ taekwondo</td>
<td>5(8.3%)</td>
</tr>
<tr>
<td>Matriculation</td>
<td>6(10%)</td>
<td>Squash</td>
<td>6(10%)</td>
</tr>
<tr>
<td>Intermediate</td>
<td>20(33.3%)</td>
<td>Handball</td>
<td>10(16.7%)</td>
</tr>
<tr>
<td>Bachelors</td>
<td>28(46.7%)</td>
<td>Jump, throw, running</td>
<td>8(13.3%)</td>
</tr>
<tr>
<td>Masters</td>
<td>5(8.3%)</td>
<td>Badminton</td>
<td>6(10%)</td>
</tr>
<tr>
<td>Body mass Index (BMI)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underweight</td>
<td>9(15%)</td>
<td>Swimming</td>
<td>6(10%)</td>
</tr>
<tr>
<td>Healthy weight</td>
<td>48(80%)</td>
<td>Table tennis</td>
<td>7(11.7%)</td>
</tr>
<tr>
<td>Overweight</td>
<td>1(1.7%)</td>
<td>Volleyball / Basketball</td>
<td>12(20%)</td>
</tr>
<tr>
<td>Obese</td>
<td>2(3.3%)</td>
<td>4 hours/day</td>
<td>16(26.7%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 hours/day</td>
<td>24(40%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 hours/day</td>
<td>20(33.3%)</td>
</tr>
</tbody>
</table>

Risks of amenorrhea section had 13 items \( r=0.82 \) and risks for low BMD \( r = 0.76 \) section had 16 items.

The EAT-26; is a widely used self-reported standardized screening measure used to assess eating disorder risk. The EAT-26 is the short version of EAT-40, which is highly reliable and valid measure. It was formulated to screen if someone needs professional assistance for an eating disorder. It is rated on six-point scale (always, usually, often, sometimes, rarely, and never) based on how often the individual engages in specific behaviors and has three sub-scales: dieting, bulimia, and food preoccupation and oral control. The EAT-26 correlates highly with the original EAT-40 scale \( r = 0.98 \). Test-retest reliability for EAT-26 has ranged from .84 to .89.\(^{20}\) The average administration time of EAT-26 is approximately two minutes. Scores on the EAT-26 above 20 are better and give an indication for need of further assessment by a professional, whereas scores less than 20 can be an indication of serious eating problems or referral. Consent was given on every questionnaire from the participants.

All the athletes that participated in national as well as international tournaments came under the jurisdiction of Pakistan Sports Board, which is the governing body to regulate the sports sector in Pakistan. Ethical approval for this study was granted from Internal Review Board of Riphah International University, Islamabad. Non-probability convenient sampling technique was used to select a total of 60 female elite athletes from metropolitan cities like Karachi, Lahore and Islamabad who attended National and Regional training camps.\(^{21–23}\) The inclusion criteria included: trained and professional female elite athletes of Pakistan, menstrual-age females without a diagnosed eating disorder any menstrual disturbance or osteoporosis, and those who could easily interpret the questionnaire language (English).

**RESULTS**

The sample size consisted of 60 elite female athletes of Pakistan and the three components of the FAT were assessed individually. Data were analyzed by descriptive statistical methods. Demographics of the subjects are provided below. (Table 1)

Regarding educational qualifications, the responses were: under matriculation, matriculation, intermediate certification, a bachelor’s in any field, and master’s degree holders.

All sixty female athletes were of 18–28 years of age. The athletes participated in a variety of different sports including: Martial arts/ Taekwondo, Squash, Handball, Jump/Throw/Running sports, Badminton, Swimming, Table tennis and Volleyball or Basketball. The BMI was calculated for each player and categorized as underweight, healthy weight, overweight, or obese as per the definition of United States Center for Disease Control and Prevention and three subcategories regarding training hours were reported. (Table 2)

EAT -26 scoring results are presented in Table 3. Fifty percent of the sample displayed a risk for an eating disorder.
Table 3. Frequency of major risk factors of The Triad

<table>
<thead>
<tr>
<th>Variables</th>
<th>n (%)</th>
<th>Variables</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Risk of Eating Disorder</strong></td>
<td></td>
<td><strong>Menstrual Cycle in past 12 months</strong></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>30 (50%)</td>
<td>10 - 12 cycles</td>
<td>51 (85%)</td>
</tr>
<tr>
<td>No</td>
<td>30 (50%)</td>
<td>4 - 9 cycles</td>
<td>7 (11.7%)</td>
</tr>
<tr>
<td>Total</td>
<td>60 (100%)</td>
<td>&lt; 4 cycles</td>
<td>2 (3.3%)</td>
</tr>
<tr>
<td><strong>Eating disordered behaviors</strong></td>
<td></td>
<td>Total</td>
<td>60 (100%)</td>
</tr>
<tr>
<td>Binge eating</td>
<td>31 (51.7%)</td>
<td>Yes</td>
<td>31 (51.7%)</td>
</tr>
<tr>
<td>Vomiting</td>
<td>16 (26.7%)</td>
<td>No</td>
<td>29 (48.3%)</td>
</tr>
<tr>
<td>Abusing laxatives</td>
<td>39 (65%)</td>
<td>Total</td>
<td>60 (100%)</td>
</tr>
<tr>
<td>Intensive training routine</td>
<td>12 (20%)</td>
<td><strong>Intake of caffeinated beverages (that may affect bone mineralization)</strong></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>60 (100%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Disordered eating behaviors and their prevalence of binge eating, vomiting, abusing laxatives and with intensive training routines were also recorded, and 83.3% of the athletes engaged in different categories of disordered eating behaviors.

Amenorrhea risks are also presented in Table 3, 24 (40%) females reported menarche at 14, 17 (28.3%) when they were 13, and 14 (23.3%) at 15 years of age. Fifty-one (85%) reported regular menstrual cycles whereas seven (11.7%) reported 4-9 cycles past year and only two (3.3%) reported less than four cycles over the year. On response to a question if they ever missed menstrual cycles 23 (38.3%) said yes and when asked about the regularity of their cycles 51 (85%) reported regular and nine (15%) reported irregular cycles. With change in intensity, frequency and duration of training 29 (48.3%) reported changes in their menstrual cycle whereas 45 (75%) reported no changes and out of all significant stressors in their lives, most commonly reported were: family stress in 25 (41.7%), 12 (20%) said financial, seven (11.7%) had professional, and four (6.7%) reported other stressors like hostel life and peer pressure, respectively. When asked regarding intensive training and exercises, 28 (46.7%) reported an intensive routine, and 32 (53.3%) did not participate in intensive exercises. Out of all subjects, only three (5%) were on estrogen supplementation, four (6.7%) on steroids/thyroid hormones, and eight (13.3%) took diuretics or weight reducing drugs.

Risk factors for low BMD were less common, and only one (1.7%) reported history of vertebral stress fracture, parents of eight (13.3%) had ever sustained a hip fracture, nine (15%) were smokers, two (3.3%) were on steroids for three months or longer, and only two reported drinking three to four alcoholic drinks per day. Most commonly reported was the intake of caffeinated beverages (51.7%). Table 3

History of medications showed that 12 (20%) took no medications, 18 (30%) took calcium, and 50 (50%) took vitamin D. Those who performed weight bearing exercises regularly were 21 (35%).

**DISCUSSION**

According to review of several studies on the prevalence of individual and combined components of the female athlete triad, the presence of all three aspects of the triad in athletes is less well investigated than reporting on individual components. Most of the prior authors have reported the presence of one or two of the three components of the triad, which is similar to the results of the current study which shows risk factors for eating disorders. Sixty elite athletes (23.57 ± 2.37 years, BMI 21.97 ± 1.90) who participated in various sports were included. EAT-26 results indicated that 50% of athletes were at risk of an eating disorder. Disordered Eating behaviors in need of referral were identified in 83.3%. Risks for amenorrhea were identified in 15%, and concerning low bone mineral density, no risks were identified, except the intake of caffeinated beverages in 51.7%.

A review of 65 studies (n=10,498, age= 21.8 ± 3.5 years, BMI = 20.8 ± 2.6 kg•m; mean ± SD) that evaluated the prevalence of triad risk factors and clinical conditions in exercising women showed that only small percentage of athletes (0%-15.9%) in nine studies exhibited all three components of the triad. In this same study the presence of two or any one of the Triad conditions ranged from 2.7% to 27.0% and from 16.0% to 60.0%, respectively, whereas the results of this study were different indicating 50% of athletes (age in years = 23.57±2.4) were at risk of eating disorders with only one presenting with highest risk, only 15% reported amenorrhea risk, and none really reported any risks concerning low BMD except caffeinated beverages intake.

Barrack et al. studied the prevalence of the three com-
ponents of the FAT and found the occurrence was very low (0-16%). When one or two components were considered, the percentage of affected athletes was 50-60% which is partially consistent with the results of the current study as one component was high with 50% females at risk of eating disorders, however risk for amenorrhea was only 15% and low BMD was almost negligible with only beverages intake reported in 51.7% elite athletes of Pakistan. It appears that FAT prevalence as a syndrome (all three parts) is low in Pakistani athletes as others have found.11,12

Another review study by Gharib Nazem, et al.10 suggested that early detection of risk factors leading towards the triad is very important to minimize the complications of the FAT. Clinical features associated with aspects of the triad often do not always appear initially, therefore prevention is the best measure. Diagnosis and treatment come later and should involve interdisciplinary therapeutic approach.

Singh Amrinder et al.19 studied prevalence of the FAT and its associated risk factors and amongst 200 athletes from India, and only seven (3.5%) participants of the total sample were determined to have all aspects of the triad. Of the 200, 49 (24.5%) were at risk of an eating disorder, 48 (24%) had irregular menstrual cycles, and 51 (25.5%) were at risk for osteoporosis. Whereas in the current study of 60 elite athletes the most prevalent risk factor was for eating disorder found in 30 (50%) participants and no athlete presented with risk for all three complications.

Cross-sectional studies may be limited by the presence of uncontrolled factors. This study had limitations including that the athletes were not assessed for their energy availability status. Secondly, the athletes completed these questionnaires at varied times (in season or out of season) in their sports related specific training, and this may have had an impact on the risk factors. Finally, the nutritional behaviors and life style factors/choices of the athletes were not recorded and may also have affected the results.

CONCLUSION

The presence of all three components of the triad in athletes appears very low in Pakistan; with the greatest number of the athletes showing risk for eating disorders/disordered eating. Amenorrhea risk factors appear to be low in Pakistani athletes as 85% reported regular menstrual cycles. Among all studied risks associated with bone health, only the ingestion of caffeinated beverages was noted as a possible risk with 51.7% of the athlete’s reporting consumption.

This study may be used to inspire further research, prevention, practice, education, awareness, and screening related to the FAT in Pakistan. The authors recommend that awareness regarding the female athlete triad syndrome and its risk factors be provided for all young female athletes of Pakistan.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Ethical approval of the study was sought from Riphah Internal Review Board, Islamabad, Pakistan.

CONSENT FOR PUBLICATION

Written informed consent was obtained from all the participants.

FUNDING

None

CONFLICT OF INTEREST

The authors declare 'No Conflicts of Interest' financial or otherwise.

ACKNOWLEDGEMENTS

We would like to thank the Pakistan Sports Board for granting permission to collect data from elite female athletes.

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REFERENCES


Appendix A

Background

There is limited evidence describing the relationship between calcaneal bone mineral density (cBMD) and activity level, menstrual history, or the development of bone stress injury (BSI).

Hypothesis/Purpose

The purposes of this study were to: 1) examine the influence of physical activity on cBMD in healthy college students (HCS), 2) determine if there is an association between cBMD, body mass index (BMI), sex, menstrual history, and history of BSI in HCS, and 3) compare the cBMD of HCS to cBMD data collected on intercollegiate athletes (ICA) from a previous study.

Study Design

Cross-sectional design

Methods

This cross-sectional study recruited a convenience sample of HCS at one institution. Subjects provided self-reported injury and menstrual history, completed a physical activity questionnaire, and cBMD and BMI measures were obtained. Descriptive statistics, statistical analyses of relationships (Chi-square and relative risk), logistic regression, and differences (t-tests) were used in the statistical analyses.

Results

One hundred three HCS (82 female, 21 male; age 21.9 ± 1.13) consented to participate. The composite score for work, leisure, and sport activity ranged from 5.6 to 11.1 (7.9 ± 1.1) for HCS subjects. There was no significant correlation between cBMD and physical activity in HCS, however, a significant correlation was found between reported age of onset of menstruation and left and right cBMD (r = -0.22 and r = -0.23; p < 0.05) and history of secondary amenorrhea and history of BSI (r = 0.32; p < 0.05). There was no difference in cBMD between the male ICA and male HCS, but highly significant differences in cBMD between the female ICA and female HCS groups (p < 0.000).

Conclusions

Age of menarche and secondary amenorrhea are significantly associated with cBMD and history of BSI in HCS subjects, respectively. Differences in cBMD among the HCS subjects
were not related to activity level. cBMD was significantly lower in female HCS as compared to female ICA. This difference in cBMD between ICA and HCS may be activity related.

**Level of Evidence**
Level 3

**INTRODUCTION**

Bone health is a significant global health issue facing our 21st century world. In 2000, there was estimated to be nine million osteoporotic fractures across the world, with hip, forearm, and vertebral fractures among the most common. Such fractures lead to decreased functional ability, inability to fulfill social roles, loss of independence, and higher mortality. The personal, social, and economic burden of poor bone health requires attention to this issue and close examination of the factors leading to poor bone health with aging.

Multiple factors have an influence on bone health including genetics, nutrition, physical activity, sex, age, and ethnicity. Some of those factors are non-modifiable (age, sex, genetics) while others including nutrition and physical activity are modifiable. The majority of bone mass is achieved by late adolescence, and, as such, maximizing bone accrual during adolescence is crucial in the prevention of early bone demineralization. Given that premenopausal bone fractures have been shown to increase the risk for future fractures in a woman’s life, attention to bone health in young women is critical. Bone mineral density (BMD) is one important indicator of bone health, and several studies have demonstrated a positive relationship between increased physical activity and higher BMD. A common theme to these studies is the importance of ground based, moderate intensity exercise as a stimulus for higher BMD. Studies by Reinking et al and Risser et al of BMD in collegiate athletes have shown lower BMD in swimmers as compared to ground-based athletes.

Given this evidence, it would be anticipated that participation in weight bearing sports would result in increased BMD. However, some evidence has shown lower BMD in endurance athletes as compared to a group of active, non-athletic subjects. Bone stress injury, including stress fracture and medial tibial stress syndrome, are commonly experienced in running and jumping athletes. Consequently, the dose-response relationship between weight-bearing physical activity and BMD is not fully understood. To encourage optimal bone health in a young adult population and minimize risk of bone demineralization and fracture in older adults, a deeper understanding of this relationship is critical.

The calcaneus is the only site recognized by the International Society of Clinical Densitometry (ISCD) for the assessment of bone density using quantitative ultrasound (QUS) bone densitometry. Consisting of 75-95% trabecular bone, the calcaneus demonstrates greater degradation in response to age and disease compared to cortical bone due to its high rate of turnover, and structurally is well-suited for the horizontal transmission of sound energy due to its two relatively opposed lateral surfaces and minimal amount of soft tissue. The speed of sound (SOS) is determined by measuring the time it takes for sound energy to travel across the width of the calcaneus, and as such, is measured in units of meters per second (m/s). Broadband ultrasound attenuation (BUA) is the slope of the line formed by plotting sound intensity (dB) across a range of sound frequencies (MHz) and is reported in units of dB/MHz. BUA has been reported to provide a general indicator of bone quality, or architecture, rather than the quantity of mineral in bone.

These measures collectively provide qualitative and quantitative information regarding the density, microarchitecture, and mechanical properties of the calcaneus. Faster SOS and greater BUA reflect more dense and homogenous bone structure, respectively, and when combined linearly provide a measure of relative bone “stiffness” referred to as the quantitative ultrasound index (QUI). The QUI value is rescaled to provide an estimate of BMD (g/cm²) allowing for determination of a t-score and comparison to previously established normative data. In vivo and in vitro QUS measures have been shown to be highly correlated (r = 0.82 - 0.85) with other measures of calcaneal bone quality such as dual-energy x-ray absorptiometry (DXA), and with measures of bone density obtained at other anatomical locations such as the femur and lumbar spine.

At present, inconsistent evidence is available pertaining to BMD values in athletic and non-athletic collegiate-aged persons, and the influence of physical activity on those values. Based on the literature review and the authors' previous work with cBMD in intercollegiate athletes, we established three purposes of this study: 1) compare cBMD of intercollegiate athlete (ICA) and healthy college students (HCS), 2) examine the influence of physical activity on cBMD in HCS, 3) investigate the effects of multiple variables on cBMD including body mass index (BMI), sex, menstrual history in females, and history of bone stress injury (BSI). Previously published data on ICAs were used to compare cBMD values obtained in HCS subjects.

**METHODS**

**STUDY DESIGN**

Following approval by the Saint Louis University Institutional Review Board, a cross-sectional sample of HCS was recruited to participate in this study. Subjects who elected to participate in the research study provided consent and were scheduled for data collection. Data collection consisted of subjects completing a health and activity questionnaire and members of the research team collecting calcaneal bone mineral density, height, and weight measures.

**SUBJECTS**

Full-time college students (82 female, 21 male) at one academic institution between 18-24 years of age (21.9 ± 1.15)
who were not currently or previously rostered as a member of an intercollegiate athletic team were recruited to participate. Students not meeting the inclusion criteria or who described an existing lower-extremity injury were excluded from the study.

PROCEDURES

HEALTH & ACTIVITY QUESTIONNAIRE

Participants completed a web-based questionnaire including date of birth, sex, age, race/ethnicity, use of foot orthotics, lifetime history of diagnosed lower extremity or pelvic stress fracture or medial tibial stress syndrome (MTSS), and menstrual history. The Habitual Physical Activity Questionnaire was included in the web-based questionnaire as a measure of self-reported activity level. The Habitual Physical Activity Questionnaire assesses activity across work, sport, and leisure not involving sport, and has been found to be a valid measure of activity level. The questionnaire consists of 16 items scored on a five-point scale which are used to calculate composite and categorical measures of self-reported physical activity.

HEIGHT AND WEIGHT

Height (inches) and weight (pounds) were recorded using conventional methods employing a standard scale and tape measure. Height and weight measures were converted to the metric scale to allow for calculation of body mass index (kg/m²).

CALCANEAL DENSITOMETRY

Quantitative ultrasound (QUS) involves the measurement of speed of sound (SOS) and attenuation of sound energy, or broadband ultrasound attenuation (BUA), as the sound wave passes through soft tissue and bone. Based on SOS and BUA measures, the quantitative ultrasound index (QUI) is obtained through simple linear combination of both values and then rescaled to give an estimate of bone mineral density. For the current study, calcaneal bone mineral density (cBMD) was determined via QUS using the Sahara clinical bone sonometer (Hologic, Inc, Waltham, MA). The Sahara clinical bone sonometer uses a specific technique involving the transmission of sound energy from one transducer through the calcaneus to a second receiver.

Calibration of the densitometer was performed as described by manufacturer guidelines each day prior to data collection. Participants were seated in a straight-back chair approximately 12-18 inches from the scanner and both heels were inspected for abrasions or open sores. The tester cleaned the sides of the heels with a towelette and dried the heel prior to testing. The tester then applied an oil-based coupling gel (Hologic, Inc.) to both elastomer transducer pads. The subject’s foot was then placed into the foot well and the leg secured using the positioning aid (Figure 1). The subject was instructed to remain still during the test and heel placement was checked to ensure proper placement prior to initiating the measurement. Once initiated, the elastomer pads moved to the measurement position contacting the sides of the calcaneus and measurement was performed. Upon completion of the measurement, SOS (m/s), BUA (dB/MHz), estimated cBMD (g/cm²), and BMD t-scores were recorded, and the steps repeated for the subject’s contralateral calcaneus.

DATA ANALYSIS

Descriptive statistics (means, percentages) for height, weight, and BMI were calculated using the demographic data of HCS subjects. The independent group t-test was used to compare self-reported physical activity scores to QUS measures in the group of HCS subjects. Self-reported physical activity, BMI, sex, and menstrual function were compared between HCS subjects with a history of BSI to the HCS subjects who denied a history of BSI using analyses of relationships (chi-square and relative risk). Comparison was made between QUS data collected on the group of 84 ICAs (64 female, 20 male) to the QUS data from the 103 HCS in this study using the independent group t-test. R statistical computing environment (R Core Team, 2013) was used for data management and analysis.

RELIABILITY

Reliability of the calcaneal bone densitometer (cBMD, SOS) was determined through random selection of subjects to have repeated density measures of both calcanei at the time of initial data collection. Intrarater reliability, calculated using intraclass correlation coefficients (ICC 3.1) for cBMD, were previously reported as demonstrating a high level of measurement consistency (> 0.95).13

RESULTS

Participant demographics for the HCS subjects are summarized in Table 1 and self-reported history of stress fracture or leg pain (defined as pain occurring on the inside of the lower leg between the knee and ankle) is reported in Table 2.

Figure 1. Measurement of Calcaneal Bone Mineral Density (cBMD)
Table 1. Healthy College Student Demographics

<table>
<thead>
<tr>
<th></th>
<th>Healthy College Students (n=103)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Female (n=82)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.64 (0.06)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>63.26 (8.65)a</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>23.46 (2.95)b</td>
</tr>
</tbody>
</table>

BMI = body mass index
*Values are mean ± SD
a,b Significantly different at p < 0.001

Table 2. Healthy College Student Bone Stress Injury History

<table>
<thead>
<tr>
<th></th>
<th>Healthy College Students (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total (n=103)</td>
</tr>
<tr>
<td>Stress Fracture Hx</td>
<td>8 (7.8)</td>
</tr>
<tr>
<td>Leg Pain Hx</td>
<td>29 (28.2)</td>
</tr>
</tbody>
</table>

Hx = history

Twenty HCS (19.4%) reported participating in organized sports and 48 HCS (46.6%) reported “more” or “much more” physical activity compared to their peers on the Habitual Physical Activity Questionnaire. Habitual Physical Activity Scores were not associated with self-reported history of BSI (stress fracture or MTSS) or with cBMD or SOS measures. However, a small but significant negative association between BMI and the Habitual Physical Activity work subscale was identified across all HCS subjects (r = -0.29, p < 0.05) and in the female HCS group (r = -0.23, p < 0.05). Small but significant negative associations were also found in the female HCS group between age of menarche and cBMD in both the left (r = -0.22, p < 0.05) and right (r = -0.25, p < 0.05) calcanei, and between a history of stress fracture in the pelvis or lower extremity and a history of secondary amenorrhea (r = 0.32, p < 0.05, Table 3).

Calcaneal QUS measures (cBMD, SOS) for all HCS subjects were significantly lower (p < 0.000) than preseason measures obtained in ICAs (Table 4). Calcaneal BMD and SOS measures were significantly lower in HCS females compared to ICA females; however, male ICA and HCS had cBMD and SOS measures that were not significantly different (Table 4). From the cBMD reliability study the intraclass correlation coefficient values (ICC 5.1) were all greater than 0.95, indicating a high level of measurement consistency.

DISCUSSION

PHYSICAL ACTIVITY AND CBMD IN HCS

Although numerous studies have reported the benefits of exercise and sport on bone accrual and bone strength, few studies have examined the relationship between physical activity level and optimal bone health. While athletes have been shown to have greater BMD and bone health when compared to a referent group of non-athletes, the level of physical activity necessary to stimulate an osteogenic response has not been identified. Researchers have provided conflicting evidence to support the benefits of physical activity on bone health in the general population. Moreover, it is important to note the limitations of available methods used to measure physical activity. For example, the Habitual Physical Activity Questionnaire addresses frequency of exercise but may not account for osteogenic differences between various exercise modes. Therefore, subjects reporting higher levels of physical activity who are performing activities that are generally considered low-load, endurance activities are less likely to demonstrate significant differences in bone development and structure when compared to less physically active subjects. Wallace et al. assessed both historical and current physical activity level in their study and reported that lifetime physical activity and lifetime weight-bearing activity accounted for 3-15% of the variance in BMD in a group of 19-25 year old regularly menstruating females. Sawyer et al. used calcaneal QUS in a group of healthy subjects aged 6.6-20 years of age (n=311) and found a significant relationship between BUA and SOS and physical activity. However, when accounting for age and weight, physical activity accounted for only 1.0-1.4% of the variance in SOS and bone stiffness. In a study of 60 healthy, eumenorrheic women aged 25-34 years of age, physical activity was found to be significantly associated with vertebral bone density (r = 0.41, p < 0.005). A study of adolescent females with a history of an eating dis-
order were compared to matched females with no history of eating disorder who were also grouped based on performing more or less than seven hours of physical activity per week. No differences in total body or site-specific BMD were found between the eating disorder group or two activity groups.40

ASSOCIATION BETWEEN BONE STRESS INJURY AND CBMD, BMI, SEX, AND MENSTRUAL FUNCTION

Bone stress injuries have been identified as a common injury among endurance athletes. The long-term consequences of maladaptive changes in bone microarchitecture and bone geometry to repetitive loading have not been studied. Methods to assess bone health during periods of development, changes in activity, and with ageing will allow medical professionals to identify risk factors for bone stress injury and evaluate interventions designed to influence bone health. Quantitative ultrasound has also been shown to have similar prediction capability for fracture risk as compared to DXA and has been shown to correlate with DXA measures in young children and adolescents.31,34,35 Van Mechelen41 has described a “sequence” for the prevention of sports injury which includes identifying factors which play a role in the occurrence of sports injury followed by the introduction of measures to address the aforementioned factors.

A number of authors have shown significantly altered bone microarchitecture and lower bone density and bone strength in athletes with stress fracture or bone stress injury when compared to healthy athletes.21,42–44 The authors of this study have shown that QUS measures in female athletes involved in ground based sports who develop a bone stress injury during the competitive season are significantly lower relative to their peers.13 It is worth noting that studies that did not find a significant difference in BMD between subjects with bone stress injury and controls reported important methodological differences. For example, Bennell et al45 reported no significant difference in BMD when comparing female runners with a history of healed tibial stress fracture to female runners without a history of stress fracture, suggesting that timing of the densitometry measurement relative to the diagnosis of bone stress injury may influence BMD measures. In a study comparing military recruits who developed a bone stress injury to healthy, matched controls, there were no differences in BMD measures at the tibia and femoral neck.46 However, military recruits present with diverse levels of physical activity history, meaning the change in volume of physical activity likely varied across subjects with basic training and therefore exposed the subjects to varied levels of risk.

A number of authors have examined the influence of menstruation, BMI, and sex on risk of developing bone stress injury in athletes and the military population. When comparing CBMD between groups and blocking for sex, ICA male and HCS male subjects were found to have similar CBMD and SOS while female subjects had significantly different CBMD and SOS measures across ICA and HCS groups. This finding suggests the influence of sex linked factors in bone accrual and structure and supports previous studies demonstrating differences between male and female bone geometry and strength.35,47 For example, Beck et al47 found significantly smaller subperiosteal diameters and thinner cortices in female military recruits compared to male recruits. Several authors reporting on the incidence of stress fracture in military and athletic populations have identified female sex as a risk factor for bone stress injury.47–49

The influence of menstruation on bone health and in the development of bone stress injury has been described extensively as part of the female athlete triad, and the results of this study support the relationship between menstrual abnormality and low bone density.50–55 More specifically, amenorrhea has been shown to be a significant risk factor for bone stress injury in female athletes. The current study demonstrated a small but significant negative correlation (r = -0.22 and r = -0.23) between age of menarche and cBMD, suggesting an important relationship between earlier onset of menstruation and greater bone accrual during adolescence. A history of amenorrhea was also found to be associated with a history of stress fracture in the pelvis or lower extremity, supporting previous studies that have shown a relationship between menstruation and risk of bone stress injury. While differences in BMI across sports are common, the authors did not identify a relationship between BMI and cBMD in either the ICA or HCS groups.

CBMD IN ICA VS HCS

This is the first known study to compare measures of bone health (SOS & BUA) in ICA and HCS using calcaneal QUS bone densitometry. The authors found significant differences in QUS measures for cBMD (p < 0.000) and SOS (p < 0.000) between the female ICA and female HCS groups, with female ICA having significantly greater cBMD. Previous studies have described the anabolic effects of physical activity on bone structure, especially in athletes involved in high-impact sports and weight training.7,11,12 Tenforde et al12 in their review of the literature found an association between impact sports (gymnastics, soccer, etc.) and greater bone mineral density, bone composition and bone geometry, while non-impact sports such as cycling and water polo were not associated with increased bone quality or quantity, and in the case of swimming were negatively associated. The authors of this manuscript reported similar findings in a sample of ICA, with significantly lower cBMD and SOS in swimmers & divers when compared to soccer and cross-country/track athletes.13 Considering ICA are typically engaged in high load activities associated with their sport and participate in regular strengthening and conditioning programs, it is not surprising that we found significantly higher measures of bone quality and quantity when compared to HCS subjects. However, when the QUS measures in ICA who developed BSI during their competitive season were compared to the QUS measures in HCS, there was no significant difference in cBMD or SOS between groups. This study consisted of a sample of convenience of healthy college students at one Midwest institution with a greater number of female than male subjects and therefore generalizability is limited. History of BSI relied on self-reporting and therefore is dependent on subject recall and susceptible to bias.
Table 3. Association Between Variables in Female Healthy College Students

<table>
<thead>
<tr>
<th></th>
<th>RcBMD</th>
<th>RSOS</th>
<th>LcBMD</th>
<th>LSOS</th>
<th>BMI</th>
<th>FXDX</th>
<th>MENA</th>
<th>AMEN2 HX</th>
<th>OLIGO HX</th>
<th>AMEN2 YR</th>
<th>OLIGO YR</th>
</tr>
</thead>
<tbody>
<tr>
<td>RcBMD</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSOS</td>
<td>.96(^a)</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>LcBMD</td>
<td>.88(^b)</td>
<td>.89(^b)</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSOS</td>
<td>.89(^c)</td>
<td>.93(^c)</td>
<td>.97(^c)</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>BMI</td>
<td>-.04</td>
<td>-.09</td>
<td>-.05</td>
<td>-.13</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>FXDX</td>
<td>-.03</td>
<td>-.05</td>
<td>-.11</td>
<td>-.12</td>
<td>.27(^d)</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MENA</td>
<td>-.23(^e)</td>
<td>-.18</td>
<td>-.22(^e)</td>
<td>-.17</td>
<td>-.19</td>
<td>.08</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMEN2 HX</td>
<td>-.07</td>
<td>-.07</td>
<td>-.02</td>
<td>-.07</td>
<td>.12</td>
<td>.32(^f)</td>
<td>.18</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OLIGO HX</td>
<td>.01</td>
<td>.01</td>
<td>.00</td>
<td>.01</td>
<td>-.01</td>
<td>.10</td>
<td>.19</td>
<td>.32(^e)</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMEN2 YR</td>
<td>-.12</td>
<td>-.11</td>
<td>.02</td>
<td>-.03</td>
<td>-.04</td>
<td>-.09</td>
<td>-.03</td>
<td>.42(^h)</td>
<td>.17</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>OLIGO YR</td>
<td>.18</td>
<td>.18</td>
<td>.15</td>
<td>.15</td>
<td>-.02</td>
<td>-.10</td>
<td>-.13</td>
<td>.15</td>
<td>.54(^i)</td>
<td>.08</td>
<td>1.00</td>
</tr>
</tbody>
</table>

RcBMD = right calcaneal bone mineral density; RSOS = right speed of sound; LcBMD = left calcaneal bone mineral density; LSOS = left speed of sound; BMI = body mass index; FXDX = stress fracture diagnosis; MENA = age of menarche; AMEN2 HX = secondary amenorrhea history not including the last 12 months; OLIGO HX = oligomenorrhea history not including the last 12 months; AMEN2 YR = secondary amenorrhea in the last 12 months; OLIGO YR = oligomenorrhea in the last 12 months.

\(^{a,b,c,h,i}\)Association between variables significant at p < 0.001

\(^{d,e,f,g}\)Association between variables significant at p < 0.05
Table 4. Speed of Sound and Calcaneal Bone Mineral Density Quantitative Ultrasound Measures Between Intercollegiate Athlete and Healthy College Students

<table>
<thead>
<tr>
<th></th>
<th>Quantitative Ultrasound Measures*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RSOS (m/s)</td>
</tr>
<tr>
<td>ICA (n=84)</td>
<td>1605.2 ± 36.1a</td>
</tr>
<tr>
<td>HCS (n=103)</td>
<td>1582.0 ± 32.3a</td>
</tr>
<tr>
<td>Male ICA (n=20)</td>
<td>1597.1 ± 33.5</td>
</tr>
<tr>
<td>Male HCS (n=21)</td>
<td>1601.7 ± 33.1</td>
</tr>
<tr>
<td>Female ICA (n=64)</td>
<td>1607.8 ± 36.8a</td>
</tr>
<tr>
<td>Female HCS (n=82)</td>
<td>1577.0 ± 30.3c</td>
</tr>
</tbody>
</table>

RSOS = right speed of sound; LSOS = left speed of sound; RcBMD = right calcaneal bone mineral density; LcBMD = left calcaneal bone mineral density; ICA = intercollegiate athlete; HCS = healthy college students

*Values are mean ± SD

CONCLUSION

Methods to assess bone health are valuable to medical professionals involved in the prevention and treatment of bone stress injuries. A thorough understanding of the influence of physical activity, menstrual history, sex, BMI, BMD, and history of BSI on bone health will aide in the management of subjects at risk of or diagnosed with a bone stress injury. Age of menarche and history of amenorrhea were found to be significantly associated with cBMD and self-reported stress fracture history, respectively, and should be considered when assessing the risk of bone stress injury in females. Female HCS with no history of intercollegiate athletic participation were found to have significantly lower cBMD than a group of female ICA. The results of this study suggest that QUS is a valuable instrument for identifying subjects with low calcaneal bone mineral density who may be at risk of developing a BSI. As a non-ionizing, efficient, portable, and low-cost modality, QUS should be considered a viable instrument in monitoring the response of bone to repetitive stress, identifying athletes with low BMD at increased risk of bone stress injury, and prescribing optimal osteogenic interventions in the management of bone stress injury. Future studies should include a larger sample of collegiate and non-collegiate athletes and non-athletes and include additional risk factors that will further help identify level of risk of bone stress injury.

CONFLICTS OF INTEREST

The authors have no conflicts to disclose

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REFERENCES


Comparison of Concurrent and Same-Day Balance Measurement Approaches in a Large Sample of Uninjured Collegiate Athletes

Jessica Saalfield1, Kelsey L. Piersol1, Robert Monaco1, Jason Womack1, Scott A Weismiller1, Carrie Esopenko2, Sabrina M Todaro2, Fiona N Conway3, Kyle Brostrand4, Jennifer F. Buckman5,6,7,8

1 Department of Kinesiology and Health, Rutgers University, New Brunswick, NJ, USA, 2 Atlantic Sports Health, Morristown, NJ, USA, 3 Department of Family Medicine & Community Health, Robert Wood Johnson Medical School, Rutgers University, New Brunswick, NJ, USA; Department of Athletics, Rutgers University, New Brunswick, NJ, USA, 4 Dept. of Internal Medicine, Penn State Health, Milton S. Hershey Medical Center, Hershey, PA, US, 5 Department of Rehabilitation and Movement Sciences, Rutgers Biomedical and Health Sciences, Newark, NJ, USA, 6 Center of Alcohol and Substance Use Studies, Rutgers University, New Brunswick, NJ, USA, 7 Steve Hicks School of Social Work, University of Texas at Austin, Austin, TX, USA, 8 Robert Wood Johnson Barnabas Health – Rutgers Sports Medicine, Rutgers University, New Brunswick, NJ, USA, 9 Department of Kinesiology and Health, Rutgers University, New Brunswick, NJ, USA; Center of Alcohol and Substance Use Studies, Rutgers University, New Brunswick, NJ, USA

Keywords: postural stability, force plate, balance, accelerometry

https://doi.org/10.26603/001c.31178

Background

Measures of postural stability are useful in assisting the diagnosing and managing of athlete concussion. Error counting using the Balance Error Scoring System (BESS) is the clinical standard, but has notable limitations. New technologies offer the potential to increase precision and optimize testing protocols; however, whether these devices enhance clinical assessment remains unclear.

Purpose

To examine the relationships between metrics of balance performance using different measurement systems in uninjured, healthy collegiate athletes.

Study Design

Cross-sectional.

Methods

Five hundred and thirty uninjured collegiate athletes were tested using the C3Logix app, which computes ellipsoid volume as a measure of postural stability during the six standard BESS conditions, while concurrently, errors were manually counted during each condition per standard BESS protocols. The association between concurrently measured ellipsoid volumes and error counts were examined with Spearman’s correlations. From this sample, 177 participants also performed two double-leg conditions on the Biodex BioSway force plate system on the same day. This system computes Sway Index as a measure of postural stability. The association of ellipsoid volume (C3Logix) and Sway Index (Biodex) was examined with Spearman’s correlations. Individual-level data were plotted to visually depict the relationships.

Results

C3Logix ellipsoid volume and concurrently recorded error counts were significantly correlated in five of the six BESS conditions (rs:.22-.62; p< 0.0001). C3Logix ellipsoid volume and Biodex Sway Index were significantly correlated in both conditions (rs=.22-.27, p< 0.004). However, substantial variability was shown in postural stability across all three measurement approaches.
Conclusion

Modest correlation coefficients between simultaneous and same-day balance assessments in uninjured collegiate athletes suggest a need to further optimize clinical protocols for concussion diagnosis.

Level of Evidence

2b

INTRODUCTION

Healthcare providers routinely assess postural stability as part of the diagnosis and management of sport-related concussion. Numerous research tools and protocols have been developed to quantify alterations in postural stability and the nature of disruptions in the postural control system; however, it remains unclear whether objective measurement systems provide a more comprehensive clinical picture than rater-assessed tests. A critical first step in determining this is to understand the relationship between different measurement systems in a large, healthy sample. The current study assesses three measures of postural stability that were collected on the same day in a large sample of uninjured NCAA Division I collegiate athletes.

The Balance Error Scoring System (BESS) is one of the most used concussion diagnosis assessments due to its ease of administration, portability, and low cost. The BESS uses a series of closed-eye stances on firm and foam testing surfaces to characterize postural stability under conditions of varying difficulty. Despite its popularity in athletics for concussion diagnosis and return-to-play judgements, the BESS has notable limitations. The BESS can detect changes in gross postural stability post-injury but may have limited utility beyond three days post-injury due to its reliance on subjective ratings and suboptimal interrater reliability. Large changes in BESS scores may be necessary to overcome rater variability and provide meaningful detection of postural stability alterations. Additional concerns are its limited sensitivity in detecting postural stability deficits post-injury when compared to an individualized pre-injury baseline measurement or to matched uninjured controls along with substantial floor and ceiling effects in uninjured samples.

In research settings, force plates are preferred for assessing postural stability due to their precision, robust quantification, and ability to assess a variety of stances and balance protocols. Force plate technologies include, but are not limited to, the BioSway (Biodex Medical Systems, Inc., Shirley, NY), the NeuroCom Balance Master (Cephalon, Norwood, Denmark), and Bertec (Bertec, Columbus, OH), and have been used to evaluate changes in postural stability following concussion. Despite providing greater precision and a variety of derived stability measures, force plates are more expensive and less portable than the BESS and therefore may have limited accessibility and feasibility for clinical or sideline assessments. Moreover, a recent study of a large NCAA Division I athlete sample revealed sizable heterogeneity of individual balance performance measured using a force plate system. This raises questions of whether the precision of such postural stability measures is necessary for monitoring an athlete’s diagnosis of, and recovery from concussion.

The past decade has seen the development of numerous mobile-based instrumented measurements of postural stability with existing balance protocols, such as the BESS, hold promise for the diagnosis and management of athlete concussion because they combine the ease of administration of the traditional BESS with the option to augment rater-assessed errors with objective measures using a portable device. Although these apps are touted as being more affordable and portable than force plates, findings regarding reliability and validity are mixed.

Inertial sensors have been shown to augment subjective balance measures, such as error counts using the BESS, with inertial sensor improved psychometric value and sensitivity to detect differences between concussed and non-concussed individuals compared to error counts alone. However, no large studies of balance performance using mobile inertial sensor measurement systems in collegiate athletes exists.

The purpose of this study was to examine the relationships between metrics of balance performance using different measurement systems in uninjured, healthy collegiate athletes. It was hypothesized that there would be significant positive, within-person correlations between ellipsoid volumes, as measured with inertial sensors, and error counts on the BESS when these measurements were collected concurrently. It was further hypothesized that significant positive, within-person correlations between ellipsoid volumes, as measured with inertial sensors, and Sway Index scores, as measured using a force plate system when the measurements were collected on the same day, but not concurrently.

METHODS

PARTICIPANTS

Collegiate athletes 17-25 years of age were recruited from a northeastern US university during standard pre-participation physicals that took place during entry into the athletic program (2013 – 2016). All uninjured members of the university’s 22 NCAA Division I athletic teams who received medical clearance for athletic participation were invited to participate. Participation was voluntary and written informed consent was obtained from 705 athletes. Of those, balance data were obtained from 534 (19.4 +/- 1.2 years at time of consent; 47% female). This study was approved by the university’s institutional review board.
Comparison of Concurrent and Same-Day Balance Measurement Approaches in a Large Sample of Uninjured Collegiate Athletes

Table 1. Participant demographics by team

<table>
<thead>
<tr>
<th>SPORT</th>
<th>Total sample (n)</th>
<th>Same day sample (n)</th>
<th>Agea Mean (SD), years</th>
<th>Heighta Mean (SD), inches</th>
<th>Weighta Mean (SD), pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men’s teamsb</td>
<td>283</td>
<td>98</td>
<td>18.4 (1.0)</td>
<td>72.0 (3.0)</td>
<td>194.6 (38.1)</td>
</tr>
<tr>
<td>Baseball</td>
<td>23</td>
<td>14</td>
<td>18.2 (0.7)</td>
<td>71.9 (2.5)</td>
<td>179.7 (19.7)</td>
</tr>
<tr>
<td>Basketball</td>
<td>18</td>
<td>5</td>
<td>19.0 (1.2)</td>
<td>75.8 (4.1)</td>
<td>202.8 (35.0)</td>
</tr>
<tr>
<td>Football</td>
<td>80</td>
<td>25</td>
<td>18.6 (1.0)</td>
<td>73.2 (2.8)</td>
<td>218.4 (42.3)</td>
</tr>
<tr>
<td>Lacrosse</td>
<td>47</td>
<td>16</td>
<td>18.3 (1.0)</td>
<td>71.6 (2.0)</td>
<td>187.2 (23.1)</td>
</tr>
<tr>
<td>Soccer</td>
<td>33</td>
<td>12</td>
<td>18.4 (1.0)</td>
<td>70.3 (2.0)</td>
<td>163.7 (14.1)</td>
</tr>
<tr>
<td>Track</td>
<td>40</td>
<td>14</td>
<td>18.3 (0.8)</td>
<td>71.9 (2.0)</td>
<td>171.9 (20.1)</td>
</tr>
<tr>
<td>Wrestling</td>
<td>39</td>
<td>9</td>
<td>18.5 (1.2)</td>
<td>69.5 (2.4)</td>
<td>186.2 (44.7)</td>
</tr>
<tr>
<td>Women’s teamsb</td>
<td>247</td>
<td>79</td>
<td>18.0 (1.0)</td>
<td>66.3 (3.0)</td>
<td>139.1 (21.0)</td>
</tr>
<tr>
<td>Basketball</td>
<td>18</td>
<td>4</td>
<td>18.2 (0.9)</td>
<td>69.1 (3.7)</td>
<td>159.1 (30.5)</td>
</tr>
<tr>
<td>Crew</td>
<td>14</td>
<td>11</td>
<td>17.9 (0.4)</td>
<td>67.4 (3.2)</td>
<td>146.1 (24.6)</td>
</tr>
<tr>
<td>Field Hockey</td>
<td>25</td>
<td>6</td>
<td>17.8 (0.4)</td>
<td>65.3 (1.4)</td>
<td>132.1 (22.0)</td>
</tr>
<tr>
<td>Gymnastics</td>
<td>16</td>
<td>1</td>
<td>18.3 (3.0)</td>
<td>61.7 (1.8)</td>
<td>125.0 (18.8)</td>
</tr>
<tr>
<td>Lacrosse</td>
<td>35</td>
<td>13</td>
<td>17.8 (0.5)</td>
<td>66.2 (2.5)</td>
<td>140.2 (17.0)</td>
</tr>
<tr>
<td>Soccer</td>
<td>41</td>
<td>10</td>
<td>18.1 (0.8)</td>
<td>65.7 (2.5)</td>
<td>138.6 (16.2)</td>
</tr>
<tr>
<td>Softball</td>
<td>17</td>
<td>6</td>
<td>17.9 (0.8)</td>
<td>67.0 (2.2)</td>
<td>149.4 (17.6)</td>
</tr>
<tr>
<td>Swim/Dive</td>
<td>20</td>
<td>8</td>
<td>17.9 (0.5)</td>
<td>65.9 (2.0)</td>
<td>140.5 (15.0)</td>
</tr>
<tr>
<td>Tennis</td>
<td>4</td>
<td>0</td>
<td>18.5 (1.0)</td>
<td>65.6 (4.2)</td>
<td>124.4 (22.8)</td>
</tr>
<tr>
<td>Track</td>
<td>39</td>
<td>11</td>
<td>18.0 (1.0)</td>
<td>66.6 (2.9)</td>
<td>128.1 (16.5)</td>
</tr>
<tr>
<td>Volleyball</td>
<td>14</td>
<td>5</td>
<td>18.4 (0.8)</td>
<td>70.8 (1.5)</td>
<td>158.3 (16.3)</td>
</tr>
</tbody>
</table>

a Data were obtained from medical chart records from approximately 75% of participants’ pre-participation physicals; b totals by sex; also include teams (golf and cross-country) with only 1-2 participants that are not shown here.

PROCEDURES AND VARIABLES

All postural stability data were collected in the Department of Sports Medicine as part of standard physical exam and health screening assessments. Participants completed one or two balance assessments depending on the year of recruitment and time constraints of the athletes and clinical staff. Of the full sample that was tested using the C3Logix app (n=554), 177 participants from 21 teams were also tested using the Biodex Biosway force plate system on the same day (18.9 +/- 1.0 years at time of consent; 45% female); Biosway data collected on a different day was not used for the present analyses. In all instances where two balance assessments were performed on the same day, BioSway testing was performed before C3Logix. Prior to beginning balance testing, participants were asked to identify their dominant foot (e.g., “push off or power foot”, “the foot you jump off to dunk”, or “3-pt stance foot”). Balance assessments were performed in socks, took less than five minutes per athlete and were administered by medical staff, certified athletic trainers, or trained graduate-level research assistants. All participants received instructions from the test administrator via a common script.

Demographics. Age, sex, height, and weight were obtained from medical charts completed by the Department of Sports Medicine as part of standard pre-participation physical exam. Medical chart review was a separate component of the larger study that examined factors that predicted concussion risk and recovery rates and some charts were unavailable at the time of review. Data from these clinical records were available to the research staff for approximately 75% of participants (216 men, 192 women). Table 1 reports estimates of athletic team demographics based on available data.

C3Logix. C3Logix (NeuroLogix Technologies, Inc., Cleveland, OH) is an iPad-based comprehensive concussion management system that combines standard BESS error counting with inertial sensor (accelerometer and gyroscope) data. Participants were assisted with placing a custom-built belt that securely held the iPad at approximately sacral height, with the screen of the device facing away from the back of the body according to C3Logix instructions. Participants were told to close their eyes and place their hands on their hips. The administrator initiated the test by pressing the button on the C3Logix app screen. Following a countdown, an auditory cue announced the start and end of each of six 20-s conditions that parallel those used by BESS: double leg, single leg, and tandem leg stances, first on a firm surface and then on a standard, six-inch thick Airex foam pad. During each condition, the C3Logix app records all postural movement and calculates ellipsoid volumes while the administrator manually counts the number of er-
errors using standard BESS procedures (hands off of the hips; eyes opened; a step, stumble, or fall; hip flexed or abducted beyond 30°; forefoot or heel lifted off of the testing surface; or out of proper test position for > 5 s) and records it in the app. Larger ellipsoid volumes and more errors indicate a more unsteady posture.

BioSway. BioSway (Biodex Medical Systems, Inc., Shirley, NY) is a portable force plate system. Participants were asked to stand on the device with their hands at their sides, look straight ahead, and remain as motionless as possible during measurement. As necessary, heels were repositioned to ensure feet were equidistant and comfortably placed. The administrator pressed the ‘Collect Data’ button to initiate the countdown and start the protocol. Participants completed four 20-s double leg stance conditions per the standard Modified Clinical Test of Sensory Interaction in Balance (mCTSIB) protocol; eyes open or eyes closed, on a firm surface (BioSway platform) or a foam surface (standard, six-inch thick Airex foam pad placed on the BioSway platform). The device recorded average movement from center, which is termed Stability Index. The standard deviation of Stability Index was used to compute Sway Index. Higher Sway Index is indicative of greater posture instability. The present data are derived from a previously published larger dataset and include only those individuals who were tested with C3Logix and BioSway on the same day.

Comparison of Concurrent and Same-Day Balance Measurement Approaches in a Large Sample of Uninjured Collegiate Athletes

Table 2. C3Logix Sample Averages: Error counts and raw ellipsoid volumes for each BESS condition from 530 uninjured prospective collegiate athletes.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Errors</th>
<th>% with 0 errors</th>
<th>Raw Ellipsoid Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double leg/firm surface</td>
<td>0.0 (0.1)</td>
<td>99</td>
<td>0.01 (0.02)</td>
</tr>
<tr>
<td>Tandem leg/firm surface</td>
<td>1.1 (1.4)</td>
<td>44</td>
<td>0.77 (1.54)</td>
</tr>
<tr>
<td>Single leg/firm surface</td>
<td>2.9 (2.3)</td>
<td>14</td>
<td>4.19 (11.85)</td>
</tr>
<tr>
<td>Double leg/foam surface</td>
<td>0.3 (0.9)</td>
<td>84</td>
<td>0.22 (0.66)</td>
</tr>
<tr>
<td>Tandem leg/foam surface</td>
<td>3.8 (2.5)</td>
<td>8</td>
<td>13.23 (21.34)</td>
</tr>
<tr>
<td>Single leg/foam surface</td>
<td>6.8 (2.3)</td>
<td>&lt;1</td>
<td>22.79 (45.82)</td>
</tr>
</tbody>
</table>

Table 2 presents normative data from the C3Logix app, including average number of errors, percent of participants showing no errors, and raw ellipsoid volumes for each condition. Errors were uncommon in the double leg/firm surface condition (1%). Errors were more common in all other conditions, and 20% of the sample demonstrated maximal error counts (10+) in the single leg/foam surface condition. Substantial individual variability in ellipsoid volumes was noted across all conditions except the double leg/firm surface condition. The wide distribution of ellipsoid volumes calculated by C3Logix is also evident in Figure 1, which shows ellipsoid volumes by error counts for each of the six conditions.

RESULTS

Table 2 presents normative data from the C3Logix app, including average number of errors, percent of participants showing no errors, and raw ellipsoid volumes for each condition. Errors were uncommon in the double leg/firm surface condition (1%). Errors were more common in all other conditions, and 20% of the sample demonstrated maximal error counts (10+) in the single leg/foam surface condition. Substantial individual variability in ellipsoid volumes was noted across all conditions except the double leg/firm surface condition. The wide distribution of ellipsoid volumes calculated by C3Logix is also evident in Figure 1, which shows ellipsoid volumes by error counts for each of the six conditions.

C3Logix: Comparison of Error Counts vs. Ellipsoid Volumes of Motion

Spearman correlation analyses of error counts and log-transformed ellipsoid volumes, collected concurrently with C3Logix, revealed significant correlations in the tandem leg/firm surface, rs (526) = .68, p < 0.0001, and single leg/firm surface rs (526) = .58, p < 0.0001, conditions, but not in the double leg/firm surface condition, rs (526) = -.02, p = 0.7139. Errors and ellipsoid volume were also significantly correlated in all three stances completed on the foam.
Comparison of Concurrent and Same-Day Balance Measurement Approaches in a Large Sample of Uninjured Collegiate Athletes

Data from the subset of the sample who completed the C3Logix and BioSway protocols on the same day were then analyzed to determine whether the two technologies provide similar rankings of postural stability. Spearman correlation analyses of log-transformed ellipsoid volumes (C3Logix) and Sway Index scores (BioSway) revealed significant correlation in the double leg/firm surface condition, $r_S (175) = .27, p = 0.0003$, and the double leg/foam surface condition, $r_S (175) = .22, p = 0.0032$. Although statistically significant, the relationship of the two same-day balance measurements showed substantial variability. Therefore, to visualize the nature of these correlations, Figure 4 presents data from the foam surface condition after normalization with z-score transformations. In Figure 4, each participant’s Sway Index (black circles), which were measured first, were ranked and plotted in ascending order on the x-axis. Ellipsoid volume z-scores (gray crosses) were plotted to align vertically with the Sway Index z-scores (i.e., ellipsoid volumes were plotted in order of Sway Index z-scores). Several outliers are evident among the Sway Index z-scores, but removal of these values did not substantively change the correlation results.

DISCUSSION

The present study assessed postural stability in a large sample of uninjured collegiate athletes using different measurement systems. Statistically significant correlations were observed but many of the correlation coefficients were modest ($r_S < .30$) and varied by condition and across modalities. Graphical illustration of individual data offer insights into how and why this may be the case.

C3LOGIX: COMPARISON OF ERROR COUNTS VS. ELLIPSOID VOLUMES OF MOTION

This is the first large dataset available in uninjured collegiate athletes from which the nature of an inertial sensor-based balance measurement and its relation to rater-assessed BESS error counts can be considered. These data may be valuable as a normative dataset for C3Logix balance assessments in collegiate athletes. However, Figure 1 reveals that the use of normative averages for ellipsoid volume as proxy measures of baseline performance may be problematic due to the large sample variance, which was evident across nearly all error count levels in the tandem and single leg conditions. This is paralleled by large sample variance in error counts which ranged from none to maximal for the three more difficult stances. Furthermore, in many conditions, the relationship between errors and average ellipsoid volumes appears non-linear across the range of error counts. For example, in the tandem leg/foam surface condition (Figure 1), average ellipsoid volumes do not substantively vary across four to nine errors. Thus, in a sample of age-restricted, young, fit, and uninjured adults, there is substantial baseline heterogeneity on both measures of postural stability. Although there were no a priori hypotheses about sex differences or sport differences, graphs were created to visually assess patterns by sex (Figure 2) or specific teams (Figure 3); none were evident. It may therefore be speculated that the non-linear relationship between measures may reflect subtle differences in balance strategies or adjustments used among individuals.19

Rank order of individual ellipsoid volumes and errors from C3Logix were significantly positively correlated, particularly during the moderately difficult, firm surface conditions; this is in line with Simon et al. 31 These correlations were hypothesized because both measurement modalities...
exhibit construct validity for postural stability and because an acute postural adjustment, such as a step, stumble, or fall, would count as an error and simultaneously increase ellipsoid volume. However, even the strongest correlation, observed in the tandem leg/firm surface condition ($r_s = .68$), was lower than would be expected when assessing the same construct concurrently, especially considering the age and health of this sample. This further supports that individuals utilize different strategies to maintain postural stability and that objective measures may provide more insight into these patterns than subjective observations.

In the double leg conditions, which are considered easier, a "floor" effect in error counts and ellipsoid volumes is clear. This effect has been shown to negatively impact reliability of the BESS, particularly during the double leg conditions, but does not have the same impact on C3Logix reliability. While floor effects are less than ideal from a statistical perspective due to their restriction of sample variance, they may be clinically useful. Based on the results of this study, a clinician should reasonably expect that during the double leg stances, an athlete or young adult would show no errors and have very small ellipsoid volumes if they are uninjured; any deviation from this "floor" may indicate clinically relevant alterations in postural stability. This aligns with a recent study that reported greater ellipsoid volumes in athletes after concussion compared to pre-injury, but only in the double leg/firm surface condition.

The C3Logix app provides potential advantages for concussion diagnosis and recovery beyond clinician-rated BESS error counts, including precise quantification less prone to interrater variability and long-term data storage, without the need to add additional balance protocols to concussion assessment batteries. This may be especially notable if ellipsoid volume is sensitive enough to detect clinically relevant disturbances in postural stability using only the double leg, firm surface condition. Securing an iPad around the waist adds very little burden to the clinician and patient within a controlled environment; however, the utility of an iPad during sideline testing should be assessed. Special considerations including testing surface (i.e., turf or court), shoe type (i.e., cleats, barefoot, or sneakers), personal padding or equipment, and the clinician-patient burden of securing the iPad quickly and effectively during a high stress and time sensitive situation remain to be investigated.

**C3Logix vs Biosway: Comparison of Ellipsoid Volumes and SWAY INDEX**

This study also assessed postural stability measured with two objective balance measurement systems (C3Logix and BioSway) at different time points on the same day. Although statistically significant, the magnitude of the correlations ($r_s$’s < .30) was surprisingly low. Previous studies have supported the validity of inertial sensors for postural stability assessments, but agreement may be dependent on the parameters measured and sensor location on the body. The weak correlations in the current study appear to be partially due to differences in calculated parameters between the devices as opposed to sensor location (i.e., sacral placement of iPad vs. underfoot center of pressure from force plate). For example, the C3Logix app, placed at the sacrum, computes ellipsoid volume using the acceleration of the center of mass along anterior-posterior, mediolateral, and trunk rotational planes of motion. Thus, ellipsoid volume considers the rate of change in position and speed over time. Contrary to the weak correlations between C3Logix and the BioSway force plate in the current study, the VSR Sport force plate sway velocity (NeuroCom, Clacka-
mas, OR) demonstrated strong correlations with C3Logix ellipsoid volume. Similar to the accelerations captured by ellipsoid volume, sway velocity measures changes in position over time. The BioSway, however, computes Sway Index by taking the standard deviation of the person’s average position relative to center, but does not consider rate of change over time. It is reasonable to suggest that this may partly explain the strong correlations shown by Miyashita et al. and the weak correlations shown in the current study. Further, the differences in results may be due to concurrent assessment in a small, single sport sample versus non-concurrent assessment analyzed in the current, large, multi-sport sample.

LIMITATIONS AND FUTURE DIRECTIONS

Despite the strengths of this study, including the use of a large and multi-sport sample assessed on three balance modalities, there are several limitations. The current study was a component of a larger study designed to prospectively track concussion; therefore, the balance protocols were not designed to provide concurrent assessment of C3Logix and BioSway, nor were tester reliability indices assessed. Data are from Division 1 athletes from a single university and while including athletes from 22 sports, results may not be generalizable to all collegiate athletes. Graphs were created to allow visual inspection of whether correlations may have systematically varied by sex or sport, but none were observed. Corresponding statistical analyses of sex and sport differences were not performed due to a lack of a priori hypotheses and, in the case of sport, insufficient power. Future studies that are designed and powered to assess such correlational patterns are thus still needed. Subsequent psychometric testing should be performed to comprehensively characterize the relationship between balance measurement approaches. In addition, future research should weigh parameter sensitivity for detecting postural stability deficits against clinician-patient burden to optimize clinical protocols. Such research should further determine the measurement modality that is the most appropriate for real-time sideline concussion assessment.

CONCLUSION

Substantial inter-individual variability in postural stability was observed in this sample of young, uninjured athletes, regardless of the assessment method used. The lower-than-expected correlation coefficients between simultaneous and same-day assessments of balance raise questions about the reliability of normative or individual baseline balance measurements for use in “change from baseline” approaches to injury diagnosis. Postural stability is a complex construct and different measurement systems may be providing unique information about the strategies or postural adjustments that individuals utilize to maintain balance. Further research is needed in order to determine and recommend the most optimal postural stability measurement system and metric for use in concussion sideline assessments, diagnoses, and recovery.

SOURCE OF FUNDING

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CONFLICT OF INTEREST

None of the authors declare a conflict of interest.

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REFERENCES


Musculoskeletal Imaging for Low Back Pain in Direct Access Physical Therapy Compared to Primary Care: An Observational Study

Michael S Crowell¹, John S Mason¹, John H McGinniss¹
¹ Baylor University - Keller Army Community Hospital Division 1 Sports Physical Therapy Fellowship

Keywords: physical therapy direct-access, diagnostic imaging, low back pain

Background
Overutilization of diagnostic imaging is associated with poor outcomes and increased costs. Physical therapists demonstrate the ability to order diagnostic imaging safely and appropriately, and early access to physical therapy reduces unnecessary imaging, lowers healthcare costs, and improves outcomes.

Hypothesis/Purpose
The primary purpose of this study was to compare rates of compliance with the National Committee for Quality Assurance – Healthcare Effectiveness Data and Information Set (HEDIS) recommendations for diagnostic imaging in low back pain between physical therapists and primary care providers in young, athletic patients.

Study Design
Retrospective cohort study.

Methods
Military Health System Data Repository (MDR) data from January 2019 to May 2020 was reviewed for compliance with the low back pain HEDIS recommendation. The low back pain imaging HEDIS measure identifies the percentage of patients who did not have an imaging study (plain X-ray, MRI, CT Scan) ordered on the first encounter with a diagnosis of low back pain or in the 28 days following that first diagnosis. Chi-square tests compared HEDIS compliance rates, with $\alpha = 0.05$ set a priori.

Results
From January 2019 to May 2020, in patients age 18-24, the MDR database identified 1,845 total visits for LBP identified in the Physical Therapy Clinic and 467 total visits for LBP in the Primary Care Clinic. In the Physical Therapy Clinic, 96.7% of encounters did not have imaging ordered within the first 28 days of onset of symptoms, compared with 82.0% in the Primary Care Clinic ($p < .001$).

Conclusions
Utilizing data from a national standardized healthcare performance measure, physical therapists practicing in a direct-access setting were significantly more likely than primary care providers to adhere to guidelines for low back pain imaging in young, athletic patients.
**Level of Evidence**

Level 3.

**INTRODUCTION**

Musculoskeletal (MSK) injuries are a leading cause of work disability in the United States.\(^1\)\(^2\) Over 20.1 million Americans report a disability, with low back pain (LBP) being the primary cause.\(^3\) The prevalence of low back pain in a young, athletic population is 18 to 65% compared to 7 to 53% in the general population.\(^5\) In a deployed military brigade combat team, the prevalence of low back pain was estimated at 21.2%.\(^4\)

Annually, over $600 billion is spent on diagnostic imaging.\(^1\)\(^5\) Overutilization of diagnostic imaging is associated with poor outcomes and increased costs, particularly in the spine, as asymptomatic findings may lead to unnecessary interventions.\(^6\)–\(^11\) Clinical practice guidelines recommend against routinely ordering imaging in patients with low back pain and the National Committee for Quality Assurance (NCQA) Healthcare Effectiveness Data and Information Set (HEDIS) regards any imaging order in a patient with low back pain, in the absence of red flags, within 28 days of symptom onset as unnecessary.\(^10\) In 2018, the mean HEDIS score for low back pain imaging ranged from 72% to 76%, depending on the type of insurance,\(^12\) meaning that approximately 20 to 30% of patients with low back pain have unnecessary imaging ordered early in their course of care. Despite clinical guidelines recommending against routine imaging in low back pain, utilization rates are rising, with imaging ordered in 14% of encounters in 2011 compared to 16% of encounters in 2016.\(^13\)

Early access to evidence-based education and clinician-directed exercise is recommended for patients with acute LBP.\(^8\)\(^10\) Physical therapists practicing in a direct-access setting can provide safe evidence-based LBP management that reduces unnecessary MSK imaging and costs, without elevated risk of harm to patients.\(^14\)\(^15\)

Three recent studies of MSK imaging in physical therapy have demonstrated that physical therapists order diagnostic imaging safely and appropriately. In a five-year retrospective analysis of imaging studies, civilian physical therapists showed appropriate diagnostic imaging use, assessed according to American College of Radiology (ACR) Criteria, in 91% of cases.\(^16\) In a two-year retrospective analysis of advanced imaging (MRI) ordered by military physical therapists, 83% were considered appropriate according to ACR criteria.\(^17\) Importantly, there were no adverse events in over 1,000 imaging studies ordered by military physical therapists.\(^15\)

Early access to physical therapy reduces unnecessary imaging, lowers healthcare costs, and leads to better outcomes.\(^14\)\(^18\) Advanced practice physical therapists are less likely to order radiographs and have lower associated costs than providers working in a similar practice setting.\(^14\)\(^19\)\(^20\)

In one study, physical therapists ordered one diagnostic imaging study for every 37 patient encounters compared to one study for every five encounters ordered by primary care providers.\(^15\) More research is needed to quantify the value of physical therapists practicing in a direct-access or advanced practice role, determine best practices for ordering imaging for various MSK conditions, and develop educational strategies to improve physical therapist practice regarding diagnostic imaging.

The purpose of this study was to compare rates of compliance with HEDIS recommendations for diagnostic imaging in low back pain between physical therapists and primary care providers in young, athletic patients. We hypothesized that HEDIS compliance would be greater for physical therapists than primary care providers. Secondary objectives were: 1. To compare the frequency of imaging orders with abnormal findings, clinically significant abnormal findings, and findings requiring referral to physical medicine, pain management, neurosurgery, or orthopaedic spine surgery between physical therapy and primary care; and 2. To compare practice patterns for the management of low back pain between physical therapists and primary care providers. It was hypothesized that physical therapists would have similar rates of imaging ordered with abnormal findings, higher rates of clinically significant abnormal findings, and higher rates of findings requiring referral to a specialist compared to primary care providers. Additionally, it was hypothesized that physical therapists would demonstrate different practice patterns regarding the time before imaging, number of active physical treatments, and lower utilization of medication than primary care providers in the treatment of acute LBP.

**MATERIALS AND METHODS**

This was a retrospective cohort study conducted at the Keller Army Community Hospital (KACH) Primary Care Clinic and the Arvin Cadet Physical Therapy Clinic at the United States Military Academy (USMA) at West Point. The Arvin Cadet Physical Therapy Clinic is a direct access clinic where USMA Cadets with MSK injuries and/or pain are evaluated and treated. The KACH Primary Care Clinic utilizes physicians, physician assistants, and nurse practitioners to serve active-duty military personnel, faculty, and dependents who work and reside on West Point. All physical therapists and providers held the same clinical privileges regarding the ability to order diagnostic imaging. Physical therapists possess clinical privileges to prescribe a limited number of medications, including non-steroidal anti-inflammatory medications (NSAIDs), non-opioid analgesics, and muscle relaxers. The Regional Health Command – Atlantic Institutional Review Board approved the research design and protocol before data collection.

When searching all databases, the patient age range was restricted to 18 to 24 years of age. This patient age range was selected to allow comparison between the Physical Therapy Clinic and the Primary Care Clinic and to generalize results to young, athletic patients. The Arvin Cadet Physical Therapy Clinic is a direct-access clinic that has primary responsibility for evaluating and treating neuromusculoskeletal injuries for USMA Cadets, most of whom are between the ages of 18 and 24. The KACH Primary Care
Clinic evaluates and treats medical illnesses in all individuals at West Point while evaluating and treating neuromusculoskeletal injuries in non-Cadets.

The Defense Health Agency Data Driven Decisions Portal (D3Portal) was utilized to view data from the Military Health System Data Repository (MDR) that assesses the use of imaging studies for low back pain HEDIS. Data were available from January 2019 to May 2020. The low back pain imaging HEDIS measure identifies the percentage of patients who did not have an imaging study (X-ray, MRI, CT Scan) ordered on the first encounter with a diagnosis of low back pain or in the 28 days following initial diagnosis (Figure 1).12

A higher rate reflects better performance on the HEDIS guideline, which prevents unnecessary harm and reduces costs. While the goal of the HEDIS measure is to avoid early imaging of patients with uncomplicated low back pain, imaging may be indicated in patients with a history of cancer, recent history of trauma, or significant neurologic impairment. For example, if a patient with acute low back pain and a history of cancer or trauma within the past 90 days receives imaging within 28 days of the initial diagnosis, the patient is considered to have an exclusionary diagnosis and the encounter is removed from the HEDIS calculation.

For the in-depth review of the management of patients with low back pain, the IMPAX imaging viewing software program was searched from 14 June 2014 to 14 June 2020 for patients with diagnostic imaging obtained for low back pain. For each patient identified, the Armed Forces Health Longitudinal Technology Application (AHLTA) electronic medical records (EMR) were independently reviewed by the principal and co-investigator physical therapists. All reviewing physical therapists held board-certification in orthopaedic or sports physical therapy and were fellowship-trained. Patient documentation and radiology exams were extracted, de-identified, and assessed. Demographic data included patient age and sex, duration of symptoms, and location of symptoms. If a provider’s note did not explicitly state the duration of symptoms in days/weeks/months, a period of seven days was input for acute symptoms, 30 days for subacute symptoms, and 90 days for chronic symptoms. Variables of interest included: (1) number of visits, (2) amount of time from initial physical therapy evaluation to imaging order, (3) types of interventions and medications utilized, (4) abnormal findings on diagnostic imaging, (5) clinical significance of abnormal findings. Abnormal findings were defined as any abnormality that was noted in the radiologist’s report. An abnormal finding was considered clinically significant when it altered the plan of care or affected prognosis. Abnormal findings that were considered not clinically significant included mild degenerative changes, findings due to body position, transitional anatomy, or anatomical variants. Clinically significant abnormal findings included moderate degenerative changes, disc protrusions and extrusions, and spondylolisthesis, among others (see Supplemental File Appendix A and Appendix B for full list of abnormal findings). After completion of the case reviews, the three physical therapists met to review each case individually and consensus by discussion was utilized to resolve any differences in the review of radiographic findings.

Statistical analyses were performed in SPSS version 24.0 (IBM Corp), with α = 0.05 set a priori for all analyses. Descriptive statistics were calculated for demographics, the number of imaging orders with abnormal findings, clinically significant abnormal findings, findings requiring subspecialist referral (physical medicine, pain management, neurosurgery, or orthopaedic spine surgery), and the interventions utilized by physical therapists and primary care providers. To compare physical therapists and primary care providers, Chi-square tests were used for categorical variables and t-tests were planned for all continuous variables. Prior to statistical analysis, all data were tested for parametric assumptions. A Mann-Whitney U test was used for duration of symptoms, time to imaging, and visits to imaging due to a non-normal distribution of data.

RESULTS

From January 2019 to May 2020 in patients aged 18 to 24, the MDR database identified 1,845 total visits for LBP identified in the Physical Therapy Clinic and 467 total visits for LBP in the Primary Care Clinic. Total visits encompass only initial and re-evaluations; physical therapy treatment appointments are not included. The comparison of HEDIS compliance for low back pain imaging are shown in Table 1.

In the Physical Therapy Clinic, 96.7% of encounters did not have imaging ordered within the first 28 days of onset of symptoms, compared with 82.0% in the Primary Care Clinic (Chi-Square 136.64, p < .001). Of the 24 physical therapists, 16 were board-certified (6 dual-certified in orthopaedic and sports physical therapy, nine board-certified in orthopaedic physical therapy, one board-certified in sports physical therapy). Of the 24 primary care providers, there were four nurse practitioners, five physician’s assistants, 10 physicians board-certified in family practice, two physicians board-certified in internal medicine, one physician board-certified in pediatrics, one physician board-certified in obstetrics and gynecology, and one general practitioner.

From 14 June 2014 to 14 June 2020 in patients aged 18 to 24 years, the IMPAX imaging viewing software program identified 94 cases of imaging for low back pain ordered by physical therapists and 106 cases of imaging for low back pain ordered by primary care providers. Two cases ordered by physical therapists and 56 cases ordered by primary care providers were excluded, resulting in 92 physical therapy and 50 primary care cases (Figure 2).

Of the 56 cases excluded from primary care, 20 were initially seen by a physical therapist before the primary care provider ordered imaging (six with clinically significant ra-
Table 1. Comparison of HEDIS compliance between Physical Therapy and Primary Care Providers for the Period of January 2019 – May 2020 for patients age 18-24 years.

<table>
<thead>
<tr>
<th></th>
<th>HEDIS LBP Compliant (% of total)</th>
<th>HEDIS LBP Noncompliant (% of total)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Therapy</td>
<td>1784 (96.7%)</td>
<td>61 (3.3%)</td>
<td>1845</td>
</tr>
<tr>
<td>Primary Care</td>
<td>383 (82.0%)</td>
<td>84 (18.0%)</td>
<td>467</td>
</tr>
</tbody>
</table>

p < 0.001, Chi-Square = 136.64.

Table 2. Demographics for Patients with Lumbar Spine Imaging Orders from 2014 to 2020.

<table>
<thead>
<tr>
<th></th>
<th>Physical Therapy</th>
<th>Primary Care</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>Mean (SD)</td>
<td>% (n)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Sex (Female)</td>
<td>20.3 (1.3)</td>
<td>41% (38)</td>
<td>20.7 (1.9)</td>
</tr>
<tr>
<td>Painful Body Regions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Lumbar</td>
<td>72/92 (78%)</td>
<td>44/50 (88%)</td>
<td>.152</td>
</tr>
<tr>
<td>- Hip/Thigh</td>
<td>32/92 (35%)</td>
<td>10/50 (20%)</td>
<td></td>
</tr>
<tr>
<td>- Below Knee</td>
<td>20/92 (24%)</td>
<td>8/50 (16%)</td>
<td>.412</td>
</tr>
<tr>
<td>- Coccyx</td>
<td>10/92 (21%)</td>
<td>3/50 (6%)</td>
<td>.337</td>
</tr>
<tr>
<td>Duration of Symptoms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Acute</td>
<td>104.8 (226.2)</td>
<td>212.5 (417.8)</td>
<td>.088</td>
</tr>
<tr>
<td>- Subacute</td>
<td>32/92 (35%)</td>
<td>20/50 (40%)</td>
<td>.538</td>
</tr>
<tr>
<td>- Chronic</td>
<td>19/92 (21%)</td>
<td>4/50 (8%)</td>
<td>.051</td>
</tr>
<tr>
<td>- Acute on Chronic</td>
<td>29/92 (32%)</td>
<td>26/50 (52%)</td>
<td>.017</td>
</tr>
<tr>
<td></td>
<td>8/92 (9%)</td>
<td>0/0%</td>
<td></td>
</tr>
</tbody>
</table>

There were no significant differences in any demographics of interest between the patients evaluated in the Physical Therapy or Primary Care Clinics. Patients were young (mean age 20.3 +/- 1.3 years) and the majority were male (59%). Acute low back pain was most frequently encountered at 35% of cases, while chronic low back pain comprised 32% of cases. The mean duration of symptoms was 104.8 (226.2) days in patients presenting to the Physical Therapy clinic and 212.5 (417.8) days in patients presenting to the Primary Care Clinic.

The results of diagnostic imaging orders placed by physical therapists are shown in Table 3. Most radiographs ordered were normal.

In Physical Therapy, 55% of radiographs ordered were normal, while 51% of radiographs ordered in Primary Care were normal (p=.673). Conversely, most MRI exams ordered were abnormal. In Physical Therapy, 86% of MRI exams ordered had abnormal findings in the radiology report while 58% of MRI exams ordered by Primary Care had abnormal findings (p=.050). Disc protrusion was the most frequent abnormal finding (38% Physical Therapy, 42% Primary Care). There were no significant differences in clinically significant findings (31% Physical Therapy, 20% Primary Care, p=.180) or orders which lead to a specialist referral (31% Physical Therapy, 16% Primary Care, p=.059) between the Physical Therapy and Primary Care Clinics.

The summary of practice patterns is shown in Table 4. There were statistically significant differences in the mean time from initial evaluation to first diagnostic imaging order (26.4 Physical Therapy, 7.6 Primary Care, p<.001) and the mean number of visits from the initial evaluation to the first imaging order (3.8 Physical Therapy, 1.1 Primary Care, p<.001). Physical therapists primarily utilized therapeutic exercise (86%) and manual therapy (54%) in the care of patients with low back pain. Primary care providers primarily referred patients to Physical Therapy (56%) or ordered nonsteroidal anti-inflammatory medications (NSAIDs) (50%). Primary care providers were more likely to prescribe NSAIDs (19% Physical Therapy, 50% Primary Care, p<.001) and muscle relaxers (4% Physical Therapy, 18% Primary Care, p<.007) than physical therapists.

DISCUSSION
The primary purpose of this study was to compare rates of compliance with HEDIS diagnostic imaging measures in low back pain between physical therapists and primary care.
Table 3. Results of Diagnostic Imaging Orders.

<table>
<thead>
<tr>
<th>Abnormal Radiographic Findings</th>
<th>Physical Therapy</th>
<th>Primary Care</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Spondylolysis</td>
<td>41/91 (45%)</td>
<td>22/45 (49%)</td>
<td>.673</td>
</tr>
<tr>
<td>- Other</td>
<td>4/91 (4%)</td>
<td>2/45 (4%)</td>
<td>.990</td>
</tr>
<tr>
<td>Abnormal MRI Findings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- DDD</td>
<td>25/29 (86%)</td>
<td>7/12 (58%)</td>
<td>.050</td>
</tr>
<tr>
<td>- Disc Protrusion</td>
<td>8/29 (28%)</td>
<td>1/12 (8%)</td>
<td>.175</td>
</tr>
<tr>
<td>- Disc Extrusion</td>
<td>11/29 (38%)</td>
<td>5/12 (42%)</td>
<td>.823</td>
</tr>
<tr>
<td>- Other</td>
<td>5/29 (17%)</td>
<td>0/12 (0%)</td>
<td>.125</td>
</tr>
<tr>
<td>Clinically Significant Findings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- All orders</td>
<td>28/92 (31%)</td>
<td>10/50 (20%)</td>
<td>.180</td>
</tr>
<tr>
<td>- Significant radiographs</td>
<td>10/91 (11%)</td>
<td>3/45 (7%)</td>
<td>.420</td>
</tr>
<tr>
<td>- Significant MRI exams</td>
<td>21/29 (72%)</td>
<td>7/12 (58%)</td>
<td>.378</td>
</tr>
</tbody>
</table>

Received a Specialist Referral

<table>
<thead>
<tr>
<th>Physical Therapy</th>
<th>Primary Care</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>28/92 (31%)</td>
<td>8/50 (16%)</td>
<td>.059</td>
</tr>
</tbody>
</table>

Abbreviations: DDD, degenerative disc disease; MRI, magnetic resonance imaging.

Figure 2. Flow diagram of included and excluded cases.

providers in young, athletic patients. Secondary aims were to describe the number of imaging orders with abnormal findings, clinically significant abnormal findings, and findings requiring referral to physical medicine, pain management, neurosurgery, or orthopaedic spine surgery as well as to describe low back pain management and diagnostic imaging utilization by physical therapists and primary care providers. Physical therapists were significantly less likely than primary care providers to order diagnostic imaging within the first 28 days of a diagnosis of low back pain. While physical therapists and primary care providers demonstrated different practice patterns, there were similar rates of abnormal imaging findings, clinically significant findings, and findings that required referral to another medical specialty. To our knowledge, this is the first study to directly compare the performance of physical therapists in a direct-access setting with primary care providers, using a national standardized healthcare performance measure.

Routine imaging for low back pain is not associated with improved outcomes and exposes patients to potential harm in the form of radiation, unnecessary treatment, and increased cost. From 2005 to 2019, data available from the NCQA database that includes all patients aged 18 to 50 years demonstrated HEDIS compliance rates ranging from 73.1% to 78.1% for commercial health maintenance organizations (HMO), 72.1% to 76.2% for preferred provider organizations (PPO), and 71.7% to 79% for Medicaid HMOs. In the age-restricted sample, approximately 96.7% of low back
pain encounters by physical therapists did not have imaging ordered within the first 28 days of onset of symptoms, compared with 82.0% by primary care providers. In this study, we restricted the range of available encounters to patients aged 18 to 24 to allow for a consistent comparison between the physical therapist and primary care provider groups, which may account for differing rates of HEDIS compliance between this sample and NCQA data.

There were significant differences between physical therapists and primary care providers managing patients with low back pain. Physical therapists waited for a significantly longer duration of time and number of visits prior to the initial diagnostic imaging order. While the difference in visits prior to an imaging order may simply reflect greater access to physical therapists, the length of time prior to an imaging order would be longer with primary care providers if the difference was attributed solely to access to the provider.

Physical therapists were more likely to utilize therapeutic exercise and manual therapy, while primary care providers were more likely to prescribe NSAIDs or muscle relaxers. In a review of studies assessing guideline compliance in low back pain management, physiotherapists prescribed exercise in 89% of cases and utilized spinal manipulation in 30% of cases, similar to the findings of this study. In the same review, physicians referred patients to physical therapy in 66% of cases, prescribed NSAIDs in 87-93% of cases, and prescribed muscle relaxants in 67-83% of cases. The rates of prescriptions for NSAIDs and muscle relaxers were lower in this study, possibly due to a younger patient sample.

While not statistically significant, the duration of symptoms for patients with low back pain evaluated by physical therapists was half of the duration for patients evaluated by primary care providers (105 versus 216 days). Some may contend that this difference justifies primary care providers to order diagnostic imaging. However, the HEDIS standards do not exclude patients initially evaluated for chronic low back pain and ACR criteria for low back pain does not recommend early imaging for acute or chronic low back pain unless there are red flags or persistent pain following six weeks of optimal medical management. Additionally, the similar distribution of painful body regions (i.e. presence of pain below the knee) and abnormal imaging findings implies that management of both groups of patients needs to follow established guidelines.

Physical therapist imaging privileges have been historically controversial. While several states have recently granted physical therapists direct access privileges, most states have not explicitly authorized imaging privileges. In this study, physical therapists practicing in a direct-access setting were significantly more likely than primary care providers to adhere to national quality of care guidelines for imaging in low back pain. These results are consistent with previous reports of appropriateness and safety in the utilization of imaging and provide additional support for physical therapists receiving imaging privileges. Widespread adoption of imaging privileges for physical therapists will ultimately enhance capabilities as a first-line provider to manage low back pain in a direct-access setting. Additional research is needed to demonstrate the impact these privileges will have on healthcare outcomes, safety, costs, and imaging utilization in other body regions.

Despite a query of radiology orders for greater than a five-year period, there were relatively few imaging orders for young patients with low back pain. While there appears to be a clinically meaningful difference in the proportion of abnormal MRI findings (86% in physical therapy vs 38% in primary care) and those who received a specialist referral (31% in physical therapy vs 16% in primary care), these results were not statistically significant and post hoc power for those two analyses were 0.50 and 0.49, respectively. Larger samples are needed to determine if there are significant differences in the results of imaging ordered by physical therapists and primary care providers and the potential effects any differences may have on overall healthcare costs.

There are several limitations to this study. The sample

### Table 4. Timelines and Patterns of Care for Physical Therapists and Primary Care Providers.

<table>
<thead>
<tr>
<th>Interventions Utilized</th>
<th>Physical Therapy</th>
<th>Primary Care</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time from Initial Evaluation to Imaging (days)</td>
<td>26.4 (36.7)</td>
<td>7.6 (25.2)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Visits from Initial Evaluation to Imaging</td>
<td>3.8 (3.4)</td>
<td>1.1 (0.6)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Medications Ordered</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- NSAIDS</td>
<td>18/93 (19%)</td>
<td>25/50 (50%)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>- Acetaminophen</td>
<td>0/93 (0%)</td>
<td>5/50 (10%)</td>
<td>--</td>
</tr>
<tr>
<td>- Oral Steroid</td>
<td>0/93 (0%)</td>
<td>3/50 (6%)</td>
<td>--</td>
</tr>
<tr>
<td>- Muscle Reliever</td>
<td>4/93 (4%)</td>
<td>9/50 (18%)</td>
<td>.007</td>
</tr>
</tbody>
</table>

Abbreviation: NSAIDS, Non-steroidal Anti-inflammatory Drugs.
comprises young, physically active individuals at a single military medical facility, which may limit generalizability to other populations and age groups. Three board-certified physical therapists reviewed imaging orders and extracted results from the official radiologist’s report, which is a potential source of bias for the observational results. The HEDIS system uses visits to establish the denominator; this may skew the metric because physical therapists usually follow-up with their patients more often. Additionally, the evaluation of HEDIS and extraction of imaging information occurred with two separate data sources, although data were taken from the same time periods. As this was a retrospective review, data quality is a limitation. While the encounter documentation was thoroughly searched, providers may have made verbal recommendations to the patient that are not reflected in the electronic medical record.

CONCLUSION

Using data from a national standardized healthcare performance measure, military physical therapists practicing in a direct-access setting were significantly less likely than primary care providers to order diagnostic imaging within the first 28 days of a diagnosis of low back pain in young, athletic patients. Physical therapists and primary care providers have different practice patterns for patients with low back pain, with physical therapists primarily utilizing therapeutic exercise, while primary care providers primarily prescribe medications. Future research should attempt to replicate these findings in large civilian healthcare systems and examine outcomes in patients with low back pain managed by various primary care providers. Examining larger data sets available through electronic medical record systems may also more clearly demonstrate differences in practice between physical therapists in a direct-access setting and primary care providers.

DISCLOSURE/DISCLAIMER

The authors have no relevant or material financial interests that relate to this study. The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or reflecting the views of the United States Army or Department of Defense.

ETHICS APPROVAL

Study was approved by the U.S. Army Regional Health Command – Atlantic Institutional Review Board.

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REFERENCES


SUPPLEMENTARY MATERIALS

Appendix A

Appendix B
Original Research

Effectiveness of a Shoulder Exercise Program in Division I Collegiate Baseball Players During the Fall Season

Hillary A. Plummer, PhD, ATC1, Shannon M. Plosser, DPT, ATC2, Paul R. Diaz, MS, ATC3, Nicholas J. Lobb, MS3, Lori A. Michener, PhD, PT, ATC, FAPTA3

1 U.S. Army Aeromedical Research Laboratory; Oak Ridge Institute for Science & Education; University of Southern California, 2 University of Southern California, 3 Division of Biokinesiology and Physical Therapy, University of Southern California

Keywords: shoulder, pitching, injury prevention, evaluation

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Background
Deficits in shoulder range of motion (ROM) and strength are associated with risk of arm injury in baseball players.

Purpose
The purpose of this study was to assess the effectiveness of a standardized exercise program, during the fall season, on shoulder ROM and rotational strength in collegiate baseball players.

Study Design
Prospective cohort study

Methods
Passive shoulder internal rotation (IR), external rotation (ER), and horizontal adduction ROM were measured with an inclinometer. Shoulder IR and ER strength was assessed using a hand-held dynamometer and normalized to body weight. Players performed a program of shoulder stretching and strengthening exercises, three times/week for one month and then one time/week for two months. Paired sample t-tests compared pre-intervention to post-intervention outcome measures.

Results
Division I baseball players (n=43; 19.6±1.2years, 185.8±5.5cm, 90.5±7.0kg) volunteered. From pre- to post-intervention, there were increases in horizontal adduction ROM in the throwing (Mean Difference (MD)=6.1°, 95%CI=3.7,8.5; p<0.001) and non-throwing arm (MD=8.0°, 95%CI=5.6,10.3; p<0.001), and a decrease in non-throwing arm ER ROM (MD=2.8°, 95%CI= 0.2,5.5; p=0.039). The ER ROM surplus (throwing – non-throwing) increased (MD=5.6°, 95%CI= 1.1,10.2; p=0.016). Throwing arm (MD=1.3%BW, 95%CI=0.5,2.1, p=0.005) and non-throwing arm (MD=1.2%BW, 95%CI=0.4,2.0; p=0.004) ER strength decreased. A notable, but non-significant increase in IR strength on the throwing arm (MD=1.6%BW, 95%CI=0.1,3.0; p=0.055) and decrease on the non-throwing arm (MD=1.2%BW, 95%CI=0.0,2.4; p=0.055) occurred. Additionally, throwing arm ER:IR strength ratio (MD=0.16, 95%CI=0.08,0.25; p=0.001) also decreased.

Conclusion
Changes in shoulder horizontal adduction ROM, IR strength and relative ER surplus on the throwing arm were noted at the end of the season. The lack of change in IR and ER ROM and may be related to the lack of deficits at the start of the fall season.

Corresponding author:
Hillary A. Plummer, PhD, ATC
Oak Ridge Institute for Science & Education, Oak Ridge, TN, USA
hplummer47@gmail.com
Effectiveness of a Shoulder Exercise Program in Division I Collegiate Baseball Players During the Fall Season

Level of Evidence

2.

INTRODUCTION

Upper extremity injuries impact player health and well-being, and can result in time-loss. The shoulder (21.2%) and elbow (15.5%) are injured most frequently in college baseball players.1 Strength and range of motion (ROM) deficits have been shown to be related to injury risk and performance.2–4 There is limited evidence that structured intervention programs can change modifiable risk factors such as strength and ROM, and the relationship to injury reduction.

Many baseball players have altered shoulder ROM related to humeral retrotorsion and posterior shoulder tissue tightness.5–11 While humeral retrotorsion is not modifiable, posterior shoulder tightness that restricts shoulder internal rotation and horizontal adduction ROM can be improved with stretching interventions.12–20 Specifically, cross-body stretching and the sleeper stretch have been shown to improve shoulder ROM.12–20 Changes in shoulder ROM and strength can occur over the baseball season related to baseball activities.21–24 Strengthening interventions may mitigate this decrease in shoulder strength,12 shoulder endurance,26 and throwing velocity25,27–29 in baseball players.

Interventions that target deficits in shoulder ROM and strength may help to reduce injury rates in baseball players. Although some studies indicate that prevention programs may reduce the incidence of injuries,30 the research is conflicting in overhead athletes.31 Shitara et al.32 found that high school baseball pitchers who performed daily posterior shoulder stretching had a lower incidence of upper extremity injury than pitchers who did not perform stretching or strengthening. Pitchers who performed both stretching and external rotation strengthening exercises had similar injury incidence as those who only performed stretching. Youth baseball players performing stretching, dynamic mobility, and balance training had a lower incidence of shoulder and elbow injury in a year than players who did not perform the intervention.33 Shoulder horizontal adduction deficits on the non-dominant side also improved with the intervention.

Characterizing the effects of an exercise program on modifiable shoulder-related risk factors in collegiate baseball players is needed. Programs that target deficits in shoulder ROM and strength may lead to a reduction in injuries. The purpose of this study was to assess the effectiveness of a standardized exercise program, during the fall season, on shoulder ROM and rotational strength in collegiate baseball players. It was hypothesized that a standardized exercise program performed over the course of the fall season, would lead to improvements in shoulder ROM and strength.

METHODS

PARTICIPANTS

This study was approved by the Institutional Review Board at the University of Southern California. Prior to participation, the procedures, risks, and benefits were explained, and written informed consent was obtained. Data were collected prospectively on Division I collegiate baseball players from a single team however not all of the participants completed every test. Data were collected pre-intervention (August 28, 2017) and post-intervention (November 27, 2017) of the fall season. The fall season, while short, allowed confounding factors of certain players playing more games than others leading to the potential vast differences in player workload that would be present in the spring season to be minimized. Only two competitive baseball games were played during the time of the intervention. Participants were included if they were free from injury at the beginning of the fall season, and on the team roster for the full fall season. Exclusion criteria included not cleared to participate in baseball activities. Data for the players who were not on the team for the full fall season were excluded from the analysis.

An a priori power analysis was conducted using G*Power3 to test the difference between two dependent means using a two-tailed test, an alpha of 0.05, and a power of 0.8. An effect size of 0.46 was calculated from previously reported data on the mean difference (4.7°) and standard deviation (10.2°) of glenohumeral internal rotation deficit (pitching arm IR - non-pitching arm IR; GIRD) between injured and non-injured youth pitchers.3 It was estimated that a sample size of 39 participants would be needed.

EXERCISE PROGRAM

Participants performed structured training three times a week from August 29, 2017 to October 3, 2017 under the supervision of a certified strength and conditioning specialist. From October 3, 2017 to November 26, 2017 training was only performed once a week. A comprehensive list of the exercises in the structured training program can be found in Appendix A. Participants performed three to five sets of 5–15 repetitions of the exercises with a load at 70-80% of their 1-repetition maximum. One-repetition maximum was determined by first estimating a near-maximal load that each athlete could perform two to three repetitions. After a two to three minute break, weight was increased 5-10% for upper body exercises and 10-20% for lower body exercises. This process was repeated until the maximal load that an athlete could lift one time was obtained.

PROCEDURES

A health history form was completed by each participant to assess demographics, injury and surgical history. Shoulder passive ROM and strength were assessed bilaterally.

SHOULDER ROM

Passive internal rotation (IR), external rotation (ER), and horizontal adduction (HAdd) were measured with a digital inclinometer (Figure 1). The measures were assessed with the participant supine and the shoulder positioned in 90° of abduction and the elbow flexed 90°. For IR and ER, the in-
Clinometer was placed parallel to the forearm. An examiner placed their hand on the anterior-superior scapula, monitoring scapular position and applying slight overpressure at the end range of each motion. Shoulder HAdd ROM at 90° of shoulder flexion and the elbow in a relaxed flexed position. An examiner stabilized the lateral border of the scapula and the humerus was moved into horizontal adduction until the lateral border of the scapula moved against the examiner's hand. The inclinometer was aligned parallel to the humerus. Two trials were performed bilaterally for each measure. Data for the two trials were then averaged for analysis. Total ROM (ER + IR), glenohumeral internal rotation deficit (pitching arm IR - non-pitching arm IR; GIRD), and external rotation surplus on the pitching arm (pitching arm ER - non-pitching arm ER; ERS) were calculated from the measured ER and IR values. Interclass correlation coefficient (ICC), standard error of the measure (SEM), and minimal detectable change (MDC90%) were calculated prior to the start of the study to determine test-retest reliability. Test-retest reliability was established on 10 individuals prior to beginning testing. Shoulder IR ROM had an ICC (3,2) of 0.91, SEM of 3.4°, and MDC90% of 1.4°; ER ROM had an ICC (3,2) of 0.98, SEM of 0.7°, MDC90% of 1.6°, ERS had an ICC (3,2) of 0.96, SEM of 2.1°, and MDC90% of 5.0°; and GIRD had an ICC (3,2) of 0.95, SEM of 2.2°, and MDC90% of 5.2°.

SHOULDER STRENGTH

Shoulder IR and ER strength were both measured with the participant seated. The arm being tested was positioned by the side, and the elbow flexed to 90° (Figure 2). A rolled towel was placed between the trunk and the humerus to standardize the positioning and ensure the elbow remained by the side during testing. A handheld dynamometer (Hoggan Scientific, Lafayette, IN) was attached to a specialized stabilizing device and aligned forearm just proximal to the wrist. Two maximal effort isometric contractions with the instructions to 'push as hard as possible for 5 seconds' were performed bilaterally. One minute of rest was allotted between each trial. The mean of the two trials was calculated for data analysis and strength values were normalized to body weight. Test-retest reliability for shoulder isometric strength was established prior to data collection. Test-retest reliability for shoulder IR strength indicated an ICC (3,2) of 0.96, SEM of 0.09N/kg, and MDC90% of 0.20N/kg; and for shoulder ER strength ICC (3,2) of 0.95, SEM of 0.08N/kg, and MDC90% of 0.18N/kg. For ER:IR, the ICC (3,2) was 0.97, the SEM was 0.05N/kg and for the MDC90% of 0.11N/kg.

STATISTICAL ANALYSIS

Each dependent variable was averaged across two trials collected for both the pre-intervention and post-intervention data collections. Mean values for each dependent variable were submitted to paired samples t-tests to determine changes in shoulder ROM and strength following the in-season exercise program. Statistical significance was set a priori at p < 0.05 and all analyses were performed using RStudio (RStudio Team (2020). RStudio: Integrated Development Environment for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/). Responders were defined as any participant whose values for a measure exceeded the MDC.

RESULTS

Data were collected on 43 baseball players (n = 43, age = 19.6 years, height = 1.86 m, weight = 90.3 kg). One participant was lost to follow-up.
Table 1. Demographics, mean (SD) unless noted N for throwing arm and position

<table>
<thead>
<tr>
<th>Subjects (N)</th>
<th>Age (yrs)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Yrs Played</th>
<th>Throwing Arm (N)</th>
<th>Position (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>43</td>
<td>19.6 (1.2)</td>
<td>185.8 (5.5)</td>
<td>90.5 (7.0)</td>
<td>13.8 (2.9)</td>
<td>32</td>
<td>11</td>
</tr>
</tbody>
</table>
Table 2. Shoulder range of motion, mean (SD) and mean differences over time

<table>
<thead>
<tr>
<th></th>
<th>Pre-Season</th>
<th>Post-Season</th>
<th>p-Value</th>
<th>Mean Difference (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Throwing Arm</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Rotation</td>
<td>29.7 (10.9)</td>
<td>29.7 (8.9)</td>
<td>0.979</td>
<td>-</td>
</tr>
<tr>
<td>External Rotation</td>
<td>109.8 (11.3)</td>
<td>112.6 (9.3)</td>
<td>0.169</td>
<td>-</td>
</tr>
<tr>
<td>Total (ER+IR)</td>
<td>140.2 (14.0)</td>
<td>142.0 (14.2)</td>
<td>0.458</td>
<td>-</td>
</tr>
<tr>
<td>Horizontal Adduction</td>
<td>-4.0 (6.4)</td>
<td>2.1 (5.6)</td>
<td>&lt;0.001</td>
<td>6.1 (3.7, 8.5)</td>
</tr>
<tr>
<td><strong>Non-Throwing Arm</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Rotation</td>
<td>36.6 (8.6)</td>
<td>37.3 (9.0)</td>
<td>0.622</td>
<td>-</td>
</tr>
<tr>
<td>External Rotation</td>
<td>105.4 (9.9)</td>
<td>102.6 (9.1)</td>
<td>0.039</td>
<td>2.8 (0.2, 5.5)</td>
</tr>
<tr>
<td>Total (ER+IR)</td>
<td>142.0 (13.8)</td>
<td>139.9 (11.0)</td>
<td>0.326</td>
<td>-</td>
</tr>
<tr>
<td>Horizontal Adduction</td>
<td>1.3 (4.7)</td>
<td>9.3 (8.4)</td>
<td>&lt;0.001</td>
<td>8.0 (5.6, 10.3)</td>
</tr>
<tr>
<td><strong>Throwing Arm vs Non-Throwing Arm</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIRD</td>
<td>-6.2 (13.1)</td>
<td>-7.9 (11.2)</td>
<td>0.368</td>
<td>-</td>
</tr>
<tr>
<td>ERS</td>
<td>5.4 (11.5)</td>
<td>11.0 (10.0)</td>
<td>0.016</td>
<td>5.6 (1.1, 10.2)</td>
</tr>
</tbody>
</table>

Bold font indicates statistical significance.

SHOULDER ROM

On the throwing arm, only HAdd ROM (p < 0.001) significantly increased from pre-intervention to post-intervention (Table 2 & Figure 3). Seventy-one percent were considered responders to the exercise intervention for HAdd ROM (Figure 3). Internal rotation, ER, and total ROM did not significantly change over time (p > 0.05). On the non-throwing arm, ER ROM decreased (p = 0.059) while HAdd ROM increased (p < 0.001) from pre-intervention to post-intervention (Table 2). There were no significant differences over time for IR or total ROM (p > 0.05). For ERS, there was a significant increase (p = 0.016) from pre-intervention to post intervention while no significant change in GIRD (p > 0.05) was observed (Table 2). Fifty-six percent of participants were considered responders to the exercise intervention for ERS (Figure 4).

SHOULDER STRENGTH

On the throwing arm, ER strength (p = 0.003) and ER:IR (p < 0.001) significantly decreased (Table 3). On the non-throwing arm, ER strength also decreased (p = 0.004), but no change in ER:IR strength ratio was observed (p > 0.05). A notable increase in IR strength on the throwing arm and decrease on the non-throwing arm was observed, but neither change was significant (p = 0.055 for both). Fifty-seven percent of participants were considered responders to the exercise intervention for IR strength (Figure 5). When comparing the strength of the throwing arm to the non-throwing arm, the IR strength ratio between arms significantly increased (p < 0.001), indicating an increase in IR strength in the throwing arm relative to the non-throwing arm, but no significant difference was observed in the ER strength ratio (Table 3).

DISCUSSION

A standardized exercise program successfully increased...
shoulder HAdd ROM from pre-intervention to post-intervention in collegiate baseball players. Additionally, ERS increased from pre- to post-intervention, indicating greater ER surplus on the throwing arm. Half of the participants (56%) demonstrated a meaningful increase in ERS following the intervention. Contrary to the hypothesis, a decrease in shoulder ER strength and ER:IR strength ratio also occurred. Athlete exposure to baseball participation can result in both acute and chronic adaptations to ROM and strength of the shoulder. Exercise interventions that maintain or increase ROM and can counteract the physiological adaptations that may occur as a result of baseball participation. These results indicate that a standardized exercise program performed throughout the season may be beneficial for targeting certain modifiable physical factors to maintain and limit the loss of strength. Targeting modifiable factors such as shoulder ROM and strength through an exercise intervention program may help to reduce injury risks in baseball players, however this aim is outside the scope of preliminary investigation.

Shoulder HAdd ROM, which assesses posterior shoulder tightness, was the only shoulder ROM variable that changed following the intervention on the throwing arm. A majority of the participants (71%) demonstrated a meaningful increase in HAdd following the intervention but some may have had limitations to begin with. There was a 6.1° increase in the HAdd from pre to post-intervention, which exceeds measurement error (MDC90%) of 4.2° for passive HAdd.2 A similar noted increase in HAdd ranging between 15.7° and 17.5° in professional baseball players from pre to post-intervention.35,36 While Chan et al.35 did not provide an intervention, all players participated in posterior shoulder stretching drills which may have accounted for their observations. McGraw et al.36 provided a stretching and mobilization intervention, but only for athletes that exhibited a deficit in ER, IR, or HAdd in their throwing arm compared to their non-throwing arm. The current intervention similarly included soft tissue mobilization of the posterior shoulder musculature with a lacrosse ball or Theragun (Therabody, Los Angeles, CA), as well as cross-body stretching, yet increases in Hadd were less than half that of previous literature. It is possible that the difference in competitive levels and temporal factors partially accounted for this discrepancy. Both Chan et al.35 and McGraw et al.36 studied professional athletes whose seasons last six to seven months. The athletes in this study were tested before and after their fall season which only lasted two months.

Contrary to the hypothesis, no changes in IR, ER, or total

Table 3. Shoulder strength (N/kg), mean (SD) and mean differences over time

<table>
<thead>
<tr>
<th></th>
<th>Pre-Season</th>
<th>Post-Season</th>
<th>p-Value</th>
<th>Mean Difference (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throwing Arm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External Rotation</td>
<td>1.47 (0.28)</td>
<td>1.34 (0.25)</td>
<td>0.003</td>
<td>0.13 (0.05, 0.21)</td>
</tr>
<tr>
<td>Internal Rotation</td>
<td>1.78 (0.48)</td>
<td>19.7 (1.93)</td>
<td>0.055</td>
<td>0.16 (0.01, 0.29)</td>
</tr>
<tr>
<td>ER:IR Ratio</td>
<td>0.88 (0.26)</td>
<td>0.71 (0.14)</td>
<td>&lt;0.001</td>
<td>0.17 (0.08, 0.25)</td>
</tr>
<tr>
<td>Non-Throwing Arm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External Rotation</td>
<td>1.51 (0.23)</td>
<td>1.39 (0.26)</td>
<td>0.004</td>
<td>0.12 (0.04, 0.20)</td>
</tr>
<tr>
<td>Internal Rotation</td>
<td>1.96 (0.39)</td>
<td>1.84 (0.39)</td>
<td>0.055</td>
<td>0.12 (0.00, 0.24)</td>
</tr>
<tr>
<td>ER:IR Ratio</td>
<td>0.79 (0.14)</td>
<td>0.77 (0.15)</td>
<td>0.64</td>
<td>-</td>
</tr>
<tr>
<td>Throwing Arm vs Non-Throwing Arm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IR Strength Ratio</td>
<td>0.92 (0.19)</td>
<td>1.09 (0.18)</td>
<td>&lt;0.001</td>
<td>0.17 (0.08, 0.27)</td>
</tr>
<tr>
<td>ER Strength Ratio</td>
<td>0.99 (0.18)</td>
<td>0.99 (0.20)</td>
<td>0.872</td>
<td>-</td>
</tr>
</tbody>
</table>

Bold font indicates statistical significance.
ROM (IR+ER) were observed on the throwing arm. In professional pitchers, decreased shoulder IR and total ROM have been observed for up to 24 hours after pitching, but the findings on long-term changes are inconsistent. Dwelly et al. found that ER ROM significantly increased by 2.9° from preseason to postseason in collegiate pitchers, but Freehill et al. found no changes in ER, IR or total ROM for professional pitchers.

Considering the effectiveness of posterior rotator cuff and cross-body stretching routines, it appears that the stretching intervention in the present study may have countered any acute changes in IR ROM typically observed, but did not further increase IR ROM beyond its preseason value. The current intervention did not further affect the players ROM beyond each pitcher’s normal arm care program. Deficits in total ROM are related to shoulder and elbow injury. However, no changes in total ROM were observed in this study. This result may have been due to players having a high total ROM of 140° prior to the exercise program so large improvements were not expected due to a ceiling effect. Total ROM was similar to what has previously been reported in collegiate baseball and softball players.

When comparing between arms, the hypothesis was partially supported. No change in GIRD was observed, but ER surplus improved as noted with an improved ERS of 5.6°. The increased ERS was driven by an increase of 2.7° in the throwing arm ER with accompanying decrease of 2.8° ER in the non-throwing arm. The change in ERS exceeded the MDC90% of 1.6° indicating the change was likely meaningful and not due to measurement error. A lack of ERS on the throwing arm has been identified as a risk factor for injury in baseball players. Specifically, those who exhibit less than 5° surplus of ER ROM on their throwing arm compared to their non-throwing arm are 1.9 times as likely to suffer an upper extremity injury.

The ratio of ER:IR strength ranges from 63-98% in the throwing arm of healthy baseball players. Baseball players in the current study had ER:IR strength ratio decreased from 88% to 71% over the course of the season. The ratio decreased due to players having a decrease in throwing arm shoulder ER strength and a notable, but insignificant, increase in shoulder IR strength. However, while the change in ER:IR ratio exceeded its MDC value, the changes in its constituents did not exceed their respective MDC values, and therefore may have been caused by measurement error. The decrease in shoulder ER strength could be related to a decrease in the frequency of training as the season progressed. Players were initially participating in training three times a week following testing and then training decreased to once a week. The internal rotators were not adversely affected by the change in the training schedule, which may be due to their role during throwing. The ER muscles act eccentrically during the deceleration phase of throwing whereas the IR muscles are required to work both concentrically and eccentrically throughout the throwing motion. Therefore, the difference in loading of the IR muscles compared to ER muscles may account for the observed changes in strength. Half of the participants (57%) demonstrated a meaningful increase in IR strength. Considering the changes in ER and IR strength were smaller than their respective MDC values, the use of any arm care interventions to maintain or build strength during the season should be further investigated. A longer intervention would likely have been beneficial for improving strength but was logistically challenging with the cohort of Division I players. The athletes are restricted to the number of hours they can participate in training and practice each week.

Shoulder isokinetic strength changes have been observed following the season in high school pitchers. Whitley et al. found that shoulder HADd and shoulder IR strength decreased in the throwing and non-throwing arm, however ER strength did not change. The intervention they used may have been helpful in increasing IR strength but not ER strength. When evaluating the exercises they prescribed for the players, the players primarily performed dynamic and compound exercises. Lack of isolated strengthening of the external rotators may have contributed to the decreased ER strength. In a study evaluating upper extremity muscular endurance on baseball players during a 20-week pre-season training program, increased posterior shoulder muscular endurance was observed. The exercises behind this change, during the 20-weeks, consisted of low resistance and high repetition with a combination of both isolated and compound exercises. Therefore, incorporating more isolated strengthening of the external rotators with emphasis on endurance may be important to sustain strength in these muscles over the course of a season. It is also possible that testing strength eccentrically may have resulted in differences following the training program since this may more closely relate to the demands of throwing.

Muscle activation for various iterations of most of the exercises used in the current intervention have been examined. Low (0-20% maximal voluntary isometric contraction) to moderate (21-40% maximal voluntary isometric contraction) level activation of the rotator cuff and scapular stabilizer muscles have been observed for most of the exercises in healthy non-overhead athletes. High muscle activation exercises may be more effective in improving isometric strength in overhead athletes but evidence of this is limited.

Figure 5. Individual responsiveness of throwing arm internal rotation strength to the intervention.

Black lines indicate individual responses for internal rotation strength and grey bars show the mean group values. Responders exceeded the minimal detectable change indicating changes were not due to measurement error.
Effectiveness of a Shoulder Exercise Program in Division I Collegiate Baseball Players During the Fall Season

Of the electromyography studies reported in the literature, most are done in healthy non-overhead athletes and not baseball players therefore it limits their generalizability to baseball players.

The outcome assessment for muscle performance in this study was isometric strength with a hand-held dynamometer. Clearly, this is just one aspect of muscle performance. The exercises may be influencing neuromuscular factors that were not assessed with the outcome measure of isometric strength. Perhaps it is not the exercises but rather the outcome assessment that contributed to the lack of observed changes. It is also possible that large changes in strength in high level athletes during the season do not occur and maybe the changes were not strength related but due to rate of force development. Rate of force development is the rate that and individual can generate maximal force production during a given activity. Rate of force development utilizes the stretch-shortening cycle of a muscle and is optimized when maximal force is produced in the shortest amount of time possible. The methods used in the current study were not able to assess the influence of rate of force development but should be considered in the future.

This study has limitations. Data were collected on a single Division I baseball team, limiting generalizability to other levels of competition. It is unknown if players did additional exercises beyond what they were prescribed by the strength and conditioning specialist. Without a control group, the authors cannot assert that the changes observed were due solely to the training. It is possible that players had ROM or strength adaptations that occurred due to baseball participation. This study was a preliminary investigation designed to test the exercise program and obtain pilot data for a future randomized controlled trial. The goal of a future randomized controlled trial would be to determine the effectiveness on injury rates. The fall season was chosen because college baseball teams focus more on practice and strength training during this time period in order to prepare for the competitive spring season. During the spring season, the focus of strength training programs moves into a maintenance phase of the periodized programming due to the number of competitive games that are played during this period. The results may have been different had changes in shoulder ROM and strength, been examined during the spring season. However, performing this study during the spring season would have introduced the confounding factors of athlete exposure to the demands of playing baseball during more games as some players who are starters would have greater exposure than players who compete less frequently. With less games being played in the fall season there was potentially less undue influence of athlete exposure on the results. Alternatively, the dosing and duration of the program may not have been adequate to elicit change in some variables.

CONCLUSIONS

Performing a standardized exercise program was demonstrated to be beneficial for improving shoulder HAAdd ROM and ERS (improving the relative amount of ER on the throwing arm) in collegiate baseball players. Baseball players often present with altered ROM and strength patterns due to the frequency and repetitive nature of the sport. Being able to effectively target shoulder musculature to improve ROM and strength may help to decrease the incidence of injury and improve performance. The lack of change in IR and ER ROM may be related to the lack of deficits at the start of the season.

ETHICS APPROVAL

The University of Southern California Institutional Review Board approved this study.

ACKNOWLEDGEMENTS

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DISCLAIMER

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of trade names in this report does not constitute an official Department of the Army endorsement or approval of the use of such commercial items.

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REFERENCES


glenohumeral passive range of motion increase risk of
elbow injury in professional baseball pitchers: A
2014;42(9):2075-2081. doi:10.1177/0363546514538391

40. Byram IR, Bushnell BD, Dugger K, Charron K,
Harrell FE Jr, Noonan TJ. Preseason shoulder strength
measurements in professional baseball pitchers:

41. Brown LP, Niehues SL, Harrah A, Yavorsky P,
Hirshman HP. Upper extremity range of motion and
isokinetic strength of the internal and external
shoulder rotators in Major League Baseball Players.

42. Ellenbecker TS, Mattalino AJ. Concentric
isokinetic shoulder internal and external rotation
strength in professional baseball pitchers. *J Orthop

43. Donatelli R, Ellenbecker TS, Ekedahl SR, Wilkes
JS, Kocher K, Adam J. Assessment of shoulder
strength in professional baseball pitchers. *J Orthop

44. Noffal GJ. Isokinetic eccentric-to-concentric
strength ratios of the shoulder rotator muscles in

45. Wilkin LD, Haddock BL. Isokinetic strength of
collegiate baseball pitchers during a season. *J Strength

46. Pozzi F, Plummer HA, Sanchez N, Lee Y, Michener
LA. Electromyography activation of shoulder and
trunk muscles is greater during closed chain
compared to open chain exercises. *J Electromyogr
Kinesiol.* Published online 2019. doi:10.1016/j.jelek
n.2019.05.007

47. Edwards PK, Ebert JR, Littlewood C, Ackland T,
Wang A. A systematic review of electromyography
studies in normal shoulders to inform postoperative
rehabilitation following rotator cuff repair. *J Orthop

48. Aagaard P, Simonsen EB, Andersen JL, Magnusson
P, Dyhre-Poulsen P. Increased rate of force
development and neural drive of human skeleton
muscle following resistance training. *J Appl Physiol.*
2002;93:1318–1326.
SUPPLEMENTARY MATERIALS

Appendix 1
Normalized Isometric Shoulder Strength as a Predictor of Ball Velocity in Youth Baseball Players

Amanda J Arnold, Charles A Thigpen, Paul F Beattie, Stacy L Fritz, Michael J Kissenberth, John M Tokish, Ellen Shanley

1 Physical Therapy, Louisiana State University; 2 ATI Physical Therapy; 3 Physical Therapy, University of South Carolina; 4 Orthopaedics, Steadman Hawkins Clinic of the Carolinas; 5 Orthopaedics, Mayo Clinic

Keywords: ball velocity, normalization, shoulder strength, baseball, youth

BACKGROUND

Despite increased awareness of factors related to athletic performance and injury prevention, youth and adolescent baseball players continue to report injuries at alarming rates. Upper extremity muscle strength is an integral part of physical assessment and injury prevention in baseball players, however minimal data exists in youth populations. Changes in anthropometric measures, inherent in physically developing athletes, have been shown to impact strength measures, however normalization methodology is rarely reported.

PURPOSE

The purposes of this study were to 1) compare the measurement properties of five potential methods for normalizing isometric shoulder strength in a cohort of 9-12 year old male baseball players and 2) examine the relationship between normalized isometric shoulder strength and ball velocity in a cohort of 9-12 year old male baseball players.

STUDY DESIGN

Prospective cohort study (n=159)

METHODS

Baseline and follow up height, weight and bilateral ulnar length measurements were assessed followed by isometric strength in both the dominant and non-dominant shoulders. Strength measures included scapular plane abduction (scaption), external rotation (ER) at 0°, ER and internal rotation (IR) at 90°. Ball velocity was assessed as a measure of throwing performance. Intraclass correlation coefficients (ICC2,1), standard errors of measurement (SEM) and minimal detectable change (MDC95) were calculated for all strength measures. Repeated measures ANOVA were conducted comparing changes in normalized strength using five separate anthropometric measures: weight, height, body mass index, ulnar length and % of non-dominant shoulder strength. Linear regression models were used to examine the relationships between normalized isometric shoulder strength and ball velocity. Statistical significance was set a priori at \( \alpha = 0.05 \).

RESULTS

Shoulder strength normalized using ulnar length was the only method that demonstrated excellent reliability (ICC2,1 0.98-0.99) and detected significant changes between strength in each of the four measures tested (SEM 0.39-0.69 Nm). Modest but significant
correlations were observed between scaption and ball velocity ($r^2 = 0.27, p < 0.001$) and ER at $0^\circ$ and ball velocity ($r^2 = 0.23, p < 0.001$).

**CONCLUSION**

Ulnar length was the most stable and reliable normalization method for assessing isometric shoulder strength in youth baseball players. In addition, normalized scaption strength was the most significant predictor of ball velocity, followed by ER at $0^\circ$ strength in this population.

**LEVEL OF EVIDENCE**

Level 2b (etiology)

**INTRODUCTION**

Baseball is a popular sport with approximately 13-17 million athletes participating across the U.S. Youth (9-12 years) and adolescent (13-18 years) players comprise the majority of this population participating at the club and high school levels. Despite increased awareness of factors related to athletic performance and injury prevention, youth and adolescent baseball players continue to sustain injuries at alarming rates. The incidence of baseball-related overuse injuries in youth and adolescent players reportedly ranges between 1.3 – 4.0 injuries per 1,000 athletic exposures. The majority of baseball-related overuse injuries occur at the upper extremity (UE), specifically the shoulder and elbow, however few studies have assessed how risk factors change as young athletes grow and develop over time.

Upper extremity muscle strength is an important factor in the assessment of athletic performance and injury prevention in baseball players. Strength is defined as the amount of force a muscle can maximally produce during a single repetition. Clinicians and researchers routinely use a battery of strength measures for performance assessments, injury diagnostics and return to sport decisions following injury. While upper extremity strength measures have been reported at the collegiate and professional levels, little to no data is available at the youth and adolescent levels. Establishing an objective, reliable and clinically accessible method for evaluating how strength changes as an athlete grows is imperative for understanding shoulder function, performance and injury risk in youth baseball players.

Despite acknowledging that anthropometric measurements, such as height and weight, influence the body’s ability to produce force and thereby muscle strength, normalization methods accounting for body size are inconsistently reported in the literature. The evaluation of isometric strength in youth and adolescent athletes is inherently different from that of collegiate and professional athletes. Height, weight and neuromuscular control can fluctuate frequently in physically developing populations with the potential to rapidly change over short periods of time. Performance assessments that rely solely upon absolute measures, without normalization, may lack the ability to discern changes in muscle strength from changes in body size in youth populations. Accounting for these alterations in growth and development through normalization is critical to accurately assessing muscle function and injury risk in young athletes.

There is a notable gap in the literature surrounding the evaluation and normalization of shoulder strength in youth baseball players. Multiple methods have been developed to normalize lower extremity muscle strength, particularly in non-athletic and non-typically developing populations. Only one study has been conducted in the upper extremity, using percent (%) of non-dominant strength to normalize dominant strength in the shoulders of adolescent throwers. Using anthropometric measures such as body mass, body mass index (BMI), height and limb length to normalize shoulder strength has not been studied. Determining a reliable and reproducible method for evaluating strength and changes in strength over time is imperative for assessing physically developing populations over time. The purposes of this study were to 1) compare the measurement properties of five potential methods for normalizing isometric shoulder strength in a cohort of 9-12 year old male baseball players and 2) examine the relationship between normalized isometric shoulder strength and ball velocity in a cohort of 9-12 year old male baseball players.

**METHODS**

**STUDY POPULATION**

One hundred and fifty-nine competitive male youth baseball players volunteered to participate in this study. All players in this study were recruited from local baseball clubs, baseball tournaments and little leagues in the Upstate Region of South Carolina. All players were male, between the ages of 9-12 years and uninjured at the time of initial examination. Players were excluded from the study if they reported any injuries that currently restricted their ability to participate in baseball activities or if they reported a shoulder or elbow injury that required medical attention during the three months prior to initial examination. The University of South Carolina’s Institutional Review Board (IRB) approved this study. Parental consent and athlete assent were obtained for each participant enrolled.

**INSTRUMENTS**

Height, weight and ulnar length were measured using a portable stadiometer, digital weight scale and tape measure, respectively. Athletes were asked to remove their footwear for anthropometric measurements. Height and ulnar length were recorded to the nearest 0.5 centimeter (cm) while weight was recorded to the nearest 0.1 kilogram (kg). Isometric shoulder strength was measured using a Lafayette

** INSTRUMENTS**

Height, weight and ulnar length were measured using a portable stadiometer, digital weight scale and tape measure, respectively. Athletes were asked to remove their footwear for anthropometric measurements. Height and ulnar length were recorded to the nearest 0.5 centimeter (cm) while weight was recorded to the nearest 0.1 kilogram (kg). Isometric shoulder strength was measured using a Lafayette
Manual Muscle Tester hand-held dynamometer (Lafayette Instrument Company, Lafayette, IN, USA). All isometric strength measurements were performed by the lead researcher who demonstrated excellent intra-rater reliability prior to initial data collection (ICC_{2,1} = 0.94-0.99). Ball velocity was assessed using a Stalker Sport Radar Gun (Stalker Radar, Richardson, TX, USA).

**PROCEDURES**

At the time of study enrollment, baseline height, weight and ulnar length measurements were assessed for each participant followed by isometric shoulder strength in both the dominant and non-dominant arms. Two repetitions of each strength measure were recorded per arm and averaged for statistical analysis. Isometric shoulder strength was assessed bilaterally using a Lafayette Manual Muscle Tester hand-held dynamometer (HHD) and methods previously reported in the literature.\(^1\) Isometric shoulder strength measures included abduction in the scapular plane (scaption) at 90°, external rotation (ER) at 0°, ER at 90° and internal rotation (IR) at 90° for the dominant and non-dominant arms. Make tests were used for each isometric strength measure based on higher reliability when compared to break tests in HHD.\(^2\)\(^3\) Athletes were instructed to exert maximal effort as the examiner stabilized HHD. The peak force of each produced for each repetition was then recorded.\(^2\) Scaption and ER at 0° forces were measured in the seated position. Scaption was measured with the dynamometer placed 5 cm distal to the cubital fossa while ER at 0° was measured with the dynamometer placed on the dorsal aspect of the forearm, 2 cm proximal to ulnar styloid process. External rotation at 90° and IR at 90° were measured in the prone position with the shoulder in 90° of abduction, 90° of ER and 90° of elbow flexion. For ER at 90°, the dynamometer was placed on the dorsal aspect of the forearm, 2 cm proximal to ulnar styloid process. Internal rotation at 90° was assessed in a similar fashion, however the shoulder was in a state of neutral rotation and the dynamometer was placed on the volar aspect of the forearm. Each participant was asked to provide maximal effort throughout each trial during examination.\(^2\)\(^4\)\(^5\) Isometric shoulder strength was then normalized prior to statistical analysis using five separate methods: body mass, BMI, height, ulnar length and % of non-dominant shoulder strength (Table 1).\(^7\)

Table 1. Normalization Methods for Isometric Shoulder Strength

<table>
<thead>
<tr>
<th>Method</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Mass (%)</td>
<td>= Shoulder Strength Measure (kg) Body Mass (kg)</td>
</tr>
<tr>
<td>BMI(^b) (m(^2))</td>
<td>= Shoulder Strength Measure (kg) BMI (kg/m(^2))</td>
</tr>
<tr>
<td>Height (kg/m)</td>
<td>= Shoulder Strength Measure (kg) Height (m)</td>
</tr>
<tr>
<td>Ulnar Length (Nm)</td>
<td>= Shoulder Strength Measure (N) \times Ulnar Length (m)</td>
</tr>
<tr>
<td>% of ND(^b) Strength (%)(^7)</td>
<td>= \frac{\text{Dominant Shoulder Strength} - \text{Non-Dominant Shoulder Strength}}{100}</td>
</tr>
</tbody>
</table>

\(^a\)BMI, body mass index.
\(^b\)ND, non-dominant shoulder.

Height, weight, ulnar length and isometric shoulder strength measurements were re-assessed in a subset of participants (n = 58) to examine changes in body size and strength over a six-month period. Previous literature has shown six months to be a sufficient amount of time to objectively detect changes in body size, thereby impacting strength, in physically developing populations.\(^29\)\(^38\) Isometric shoulder strength measures were normalized again for statistical analysis using the five previously stated methods: body mass, BMI, height, ulnar length and % of non-dominant shoulder strength (Table 1).\(^7\)

Throwing performance was assessed using ball velocity during an overhead throw. This measure was assessed in a subset of participants (n = 80). Following a warm up period during team practice, participants were asked to throw three balls, using maximal effort, to a specified target 46 feet away. All throws were performed on flat ground. A Stalker Sport Radar Gun (Stalker Radar, Richardson, TX, USA) was used to record the velocity of each throw in miles per hour (mph). The three throws were recorded and averaged for statistical analysis.

**STATISTICAL ANALYSIS**

Means and standard deviations (SD) were calculated across all participants for the dependent variables: height, weight, BMI and normalized shoulder strength measures. Reliability was assessed for all baseline and follow-up strength measures using intraclass correlation coefficients (ICC) with corresponding 95% confidence intervals (CI).\(^39\) Standard errors of measurement (SEM) were also calculated to determine the absolute reliability of each strength measure using the largest SD in the formula SD × \(\sqrt{1 - ICC}\).\(^39\) Individual SEMs were then used to calculate corresponding minimal detectable change (MDC\(_{95}\)) values for each of the normalized strength measures using the formula \(SEM \times 1.96 \times \sqrt{2}\).\(^39\) Mean change scores were calculated for each normalized strength measure by subtracting the baseline value from its corresponding follow-up value. Effect sizes were then determined, using partial eta squared (\(\eta^2\)), to identify the magnitude of change detected between the two time points for each of the normalized strength measures. A method’s ability to detect changes in strength over time was determined for each strength measure using two criteria: (1) whether the observed change score ex-
ceeded the corresponding MDC_{95} and (2) the measure’s effect size. Bivariate Pearson correlation coefficients and linear regression models were used to examine the relationships between the normalized isometric shoulder strength measures and ball velocity in youth baseball players. The method with the most consistent measurement properties for normalizing isometric shoulder strength in youth baseball players was determined based on each measure’s test-retest reliability, ability to detect changes over time and strength of association with ball velocity. Statistical significance and power criteria were set a priori at 0.05 and 0.80, respectively. A priori power analyses were performed, using a small (0.20) effect size to determine the power needed to detect changes in shoulder strength over time. A moderate (0.40) effect size was used to determine the power needed to assess the significance of association between strength and ball velocity in youth throwers. The effect sizes for these comparisons were calculated using pilot data collected in previous studies. An estimated sample of at least 46 players was determined to be necessary to detect statistically significant differences in strength over time as well as significant associations between strength and ball velocity. All statistical analyses were performed using SPSS Statistics 21.0 (SPSS Inc., Chicago, IL, USA) software.

RESULTS

RELIABILITY OF NORMALIZED SHOULDER STRENGTH

Baseline and follow-up anthropometric characteristics of the youth baseball players included in this study are reported in Table 2. The anthropometric data taken at each time point was then used to normalize each of the shoulder strength measures assessed at baseline and then again at the six-month follow-up. Normalized dominant isometric shoulder strength was the main variable of interest. Intrarater reliability across the four baseline and four follow-up strength measures was the primary variable of interest. Inter-rater reliability across the four baseline and four follow-up strength measures using the five separate normalization methods were: body mass ICC_{2,1} 0.97-0.98, BMI ICC_{2,1} 0.95-0.98, height ICC_{2,1} 0.94-0.98, ulnar length ICC_{2,1} 0.98-0.99 and % of non-dominant shoulder strength ICC_{2,1} 0.80-0.98. Their respective SEM values were: body mass 0.46-0.65%, BMI 0.95-1.16 m\(^2\), height 0.12-0.28 kg/m, ulnar length 0.39-0.69 Nm and % of non-dominant shoulder strength 4.15-15.00%. All five normalization methods demonstrated good to excellent reliability across each of the four shoulder strength measures with some variability in the SEM values reported.

ABILITY TO DETECT CHANGES IN SHOULDER STRENGTH

Minimal detectable change scores, using SEM values, were then calculated for each of the normalized shoulder strength measures: body mass 1.3-1.8%, BMI 2.6-4.0 m\(^2\), height 0.5-0.8 kg/m, ulnar length 1.1-1.9 Nm and % of non-dominant shoulder strength 9.2-41.5%. Mean change scores for each of the five normalization methods were compared to their respective MDC_{95} values across all four measures of shoulder strength (Figure 1). In addition to the MDC_{95} scores, effect sizes were calculated for each of the five normalization methods: body mass 0.04-0.24, BMI 0.24-0.44, height 0.11-0.33, ulnar length 0.41-0.54 and % of non-dominant shoulder strength 0.00-0.02. Ulnar length was the only method that demonstrated mean change scores that exceeded their respective MDC_{95} values and exhibited medium effect sizes in each of the four shoulder strength measures assessed (Table 3). The remaining four methods did not consistently exceed their MDC_{95} values (Figure 1) and demonstrated wide variability in effect sizes across each of the strength measures assessed.

RELATIONSHIPS BETWEEN SHOULDER STRENGTH AND BALL VELOCITY

The relationships between normalized dominant isometric shoulder strength and ball velocity were examined using bivariate Pearson correlation coefficients followed by stepwise linear regression models with forward selection. The height and ulnar length normalization methods demonstrated significant correlations with ball velocity across all four shoulder strength measures, while the body mass, BMI and non-dominant shoulder strength methods did not. Based on these findings, only normalized strength measures using the height and ulnar length methods and were included in the linear regression models.

Small to moderate positive correlations were observed between normalized shoulder strength using the height method and ball velocity in youth baseball players: scaption \( r = 0.47, p < 0.001; \) ER at 0° \( r = 0.41, p < 0.001; \) ER at 90° \( r = 0.27, p = 0.02; \) and IR at 90° \( r = 0.58, p < 0.001. \) Normalized shoulder strength using the ulnar length method demonstrated positive relationships with ball velocity at all scaption, ER at 0°, and IR at 90°.
Table 3. Reliability of Normalized Dominant Isometric Shoulder Strength using the Ulnar Length Method

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD(^a)</th>
<th>ICC(^2,1) (95% CI)(^b)</th>
<th>SEM(^c)</th>
<th>MDC(_{95})^d</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline Strength (n=159)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scaption</td>
<td>17.9</td>
<td>5.2</td>
<td>0.99 (0.94, 0.99)</td>
<td>0.57</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>External Rotation at 0°</td>
<td>15.2</td>
<td>4.1</td>
<td>0.99 (0.99, 1.00)</td>
<td>0.52</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>External Rotation at 90°</td>
<td>11.9</td>
<td>3.0</td>
<td>0.98 (0.93, 0.99)</td>
<td>0.39</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>Internal Rotation at 90°</td>
<td>16.3</td>
<td>4.0</td>
<td>0.99 (0.95, 0.99)</td>
<td>0.45</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td><strong>Follow-Up Strength (n=58)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scaption</td>
<td>20.7</td>
<td>6.2</td>
<td>0.99 (0.98, 0.99)</td>
<td>0.69</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>External Rotation at 0°</td>
<td>19.0</td>
<td>5.5</td>
<td>0.99 (0.97, 0.99)</td>
<td>0.54</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>External Rotation at 90°</td>
<td>14.1</td>
<td>3.3</td>
<td>0.98 (0.98, 0.99)</td>
<td>0.46</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Internal Rotation at 90°</td>
<td>19.0</td>
<td>4.5</td>
<td>0.99 (0.96, 0.99)</td>
<td>0.55</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td><strong>Strength Change over Time (n=58)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scaption</td>
<td>2.8</td>
<td>3.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.41</td>
</tr>
<tr>
<td>External Rotation at 0°</td>
<td>3.8</td>
<td>3.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.54</td>
</tr>
<tr>
<td>External Rotation at 90°</td>
<td>2.2</td>
<td>2.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.51</td>
</tr>
<tr>
<td>Internal Rotation at 90°</td>
<td>2.7</td>
<td>2.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.51</td>
</tr>
</tbody>
</table>

\(^{a}\) SD, standard deviation.

\(^{b}\) ICC\(^2,1\) (95% CI), intraclass correlation coefficient with 95% confidence interval.

\(^{c}\) SEM, standard error of the mean.

\(^{d}\) MDC\(_{95}\), minimal detectable change.

Figure 1. Changes in Normalized Dominant Shoulder Strength by Method over 6-Month Period.

Strength Measures: Blue – Scaption, Red – ER at 0°, Green – ER at 90°, Purple – IR at 90°. Asterisk indicates that normalized strength measure exceeded MDC\(_{95}\) value.

The first linear regression models examined dominant shoulder strength and ball velocity using the height normalization method. Normalized scaption strength demonstrated a high correlation with ball velocity and was entered into the model first followed by ER at 0° strength, ER at 90° strength and IR at 90° strength. A significant relationship was observed between normalized scaption strength and ball velocity (\(r^2 = 0.22, p < 0.001\)). The remaining measures demonstrated non-significant relationships with ball velocity when scaption was entered first into the model (ER at 0° strength \(r^2 = 0.23, p = 0.42\); ER at 90° strength \(r^2 = 0.23, p = 0.70\)). Internal rotation strength was completely removed from this model. A second model was run with ER at 0° strength entered first followed by the three remaining measures. Significant relationships were observed be-
tween ER at 0° strength and ball velocity ($r^2 = 0.17, p < 0.001$) and between scaption strength and ball velocity ($r^2 = 0.24, p = 0.04$) in this model. The remaining measures demonstrated non-significant relationships with ball velocity when ER at 0° strength was entered first into the model (ER at 90° strength $r^2 = 0.18, p = 0.31$; IR at 90° strength $r^2 = 0.19, p = 0.34$).

Next, linear regression models were run using the ulnar length normalization method. Normalized scaption strength using the ulnar length method demonstrated the highest correlation with ball velocity of any normalized measure and was entered into the model first followed by ER at 0° strength, ER at 90° strength and IR at 90° strength. A significant relationship was observed between normalized scaption strength and ball velocity in this model ($r^2 = 0.27, p < 0.001$) (Figure 2). The remaining measures demonstrated non-significant relationships with ball velocity when scaption was entered first into the model (ER at 0° strength $r^2 = 0.27, p = 0.59$; ER at 90° strength $r^2 = 0.28, p = 0.69$). Internal rotation strength was completely removed from this model. A second model was run with ER at 0° strength entered first followed by the three remaining measures. Significant relationships were observed between ER at 0° strength and ball velocity ($r^2 = 0.23, p < 0.001$) and scaption strength and ball velocity ($r^2 = 0.23, p = 0.04$) in this model (Figure 2). The remaining measures demonstrated non-significant relationships with ball velocity when ER at 0° strength was entered first into the model (IR at 90° strength $r^2 = 0.28, p = 0.50$). External rotation at 90° strength was completely removed from the model.

Tests for collinearity indicated that a high level of collinearity was present between scaption and ER at 0° strength measures ($Eigenvalue = 1.96$) in the models, regardless of the normalization method used. Based on the findings from the models above, dominant shoulder scaption strength and ER at 0° strength, using the height normalization method, were able to predict 22% and 17% of ball velocity, respectively, in a cohort of youth baseball players. Dominant shoulder scaption strength and ER at 0° strength, using the ulnar length normalization method, were able to predict 27% and 23% of ball velocity, respectively. Based on these results, normalized shoulder strength, using the ulnar length method, was able to explain a larger portion of the variance in ball velocity in youth baseball players when compared to shoulder strength using the height normalization method.

**DISCUSSION**

Five separate normalization methods were examined to determine which had the best measurement properties for assessing isometric shoulder strength in youth baseball players.

The ulnar length method was determined to be the most objective and reliable normalization method in this study. Shoulder strength normalized using ulnar length was the only method to demonstrate: 1) excellent intra-rater reliability, 2) the lowest reported SEM and MDC values of any method examined and 3) a significant predictive relationship with ball velocity, specifically with respect to shoulder scaption and ER at 0° strength, in youth throwers.

**NORMALIZING STRENGTH IN YOUTH ATHLETES**

Few original research studies have employed normalization
methods when examining muscle strength measures and none have compared findings to determine the most appropriate method based on a specific population.7,40 Previous literature impresses the importance of normalizing strength measures for accurate comparison across multiple time points, particularly in longitudinal and repeated measures study designs.27,29 As an integral part of a physical examination, the ability to accurately monitor changes in shoulder muscle strength could aid clinicians in identifying when young players are at an increased risk for injury as well as determine when they can safely return to sport following injury.7,31 Accurately tracking shoulder muscle strength could also aide in the development and implementation of injury prevention programs for youth athletes.25,26,41 In the absence of normalization, any observed changes in muscle strength may be misinterpreted as simply functions of growth and physical development as opposed to definitive changes in the strength measures themselves.27,29

The only published study that examined normalized shoulder muscle strength measures in physically developing athletes was by Trakis.7 This study used isometric testing and HHD to develop a ratio that referenced dominant shoulder strength measures to non-dominant shoulder strength measures as a means of normalizing muscle strength in adolescent baseball players.7 The theory was based on the concept of using non-dominant shoulder strength values as internal reference points for each athlete.7 When the % of non-dominant shoulder strength method was applied in younger players, ages 9-12 years old, excessive inter-participant variability was noted both in single session measures and repeated measures over time. Neuromuscular control patterns in youth athletes are not as well developed as their adolescent and adult counterparts, which may have impacted their ability to reproduce consistent results with isometric muscle strength measures in this study.32,41–43 Biomechanical studies have suggested the use of body mass and derivations of body mass, including BMI, as potential normalizing factors though few studies have formally tested those theories on youth and adolescent athlete populations.28,40 Frequent fluctuations in body mass measures imply that, while the weight of a youth athlete certainly contributes to their ability to produce muscle force, it may not possess the stability required to accurately detect changes in muscle strength measures over time.28,29 Height and limb length (i.e. ulnar length), a derivation of height, appeared to be more stable choices for normalization factors as the measures only increase over time. This results in a more predictable growth pattern in youth athlete populations. When the normalization methods containing height and ulnar length were compared, the limb-specific ulnar length method outperformed the more generalized height method in test-retest reliability as well as internal consistency as evidenced by lower SEM and MDC values. These findings suggest that ulnar length was the most consistent normalization method for assessing isometric shoulder strength in youth baseball players.

Normalized Isometric Shoulder Strength as a Predictor of Ball Velocity in Youth Baseball Players

LIMITATIONS

Isometric muscle strength testing using HHD has several clinical advantages such as low cost, portability and ease of use however it also has acknowledged limitations.17,30 Isometric testing is a static measure that assesses strength at a single point in a player’s available range of motion.30,47 As throwing is dynamic, isokinetic testing is considered the gold standard in strength assessment, however the high equipment costs and lack of portability made it impractical for use outside of a laboratory setting.30,47–49 Another limitation of this study was that no external stabilization methods were applied to the athletes during the assessments. This decision was based on the feasibility and clinical ap-
The applicability of the methods described in this study. Extreme effort was expended to standardize all measurements and testing procedures, including using a single investigator with excellent intra-rater reliability, however this decision may have influenced the results.

Another potential limitation of this study was the collinearity between the isometric shoulder scaption and ER at 0° strength measures in this population. The current results indicate that either normalized strength measure is predictive of ball velocity, however further research is needed to determine what additional variables should be included in the model to better explain what drives this performance measure in youth athletes. Overhead throwing is a complex motor skill that requires coordination and the proper sequencing of a series of linked movements that start in the lower extremities and ultimately culminate in ball release. This statement supports our findings that isometric shoulder strength explains only a small portion of the variability observed in ball velocity in young throwers.

Lastly, the high levels of inter-participant variability observed in isometric shoulder ER and IR at 90° strength may have negatively influenced the predictability of these measures in youth athletes. The variability may be attributable to age-appropriate deficits in neuromuscular control in the prone overhead position. Further study is needed to better understand the role neuromuscular control plays in youth baseball throwing mechanics as well as which positions are best to accurately assess shoulder strength in this population. Future studies should consider the use of the ulnar length method when normalizing isometric shoulder strength, not only in performance assessments of youth athletes, but in injury prevention programs as well. The relationship between upper extremity injury risk and normalized isometric shoulder strength is not well understood in youth populations suggesting that further study is warranted.

CONCLUSION

The ulnar length method was determined to have the best measurement properties of any normalization method for assessing isometric shoulder strength in youth baseball players. Ulnar length was the most stable and reliable anthropometric measure evaluated in this study. Once normalized using ulnar length, dominant isometric shoulder scaption strength was the most significant predictor of ball velocity, followed by ER at 0° strength in 9–12-year-old baseball players. Muscle strength assessments performed in 90° of shoulder abduction demonstrated high inter-subject variability and provided minimal information concerning the shoulder function and athletic performance of youth baseball players.

CONFLICTS OF INTEREST

All authors declare no conflicts of interests.

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REFERENCES

1. ESPN. Hidden Demographics of Youth Sports. Published online 2013.


3. Statista. Number of Baseball & Softball Players in the U.S. Published online 2017.


Normalized Isometric Shoulder Strength as a Predictor of Ball Velocity in Youth Baseball Players


Background
Shoulder exercises focused on strengthening the rotator cuff and scapular stabilizing muscles as well as addressing scapular dyskinesis and motor control have been shown to improve rotator cuff function and decrease shoulder pain. A single motion shoulder exercise that effectively activates the rotator cuff and scapular stabilizing muscles, engages the scapulohumeral rhythm, and includes eccentric contractions may be more effective and easier for patients to consistently perform as compared to multiple standard shoulder exercises.

Purpose
To compare the electromyographic muscle activation of key shoulder complex muscles during a single motion exercise and individual exercises (standard exercises) typically included in shoulder rehabilitation protocols.

Study Design
Case-controlled, cohort study

Methods
Nineteen healthy men and women without shoulder pain or dysfunction were studied. Muscle activity of the rotator cuff and scapular stabilizing muscles (supraspinatus, infraspinatus, teres minor, trapezius [upper, middle and lower], serratus anterior, middle deltoid) was measured using surface EMG while subjects performed, in a standing position, several standard shoulder exercises typically included in shoulder rehabilitation protocols (resisted shoulder flexion, abduction in the scapular plane/scaption, external rotation, extension) and a single motion shoulder exercise consisting of a continuous movement creating the shape of “Figure of 8” in the transverse plane. The subjects used a weight between 5-15 pounds that produced muscle activation at 40-60% maximum voluntary isometric contraction (MVIC) for shoulder external rotation. That weight was then used for all of the exercises performed by the subject. The single highest EMG reading for each of the eight muscles studied, expressed as a percentage of MVIC, at any point during the second, third and fourth repetitions in a five repetition set was used to compare the single motion shoulder exercise and each exercise in the standard exercises set.

Results
Ten men and nine women between 18-65 years of age were tested. No significant
difference (p=.05) between the exercises was noted for the supraspinatus, infraspinatus, teres minor, serratus anterior, middle deltoid or upper trapezius. There was a significant difference favoring the standard exercises in the middle and lower trapezius. (p= 0.0109 and 0.0002 respectively)

Conclusion
In this pilot study, muscle activation during the single motion, Figure of 8 pattern exercise was not significantly different from the standard shoulder exercises in six of eight key muscles that are usually included in shoulder rehabilitation protocols. The exceptions were the middle and lower trapezius which were activated to a significantly higher degree with the standard exercises. Further evaluation of the clinical effectiveness of the single motion shoulder exercise is needed.

Level of Evidence
Level 3b

INTRODUCTION
Shoulder exercises focused on strengthening the rotator cuff and scapular stabilizing muscles as part of a shoulder rehabilitation program have been shown to improve rotator cuff function and decrease pain.1–3 However, there is little consensus on an ideal exercise program. Furthermore, addressing scapular dyskinesis and motor control have also been described as effective components of a shoulder rehabilitation program.4–6 The standard shoulder exercise program typically consists of individual resistance exercises usually including external rotation, internal rotation, abduction/scaption, forward flexion, extension and in some instances, rowing, dips and modified push-ups.7 Activation of muscles to 40–60% maximum voluntary isometric contraction (MVIC) is considered high activity and may be optimal for use during a rehabilitation program.8,9 Strengthening of the scapular stabilizers has been shown to be helpful as well.10,11 Eccentric contractions may also be important in the rehabilitation of shoulder impingement.12 As shoulder rehabilitation protocols become more complex, compliance and possibly clinical outcomes may suffer.13 A single motion shoulder exercise that effectively activates the rotator cuff and scapular stabilizing muscles, engages the scapulohumeral rhythm and includes eccentric contractions, offers the advantage of a simple movement pattern that may be more effective and will be easier for patients to remember and perform as part of a home exercise program. The single motion shoulder exercise evaluated in this study offers a novel shoulder rehabilitation option that could improve long-term exercise compliance and therefore, possibly improve long-term outcomes in the management of chronic shoulder pain.

The standard shoulder exercises studied include resisted shoulder flexion, abduction in the scapular plane/scaption, external rotation and extension, all performed in the standing position. The single motion exercise used in this study was a continuous movement creating the shape of a "Figure of 8" in the transverse plane while in the standing position. Starting at the subject’s side, the top circle of the 8 is in front of the subject and the bottom continues behind them. As subjects move the arm medially, they were instructed to move past the midline of their body in both the front and back portions of the movement. Shoulder abduction was kept below 45 degrees in all parts of the movement. The exercise takes approximately five seconds to complete one cycle. (Figure 1)

The purpose of this study was to compare the electromyographic muscle activation of key shoulder complex muscles during a single motion exercise and individual exercises (standard exercises) typically included in shoulder rehabilitation protocols. Investigation of the single motion exercise is a step toward creating a larger study measuring clinical outcomes when comparing the single motion shoulder exercise to standard shoulder rehabilitation exercises.

METHODS
The study protocol was approved by the San Jose State University Human Subjects Institutional Review Board.

SUBJECTS
Ten men and nine women between 18-65 years of age were
tested. Primary exclusion criteria included: under the age of 18, previous shoulder surgery, shoulder pain at the time of the study, shoulder pain lasting more than three days in the prior month or participation in a shoulder rehabilitation program within the preceding three months.

STUDY PROTOCOL

The skin was vigorously cleaned with alcohol, and surface EMG sensors (Delsys Trigno Avanti™ Sensor, Delsys inc, Natick, MA) with interelectrode spacing of 10 mm were placed over eight different muscle bellies: 1) supraspinatus (SS), 2) infraspinatus (IS), 3) teres minor (TMi), 4) middle deltoid (MD), 5) upper trapezius (UT), 6) middle trapezius (MT), 7) lower trapezius (LT) and 8) serratus anterior (SA). Since surface EMG recordings were used in this study, it is presumed that for the theoretical basis of the study, each of the electrode locations was representative of each of the muscle functions in the subjects. Electrode placement was performed as described by Tsuruiki. Care was taken to ensure lead placement was standardized between subjects. All eight leads were monitored simultaneously during performance of the exercise protocols for each subject.

The muscle electrical activity from a MVIC of the muscles to be studied was then recorded. The positions used to discern MVIC’s were standing for resisted external rotation (IS, TMi), scaption (SS), abduction to 90 degrees with the elbow fully flexed and the humerus internally rotated (MD), shoulder shrug (UT), and quadruped for abduction at 100° with full external rotation (MT). Use of these positions to measure MVIC has been validated previously. Resisted scaption while standing was used to generate the MVIC for both the LT and SA as supported by the data from Boettcher, et al. The mean EMG activity of the middle two seconds of each 5-second MVIC was calculated to determine the individual’s MVIC. The subjects were then asked to select a weight between 5-15 pounds that they felt would offer a comfortable amount of resistance when externally rotating the arm at 90 degrees elbow flexion and 0 degrees shoulder abduction. EMG activity of the infraspinatus muscle was recorded during external rotation with the subject in a standing position using their chosen weight. The weight was then adjusted to produce muscle activation between 40-60% of the MVIC. Self-selection of weights was utilized to mimic what most patients do in a home setting. This weight was then used for all of the exercises in order to standardize the resistance load for a given subject. Since this is a case-controlled study, this method provided a consistent load for each patient.

The standard exercise protocol was performed in the standing position and consisted of four exercises: shoulder flexion, abduction in the scapular plane (scaption), extension to 60 degrees and external rotation to 90 degrees at 0 degrees abduction, performed in succession (grouped together). The single motion exercise was described previously and is shown in Figure 1. The subject was instructed to cross the midline with the movement both in front and back. They were also instructed to bring the weight up to 45 degrees in front and keep the weight low and next to the body with the behind the back portion of the movement. The subject was allowed to do several practice movements before data were collected.

All exercises were performed in the standing position. Five repetitions were made with all movement patterns in both the single motion and standard exercise protocols. Repetitions two through four were used for data analysis to reduce artifacts from starting and stopping the exercise patterns. To control for muscle fatigue as a possible confounding variable, there was a one-minute rest period between different exercises and the order of the exercises, single motion versus standard exercises grouped together, was alternated between subjects (standard exercise group first/single motion exercise second or single motion exercise first/standard exercise group second) and assigned on an alternating basis as the subjects enrolled in the study. The order of the exercises within the standard exercise group was kept the same for all subjects.

EMG activity was continuously recorded during the exercise cycles. Care was taken to ensure that all recordings were made with the same lead placement. In two cases, a lead came off during the exercises. The lead was replaced and the entire exercise protocol was repeated with the new placement position. The speed of the exercises was standardized by having the subject complete the movements paced to a metronome set at 60 beats per minute. The EMG electrodes were pre-amplified and routed through the EMG mainframe, which further amplified with bandwidth filtered (20–450 Hz) signals. The EMG activities were then collected with a sample rate of 1000 Hz; all data were recorded and stored in a computer for off-line analysis. All data were calculated in root-mean-square (RMS) values, normalized to MVIC of the corresponding muscles, and analyzed as a percentage of MVIC (% MVIC). The EMG value used for analysis of the single motion and standard exercises was the highest peak reading, as a percentage of MVIC, at any point during the second, third and fourth repetitions in the five repetition cycles. Two tailed, paired t-tests were performed, for each muscle studied, comparing the EMG value for the single motion shoulder exercise to an EMG value obtained during any of the standard shoulder exercises as they were performed in a group.

RESULTS

No significant difference was noted in the supraspinatus, infraspinatus, upper trapezius, serratus anterior, middle deltoid and teres minor between the single motion and standard shoulder exercises when comparing the maximum peak EMG values for each muscle group tested, expressed as a percentage of MVIC. A significant difference, favoring the standard exercises, was noted between the single motion and standard shoulder exercises in the middle and lower trapezius. The two tailed, paired t-test comparisons are presented in Table 1.

DISCUSSION

Simplified exercise programs have been shown to increase compliance with home exercise performance. The potential clinical advantage of the single motion shoulder exercise may be that, due to its simplicity, it will be easier for
patients to integrate into their regular exercise programs and may provide a new shoulder rehabilitation option to help maintain long term improvements in shoulder biomechanics and pain reduction. This pilot study demonstrates that the single motion exercise is not significantly different in activating rotator cuff and scapular stabilizing muscles, with the exception of the middle and lower trapezius, when compared to the standard exercises used in this study. With its similarity to standard shoulder exercises in activating key rotator cuff and scapular muscles established, as well as its simplicity and multiplanar movement pattern, a larger outcome study is indicated to evaluate whether these potential advantages of the single motion shoulder exercise translate to increased clinical effectiveness.

There are several limitations to this study. First, the value of using surface EMG electrodes for the measurement of shoulder muscles has been questioned. However, the authors feel that any error introduced by using surface electrodes would be equal for each exercise trial since the data were case-controlled.

Second, it was a challenge in this study to compare a continuous motion, multiplanar exercise that took about five seconds to perform and six uniplanar exercises that took approximately two seconds each to perform. Applying standard MVIC uniplanar movements to a multiplanar single motion exercise has not been previously validated, but the authors feel that this was the most standardized metric to use for comparison. The case-controlled design used in this study is also important in helping to mitigate potential errors produced by MVIC measurement technique as well as exercise performance variability and the subjects self-selecting the weight they used for the exercises. By comparing each subject to themselves, these possible confounding variables would affect both the single motion and standard shoulder exercises to the same degree.

**CONCLUSIONS**

The results of this pilot study indicate that the Figure of 8 pattern, single motion shoulder exercise activates key muscle groups in the rotator cuff and shoulder girdle, similarly to the group of standard exercises consisting of resisted flexion, abduction (scaption), extension and external rotation to 90 degrees at 0 degrees abduction, when performed with the same weight. However, the middle and lower trapezius, were activated to a greater extent during the standard exercises than with the single exercise. These data suggest that the single motion exercise may have utility as part of a shoulder rehabilitation program and warrants additional evaluation for clinical effectiveness. In particular, further studies are needed to determine whether this novel shoulder exercise, because of its simplicity, offers any clinical advantage to produce improved, long term outcomes in managing rotator cuff pathology and decreasing the incidence of chronic shoulder pain when compared to groups of standard shoulder exercises.

**CONFLICTS OF INTEREST**

None

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**Table 1. Results of two-tailed, paired t-tests comparing the peak EMG value, as a percentage of MVIC, for the single motion exercise and the highest peak EMG value, as a percentage MVIC, among any of the standard exercises.**

<table>
<thead>
<tr>
<th>Muscle</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supraspinatus</td>
<td>1.1100</td>
<td>0.2806</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>1.1000</td>
<td>0.2852</td>
</tr>
<tr>
<td>Upper Trapezius</td>
<td>0.1193</td>
<td>0.8657</td>
</tr>
<tr>
<td>Middle Trapezius</td>
<td>2.8369</td>
<td>0.0109</td>
</tr>
<tr>
<td>Lower Trapezius</td>
<td>4.5639</td>
<td>0.0002</td>
</tr>
<tr>
<td>Serratus Anterior</td>
<td>-1.0981</td>
<td>0.2867</td>
</tr>
<tr>
<td>Middle Deltoid</td>
<td>-0.6004</td>
<td>0.5557</td>
</tr>
<tr>
<td>Teres Minor</td>
<td>-1.8591</td>
<td>0.0794</td>
</tr>
</tbody>
</table>

N= 19
REFERENCES


Background
Reliability and agreement of goniometric measurements can be altered by variations in measurement technique such as restricting adjacent joints to influence bi-arthicular muscles. It is unknown if the influence of adjacent joint restriction is consistent across different range of motion (ROM) tests, as this has yet to be assessed within a single study. Additionally, between-study comparisons are challenged by differences between methodology, participants and raters, obscuring the development of a conceptual understanding of the extent to which adjacent joint restriction can influence goniometric ROM measurements.

Purpose
To quantify intra- and inter-rater reliability and levels of agreement of goniometric measurements across five ROM tests, with and without adjacent joint restriction.

Study Design
Descriptive reliability study

Methods
Three trained and experienced raters made two measurements of bilateral ankle dorsiflexion, first metatarsophalangeal dorsiflexion, hip extension, hip flexion, and shoulder flexion, with and without adjacent joint restriction. Intraclass correlation coefficient (ICC), standard error of measurement (SEM), along with participant, measurement/rater and random error variance were estimated.

Results
Eleven females (age 21.4 ±2.3 years) and 19 males (age 22.1 ±2.8 years) participated. Adjacent joint restriction did not influence the reliability and agreement in a consistent way across the five ROM tests. Changes in the inter-rater reliability and agreement were more pronounced compared to the intra-rater reliability and agreement. Assessing variance components (participant, measurement/rater and random error variance) that are used to calculate the ICC and SEM, improved interpretation of ICC and SEM scores.

Conclusion
The effects of adjacent joint restriction on reliability and agreement of goniometric
measurements depend on the ROM test and should be considered when comparing measurements between multiple raters. Reporting variance components that are used to calculate the ICC and SEM can improve interpretation and may improve between-study comparisons, towards developing a conceptual framework to guide goniometric measurement technique.

Level of Evidence

INTRODUCTION

The universal goniometer is a portable, low cost and easy to use tool which can quantify joint range of motion (ROM). This has favoured its use in clinical settings as well as in research.\textsuperscript{1,2} Although it can have a close association with technologically advanced techniques,\textsuperscript{3,4} the measurement reliability and agreement of goniometry can vary due to multiple factors. These factors include the rater, the individual being measured, the joint being measured and differences in ROM measurement technique such as test posture, imposed restraints (e.g. adjacent joint(s) restriction) and assistance (e.g. active vs. passive).\textsuperscript{5} It is important to understand the extent to which these different factors can influence goniometry to inform best practices in the clinic and research.

Intra-rater reliability and agreement has consistently been shown to be higher than inter-rater reliability and agreement.\textsuperscript{5–8} Pain and spasticity have the potential to reduce reliability.\textsuperscript{5} Each joint can have different characteristics that can influence alignment and placement of the goniometer to influence ROM measurements.\textsuperscript{9} Similarly, different ROM tests measuring different ranges of the same joint (i.e. movement directions such as flexion or extension) can potentially influence reliability and agreement due to different position and goniometer alignment requirements. However, the extent to which different types of techniques can influence goniometry is uncertain. For instance, restricting adjacent joints can be used to assess the flexibility and the contribution of bi-articular and mono-articular muscles to the joint ROM which can inform on function and risk of muscle injury.\textsuperscript{10} Yet, it is unknown if restricting adjacent joints influences measurement reliability and agreement in a consistent way across different ROM measurements.

Comparing results between studies is challenged by differences between methodology, participants and the raters, as these all have the potential to influence the intraclass correlation coefficient (ICC) and the standard error of measurements (SEM) which have been recommended as the preferred estimate of reliability and agreement.\textsuperscript{11–13} The ICC is calculated as the ratio of between-participant variance to total variance, where the total variance is the sum of the between participant variance and error variance.\textsuperscript{14} When there are an equal number of repeated measurements for each participant (at least two per participant), a two-way model can be used to partition the error into systematic error and random error,\textsuperscript{15,14} such that the absolute agreement, two-way random effects, single measurement ICC (i.e. ICC[2,1]) can be calculated as:

\[
\text{ICC} [2, 1] = \frac{\sigma_p^2}{\sigma_p^2 + \sigma_r^2 + \sigma_e^2}
\]

Where \(\sigma_p^2\) is the variance between participants, \(\sigma_r^2\) is the systematic error variance due to systematic differences between the measurements or raters being compared, and \(\sigma_e^2\) is the random error variance.\textsuperscript{11,15,15} There are other formulas for calculating the ICC that reduce the influence of \(\sigma_p^2\) and \(\sigma_e^2\), which results in an increased ICC score (e.g. ICC[3,1] and ICC[2,k]).\textsuperscript{13} However, the use and reporting of ICCs between studies is inconsistent and often lacks sufficient detail.\textsuperscript{2,16,17} Additionally, the SEM can be calculated as \(SD_{\text{pooled}} \times \sqrt{1 - \text{ICC}}.\textsuperscript{14}\) Hence, both the ICC and SEM are influenced by any changes that could influence the components of variance within the data. For this reason, differences between the methodology, participants and raters, challenges the comparison of ICC and SEM scores between studies. Further, few studies usually report the components of variance which limit the consolidation of different or conflicting results.\textsuperscript{11}

There is a paucity of research investigating the effect of technique, such as adjacent joint restriction, across more than one joint or ROM test within a single study to overcome the difficulties in comparing results between different studies.\textsuperscript{5} Additionally, differences between restricting and not restricting the adjacent joint could influence the variance between participants (e.g. due to differences in bi-articular muscle flexibility leading to changes in ROM), variance between measurements/raters and random error in different ways. Thus, understanding if the effect is consistent across different ROM tests and investigating why any changes occur can contribute to the conceptual framework used to guide goniometry in research and practice.

The purpose of this study was to quantify intra- and inter-rater reliability and levels of agreement of goniometric measurements across five ROM tests, with and without adjacent joint restriction. Using the same participants and raters as well as reporting the components of variance may improve understanding of whether adjacent joint restriction consistently influences goniometer measurement reliability and agreement across different ROM tests. This knowledge may contribute to creating a conceptual framework to guide effective use of goniometers.

MATERIALS AND METHODS

A convenience sample of 30 healthy participants provided written informed consent. All procedures were approved by the University of Toronto’s Office of Research Ethics. Two Certified Athletic Therapists and one Registered Physiotherapist rated each participant in a random order. Raters had similar field experience and worked interchangeably.
within the same clinic. Raters underwent specific training for this study, which included standard instructions for each ROM test (Appendix A) and a practice session involving three participants who were not part of the study. To control for differences in repositioning participants between measurements, a trained research assistant positioned all participants. A second research assistant documented the measured values.

Participants performed a warm up session upon arrival that consisted of five minutes of light stationary cycling and 10 repetitions of bodyweight squats, lunges, calf-raises and arm circles. The ROM tests included ankle dorsiflexion, first metatarsophalangeal (MTPJ1) dorsiflexion, hip extension, hip flexion, and shoulder flexion. Each ROM test was performed twice bilaterally, with and without restraining the adjacent joint position. The left side was measured first, followed by the right side, and then both sides were repeated to obtain two measurements per side. This repositioning between each measurement avoided residual effects from holding the testing position (i.e. stretching). Each rater performed all measurements in the same order but rated each participant in a random order with approximately two minutes of rest between each rater. This allowed for equal time between each rater’s evaluation of each ROM test.

Details of the testing positions and goniometer placements can be found in Appendix A. The following provides a brief description:

**ANKLE DORSIFLEXION**

Measured in a lunge/split stance. Unrestricted ROM was measured on the front foot, while the rear foot was used to measure restricted ROM by keeping the rear knee extended to influence the gastrocnemius muscles (Figure 1A).

**MTPJ1 DORSIFLEXION**

Measured while participants sat on a table with their feet hanging freely above the floor. Unrestricted ROM was measured with the ankle in its natural hanging position, whereas the restricted ROM was measured in maximal ankle dorsiflexion to influence flexor hallucis longus (Figure 1B).

**HIP EXTENSION**

Measured with the participant lying supine with their hips on the edge of a table and a rolled towel beneath their lower back. The test leg hung off of the edge while the non-test leg was supported in hip and knee flexion by the research assistant. Unrestricted hip extension was measured by pushing the hanging leg down until the pelvis started to rotate anteriorly, while controlling for leg rotation. Restricted hip extension was performed in the same manner but while holding the hanging leg in 90° of knee flexion to influence rectus femoris (Figure 1C).

**HIP FLEXION**

Tested in a supine position. The test hip was flexed with the test side knee either flexed or extended to influence the hamstring muscle group, for the unrestricted and restricted measurements respectively (Figure 1D).

**SHOULDER FLEXION**

Measured while participants sat with their feet firmly on the ground. The research assistant supported the scapula while raising the participants’ arm with the elbow either extended or flexed to influence the triceps brachii, for the unrestricted and restricted measurements respectively (Figure 1E).

To determine the effects of adjacent joint restriction on intra- and inter-rater reliability and agreement, changes in ICC and SEM scores were assessed between the unrestricted and restricted conditions across the five ROM tests. An absolute agreement, two-way random effects, single measurement ICC (i.e. ICC [2,1]) was used to measure intra- and inter-rater reliability (psych package, RGui Version 4.0.2, The R Foundation, Vienna, Austria). Inter-rater ICC was calculated using the mean of each rater’s two measurements to account for the deviation within their respective mea-
measurements. ICC scores were interpreted as <0.40 is poor, 0.41-0.59 is fair, 0.60-0.74 is good, and 0.75-1.0 is excellent. SEM was calculated as SEM= SDpooled × \sqrt{1-ICC}. The mean squares from the ICC calculation were used to estimate σ^2_p, σ^2_r, and σ^2_e.15

RESULTS

Participant characteristics are provided in Table 1.

ICC and SEM scores changed with the restricted technique in different ways across ROM tests (Tables 2 and 3). Specifically, the mean intra-rater ICC and SEM scores across raters respectively decreased and increased (left and right ankle and MTPJ1 dorsiflexion), increased and decreased (left and right shoulder flexion and left hip extension), or both increased (left and right hip flexion and right hip extension) with adjacent joint restriction. However, each rater had different changes between unrestricted and restricted techniques. For example, rater 2 had a decrease in ICC and increase in SEM for shoulder flexion (Table 2).

Changes in intra-rater ICC and SEM scores between the unrestricted and restricted techniques matched changes in variance between participants (σ^2_p) and random error variance (σ^2_e) respectively. Specifically, σ^2_p and σ^2_e respectively decreased and increased (left and right ankle and MTPJ1 dorsiflexion), increased and decreased (left and right shoulder flexion and left hip extension) or both increased (left and right hip flexion and right hip extension) with adjacent joint restriction. Although adjacent joint restriction modified ICC scores, intra-rater ICCs were still good to excellent across the ROM tests even with the associated decreases with or without adjacent joint restriction (Table 2).

Inter-rater ICC and SEM scores showed similar changes to intra-rater scores with adjacent joint restriction for some tests (left and right ankle dorsiflexion, right hip extension, left hip flexion and right shoulder flexion) but not others (increased and decreased with restriction for left and right MTPJ1, decreased and increased with restriction for right side hip flexion and both ICC and SEM increased for left hip extension and left shoulder flexion, Table 3).

Inter-rater ICCs ranged from poor to good and had broader 95% CIs than the intra-rater comparison. Similarly, SEM was higher between raters compared to SEM within each rater’s measurements (Tables 2 and 3). The effects of adjacent joint restriction were more pronounced in the inter-rater comparison. The restricted technique reduced the inter-rater ICC score from fair to poor for left and right ankle dorsiflexion. Conversely, the restricted technique increased ICC scores from poor to fair for left and right hip extension and left shoulder flexion, and improved the ICC score from fair to good for left MTPJ1 flexion. SEM also decreased by approximately 3° with the restricted technique for right MTPJ1 flexion (Table 3).

The systematic variance between measurements/raters (σ^2_p) and the random error variance (σ^2_e) were higher for the inter-rater comparison than any of the intra-rater comparisons, but the changes in the ICC and SEM scores due to adjacent joint restriction varied due to differing changes across each component of variance (i.e. σ^2_p, σ^2_r, and σ^2_e). The lower inter-rater ICC for the restricted ankle dorsiflexion was due to a decrease in σ^2_p and increase in σ^2_r and σ^2_e compared to unrestricted ankle dorsiflexion. The notable increases in ICC for restricted hip extension and left side shoulder flexion were also due to σ^2_e, as it increased but σ^2_p and σ^2_r remained similar compared to the unrestricted techniques. Conversely, the improved ICC and SEM scores for restricted MTPJ1 were not due to changes in σ^2_p, but due to decreases in σ^2_r and σ^2_e compared to the unrestricted technique (Table 3).

DISCUSSION

No known study has evaluated intra- and inter-rater goniometer measurement reliability and agreement across multiple ROM tests, with and without adjacent joint restriction. Reliability and agreement were differentially influenced by adjacent joint restriction across the five ROM tests. Joint restriction does not appear to substantially influence intra-rater reliability and agreement. Conversely, inter-rater reliability and agreement were more substantially influenced by adjacent joint restriction, but this was due to different changes across the components of variance used to calculate the ICC and SEM.
### Table 2. Intra-rater ICC with 95% CI, SEM, variance between participants ($\sigma^2_p$), systematic error variance ($\sigma^2_r$), and random error variance ($\sigma^2_e$).

<table>
<thead>
<tr>
<th>ROM Test</th>
<th>Side</th>
<th>ICC [95% CI]</th>
<th>SEM</th>
<th>$\sigma^2_p$</th>
<th>$\sigma^2_r$</th>
<th>$\sigma^2_e$</th>
<th>ICC [95% CI]</th>
<th>SEM</th>
<th>$\sigma^2_p$</th>
<th>$\sigma^2_r$</th>
<th>$\sigma^2_e$</th>
<th>ICC [95% CI]</th>
<th>SEM</th>
<th>$\sigma^2_p$</th>
<th>$\sigma^2_r$</th>
<th>$\sigma^2_e$</th>
<th>ICC [95% CI]</th>
<th>SEM</th>
<th>$\sigma^2_p$</th>
<th>$\sigma^2_r$</th>
<th>$\sigma^2_e$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankle Dorsiflexion Unrestricted</td>
<td>Left</td>
<td>0.92 [0.85, 0.96]</td>
<td>2.2</td>
<td>57.7</td>
<td>0.0</td>
<td>5.1</td>
<td>0.93 [0.87, 0.96]</td>
<td>1.8</td>
<td>43.5</td>
<td>0.0</td>
<td>3.3</td>
<td>0.94 [0.90, 0.97]</td>
<td>2.0</td>
<td>61.8</td>
<td>0.0</td>
<td>3.6</td>
<td>0.93 [0.90, 0.97]</td>
<td>2.0</td>
<td>54.3</td>
<td>0.0</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>0.83 [0.71, 0.91]</td>
<td>3.0</td>
<td>45.2</td>
<td>0.0</td>
<td>9.1</td>
<td>0.93 [0.87, 0.96]</td>
<td>2.0</td>
<td>50.7</td>
<td>0.0</td>
<td>4.0</td>
<td>0.9 [0.83, 0.95]</td>
<td>2.4</td>
<td>50.3</td>
<td>0.1</td>
<td>5.3</td>
<td>0.89 [0.83, 0.95]</td>
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<td>48.7</td>
<td>0.0</td>
<td>6.1</td>
</tr>
<tr>
<td>Ankle Dorsiflexion Restricted</td>
<td>Left</td>
<td>0.93 [0.87, 0.96]</td>
<td>1.8</td>
<td>43.1</td>
<td>0.0</td>
<td>3.3</td>
<td>0.92 [0.86, 0.96]</td>
<td>2.0</td>
<td>47.2</td>
<td>0.0</td>
<td>4.1</td>
<td>0.87 [0.78, 0.93]</td>
<td>2.8</td>
<td>51.5</td>
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<td>7.6</td>
<td>0.91 [0.87, 0.93]</td>
<td>2.2</td>
<td>47.3</td>
<td>0.0</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>0.89 [0.81, 0.94]</td>
<td>2.0</td>
<td>31.1</td>
<td>0.1</td>
<td>3.7</td>
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<td>2.1</td>
<td>43.9</td>
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<td>4.2</td>
<td>0.81 [0.71, 0.89]</td>
<td>3.0</td>
<td>37.9</td>
<td>0.0</td>
<td>9.0</td>
<td>0.87 [0.76, 0.97]</td>
<td>2.3</td>
<td>37.6</td>
<td>0.0</td>
<td>5.6</td>
</tr>
<tr>
<td>MTP1 Dorsiflexion Unrestricted</td>
<td>Left</td>
<td>0.91 [0.84, 0.95]</td>
<td>3.6</td>
<td>131.9</td>
<td>0.0</td>
<td>12.9</td>
<td>0.83 [0.70, 0.90]</td>
<td>4.6</td>
<td>101.2</td>
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<td>21.2</td>
<td>0.94 [0.90, 0.97]</td>
<td>3.7</td>
<td>215.4</td>
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<td>12.8</td>
<td>0.89 [0.83, 0.96]</td>
<td>4.0</td>
<td>149.5</td>
<td>0.0</td>
<td>15.6</td>
</tr>
<tr>
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<td>Right</td>
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<td>4.5</td>
<td>235.3</td>
<td>0.0</td>
<td>20.7</td>
<td>0.9 [0.82, 0.94]</td>
<td>4.2</td>
<td>157.7</td>
<td>0.0</td>
<td>17.5</td>
<td>0.96 [0.93, 0.98]</td>
<td>3.5</td>
<td>296.7</td>
<td>1.0</td>
<td>10.5</td>
<td>0.93 [0.91, 0.98]</td>
<td>4.1</td>
<td>229.9</td>
<td>0.3</td>
<td>16.2</td>
</tr>
<tr>
<td>MTP1 Dorsiflexion Restricted</td>
<td>Left</td>
<td>0.89 [0.80, 0.94]</td>
<td>4.0</td>
<td>131.4</td>
<td>0.0</td>
<td>16.9</td>
<td>0.8 [0.66, 0.89]</td>
<td>5.4</td>
<td>117.3</td>
<td>0.0</td>
<td>28.9</td>
<td>0.8 [0.65, 0.89]</td>
<td>5.9</td>
<td>141.8</td>
<td>1.5</td>
<td>34.5</td>
<td>0.83 [0.78, 0.93]</td>
<td>5.1</td>
<td>130.2</td>
<td>0.5</td>
<td>26.8</td>
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<tr>
<td></td>
<td>Right</td>
<td>0.83 [0.70, 0.90]</td>
<td>4.0</td>
<td>79.4</td>
<td>0.0</td>
<td>16.5</td>
<td>0.76 [0.60, 0.86]</td>
<td>6.5</td>
<td>133.5</td>
<td>1.5</td>
<td>40.5</td>
<td>0.88 [0.78, 0.93]</td>
<td>4.1</td>
<td>124.2</td>
<td>0.0</td>
<td>17.5</td>
<td>0.82 [0.78, 0.93]</td>
<td>4.9</td>
<td>112.4</td>
<td>0.5</td>
<td>24.8</td>
</tr>
<tr>
<td>Hip Extension Unrestricted</td>
<td>Left</td>
<td>0.86 [0.75, 0.92]</td>
<td>2.2</td>
<td>29.5</td>
<td>0.5</td>
<td>4.4</td>
<td>0.74 [0.57, 0.85]</td>
<td>3.3</td>
<td>31.8</td>
<td>0.0</td>
<td>10.9</td>
<td>0.79 [0.65, 0.88]</td>
<td>3.9</td>
<td>57.8</td>
<td>0.0</td>
<td>15.0</td>
<td>0.80 [0.65, 0.88]</td>
<td>3.1</td>
<td>39.7</td>
<td>0.2</td>
<td>10.1</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>0.94 [0.89, 0.97]</td>
<td>1.4</td>
<td>31.4</td>
<td>0.0</td>
<td>2.1</td>
<td>0.8 [0.66, 0.89]</td>
<td>3.1</td>
<td>39.6</td>
<td>0.2</td>
<td>9.6</td>
<td>0.81 [0.81, 0.94]</td>
<td>2.6</td>
<td>59.0</td>
<td>0.5</td>
<td>6.4</td>
<td>0.88 [0.81, 0.94]</td>
<td>2.4</td>
<td>43.3</td>
<td>0.2</td>
<td>6.0</td>
</tr>
<tr>
<td>Hip Extension Restricted</td>
<td>Left</td>
<td>0.92 [0.85, 0.95]</td>
<td>2.1</td>
<td>48.9</td>
<td>0.0</td>
<td>4.4</td>
<td>0.9 [0.83, 0.95]</td>
<td>3.2</td>
<td>91.8</td>
<td>0.0</td>
<td>9.8</td>
<td>0.92 [0.86, 0.96]</td>
<td>2.7</td>
<td>86.1</td>
<td>0.2</td>
<td>7.3</td>
<td>0.91 [0.87, 0.93]</td>
<td>2.7</td>
<td>75.6</td>
<td>0.1</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>0.92 [0.83, 0.96]</td>
<td>2.0</td>
<td>48.3</td>
<td>0.8</td>
<td>3.4</td>
<td>0.94 [0.89, 0.97]</td>
<td>2.6</td>
<td>104.1</td>
<td>0.0</td>
<td>6.8</td>
<td>0.85 [0.74, 0.92]</td>
<td>3.5</td>
<td>67.6</td>
<td>0.0</td>
<td>11.7</td>
<td>0.90 [0.74, 0.92]</td>
<td>2.7</td>
<td>73.3</td>
<td>0.3</td>
<td>7.3</td>
</tr>
<tr>
<td>Hip Flexion Unrestricted</td>
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<td>0.96 [0.93, 0.99]</td>
<td>2.0</td>
<td>98.9</td>
<td>0.0</td>
<td>4.2</td>
<td>0.88 [0.79, 0.97]</td>
<td>3.8</td>
<td>106.8</td>
<td>0.0</td>
<td>14.3</td>
<td>0.88 [0.78, 0.97]</td>
<td>4.2</td>
<td>128.1</td>
<td>1.8</td>
<td>15.4</td>
<td>0.91 [0.78, 0.97]</td>
<td>3.3</td>
<td>111.3</td>
<td>0.6</td>
<td>11.3</td>
</tr>
</tbody>
</table>

*Note: ICC = Intraclass Correlation Coefficient, SEM = Standard Error of Measurement, $\sigma^2_p$ = Variance between participants, $\sigma^2_r$ = Systematic error variance, $\sigma^2_e$ = Random error variance.*
<table>
<thead>
<tr>
<th>Joint</th>
<th>Side</th>
<th>Intraclass Correlation Coefficient</th>
<th>Standard Error of Measurement (°)</th>
<th>Reliability Coefficient</th>
<th>Agreement Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip Flexion Restricted</td>
<td>Right</td>
<td>0.95 (0.92, 0.98)</td>
<td>11.3</td>
<td>0.93</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>0.98 (0.96, 0.99)</td>
<td>199.1</td>
<td>0.93</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>0.95 (0.91, 0.97)</td>
<td>218.6</td>
<td>0.87</td>
<td>14.1</td>
</tr>
<tr>
<td>Shoulders Flexion</td>
<td>Left</td>
<td>0.92 (0.86, 0.96)</td>
<td>103.1</td>
<td>0.93</td>
<td>14.1</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>0.94 (0.89, 0.97)</td>
<td>136.9</td>
<td>0.93</td>
<td>65.3</td>
</tr>
<tr>
<td>Shoulders Flexion</td>
<td>Left</td>
<td>0.93 (0.86, 0.96)</td>
<td>132.7</td>
<td>0.90</td>
<td>13.3</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>0.96 (0.93, 0.98)</td>
<td>141.8</td>
<td>0.91</td>
<td>13.7</td>
</tr>
</tbody>
</table>

*International Journal of Sports Physical Therapy*
The differing changes in intra-rater reliability and agreement with adjacent joint restriction were primarily influenced by $\sigma^2_p$ and $\sigma^2_e$. Although changes in $\sigma^2_p$ and $\sigma^2_e$ each have the potential to influence the ICC and SEM, it appears as though changes in ICC were more influenced by changes in $\sigma^2_p$ and changes in SEM were more influenced by changes in $\sigma^2_e$ (Table 2). However, it may not be appropriate to generalize these associations. Regardless, intrarater reliability and agreement were not substantially influenced by adjacent joint restriction as the ICC scores were still excellent and the differences between the SEM scores were not larger than approximately 1°, with the exception of right-side unrestricted shoulder flexion (Table 2). Upon examining the data, the lower ICC and higher SEM for right side shoulder flexion was likely caused by an outlier trial from rater 3, which measured 270° of shoulder flexion. It appears as though this may be unrealistic but the trial was not removed from the data to maintain equal number of trials across raters.

Inter-rater comparisons provided a more complex scenario due to the higher $\sigma^2_r$, which was almost nonexistent in the intra-rater comparison. The decreased inter-rater ICC and increased SEM can be attributed to the systematic and random error that occurred between raters, as $\sigma^2_r$ and $\sigma^2_e$.
were higher while $\sigma^2_p$ was similar to the intra-rater values. Adjacent joint restriction differentially influenced these components of variance and the resulting ICC and SEM. Improvements in reliability and agreement observed with hip extension and shoulder flexion were due to changes $\sigma^2_p$, which suggests that raters were not necessarily better at making the measurements even though ICC and SEM scores improved with adjacent joint restriction. Conversely, the improvements in MTPJ1 with joint restriction, can be attributed to fewer differences between raters and less random error as decreases in $\sigma^2_e$ and $\sigma^2_p$ caused the observed improvements in ICC and SEM. When multiple raters are involved in the measurement process, it may be beneficial to determine which technique (unrestricted/restricted) provides higher reliability and agreement and standardize it across raters. Although this may also be important with intra-rater comparisons, it may not be as important, because the intra-rater comparisons scores were excellent even with changes due to adjacent joint restriction.

The inter-rater comparison demonstrates the utility of reporting the components of variance used to calculate the ICC and SEM, as it improved interpretation of the scores. Without investigating the components of variance, it is difficult to determine why the changes in ICC and SEM occurred which can lead to misleading conclusions. Reporting the components of variance has the potential to also improve between-study comparisons that use different participants, raters and methodologies, towards enhancing the consolidation of knowledge to guide goniometry. For example, standardizing the measurement protocol and training raters has been investigated as a means to improve reliability and agreement. Evaluating the variance components within the data can elucidate how different protocols may differentially influence the systematic and random error, which can be used to inform on how protocols can be tailored to target improvements in reliability and agreement, beyond the constraints of a specific study. Interpreting the data in this way can contribute to developing a conceptual framework that can inform future research and decision making in practice.

Considering the limitations associated with the current investigation, maximal ROM may not have changed between measurements, but it is possible that the repositioning between raters could have contributed to $\sigma^2_p$ and $\sigma^2_e$. Although a single researcher positioned participants to control these differences, a criterion measure to confirm repositioning consistency and accuracy was not performed. The study design only provides rater reliability within a single session or day. Although apparently healthy participants were investigated, it is certainly possible that they could have had limitations in bi-articular muscle flexibility which would have influenced their ROM with adjacent joint restriction and the variance between participants ($\sigma^2_p$). Thus, the results from this study could represent the reliability and agreement when assessing heterogeneous groups such as sport teams but would not necessarily be well representative of other homogenous groups such as those with a specific condition that would influence their muscle flexibility. Due to challenges in making comparisons between studies and the scarcity of research on the specific ROM tests and techniques investigated here, it is difficult to make meaningful comparisons to other studies.

CONCLUSION

Restriction of adjacent joints influenced measurement reliability and agreement differentially across the five ROM tests. The changes due to adjacent joint restriction were more pronounced in the inter-rater reliability and agreement, whereas intra-rater reliability and agreement were not substantially influenced. Thus, the effects of adjacent joint restriction on reliability and agreement depends on the ROM test and is of higher importance when multiple raters are involved. Estimating the components of data variance improved the interpretation of the ICC and SEM scores, which demonstrates the utility in reporting variance components in future work, to potentially improve between-study comparisons and towards developing a conceptual framework to guide goniometry.

DECLARATION OF INTEREST

The authors do not have any conflicts of interest to declare.

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REFERENCES


Appendix A

Background

Currently there is no reliability data available for the isometric soleus strength test (ISST), commonly used as a monitoring tool in elite football settings. Isometric strength testing for other muscle groups, most notably the hamstrings, is utilized to identify injury risk and readiness to train/play. To profile athletes efficiently, performance practitioners require optimal measures that are reliable. The aim of this study was to investigate the test-retest reliability of the isometric strength test of the soleus and propose a standardized protocol for its use within an elite male football population.

Study Design

Test-retest reliability single cohort study.

Methods

Thirty elite male footballers (age = 22.8±5.0 years, height = 180.0±0.08 cm, weight = 70.57±4.0 kg) performed the ISST, through three maximum 3-second hold efforts with one minute rest between repetitions and 48 hours between tests, in each test. The test was performed mid-competitive season. All data bilaterally were checked for normality using the Shapiro-Wilk test before a Pearson’s Correlations and Bland-Altman’s analyses were performed.

Results

Test-retest reliability demonstrated high reliability for ISST bilaterally (Right: r = 0.89; Left: r = 0.79, p<0.05). The standard error of measurement (SEM) (%) was 9.09 - 12.47% and minimal detectable change (MDC) was 25.19 – 34.56 (N) for Peak Force (PF) measures of the ISST. Bilateral levels of agreement were found to be +/- 2 standard deviations (SD) of the interval of agreement bilaterally for ISST (Levels of agreement (LOA): Right: Upper 352.49 - Lower -494.76; Left: Upper 523.82 - Lower -591.30. Bilaterally no significant difference was detected between values (Right: p=0.09, CI: -153.21-10.95; Left: p=0.52, CI: -139.81-72.33).

Conclusion

The results of this study demonstrate high reliability for the ISST. The ISST displays a high test-retest reliability for assessing PF characteristics of the soleus in elite male...
academy footballers. This test may be beneficial for performance practitioners for profiling soleus function of athletes.

INTRODUCTION

An important issue in elite football settings is quantifying muscle function for performance. Identifying muscular dysfunction/weakness through appropriate testing related to injury aetiology provides practitioners with valuable information to intervene with appropriate programs to address these issues. Such programs may mitigate the negative impact injuries can have on team performance through time loss and financial cost. The physical demands of football (soccer) are known to have increased and risk of injury is high. Consequently, performance practitioners in elite settings aim to implement testing protocols to identify an athlete’s readiness to train/play, maximising performance and minimising potential injury risk factors. Muscle strength has been a key etiological factor associated with injury risk. Muscle injuries are a predominant feature in many football-related investigations. The use of isometric testing to identify reductions in muscle strength is common practice and integral for the decision-making process that takes place on a daily basis in an elite football setting to maximize performance and increase player availability.

Literature has focussed heavily on quantifying hamstring and quadricep muscle function and the reliability of such measures are well reported. This has led to widespread use of these measures in practical settings, particularly in elite football, where muscle testing equipment is widely available. This focus has been predominantly driven by injury occurrence, identifying risk in athletes, and increasing performance. Occurrence of posterior lower leg injuries is prevalent in elite football and team sports. It is important to note the key contribution of the posterior lower leg, particularly the soleus, on running performance. Highlighting the need within elite sport to identify reliable methods to quantify soleus function. Reliable quantification methods are essential for effective monitoring or athlete profiling and could provide practitioners with data that can influence decision making in relation to readiness to train/play, training prescription and rehabilitation processes.

Isometric muscle strength testing is commonly utilized to determine musculoskeletal status, markers for return to play and address strength deficits affecting performance. The use of isometric muscle strength testing is commonly utilized within elite sport, due to it being less provocative than eccentric testing. This allows testing to be completed more frequently and during heavy fixture congested periods, identifying any deficits that may be associated with reductions in performance or potential injury risk factors. Isometric contractions are a highly reliable and efficient way of measuring and monitoring changes in the generation of force. The isometric soleus strength test (ISST) is utilized to determine the strength of plantar flexors, notably the soleus muscle. No standardization of testing or reliability data is available to the authors knowledge for the ISST. A standardized and reliable measure that can be utilized to test for isometric soleus strength may provide medical and performance practitioners with the utility to optimally monitor and profile athletes. Therefore, the aim of this study was to investigate the test-retest reliability of the isometric strength test of the soleus and propose a standardized protocol for its use within an elite male football population.

MATERIALS AND METHODS

PARTICIPANTS

An a priori power calculation using G-power indicated that a total of 30 participants would be required to detect a high correlation with an alpha of 5% and power of 80%. Thirty male elite academy footballers (age = 22.76±5.0 years, height = 180.0±0.8 cm, weight = 70.57±4.0 kg) participated in this study during the 2019-2020 season. Participants were advised of the advantages and risks of the study and the testing protocol was clearly defined verbally before participants provided written and verbal consent to participate, with the option to withdraw from testing at any point. Participants had a minimum of four years’ experience in resistance training and strength-based testing protocols and met the inclusion criteria of healthy with no current injury and were of male gender. All players eligible for the study were in full training, free from injury, and available for competitive selection. The host football club permitted the dissemination of anonymous data for publication of the study findings and the study commenced in accordance with the 2015 Declaration of Helsinki and was approved by the University of Central Lancashire ethical committee (STEMH).

This study evaluated the test-retest reliability of the ISST within an elite male academy football population using a correlation design. Data collection was performed in a temperature-controlled physiology laboratory on site at the host football club training ground by the same two researchers throughout. Testing occurred at the same time of day for the re-test data 72hrs apart to account for potential diurnal or circadian rhythm that could have affected performance. Players refrained from strenuous exercise between these two testing periods and completed their normal daily routine.

STUDY DESIGN

Participants were familiar with the test protocol, as it has been utilized within the previous season consistently throughout the clubs’ regular screening, testing and readiness to train/play protocols. Testing for the present study took place within pre-season. Test procedures for the ISST were appropriately standardized following previous recommendations in the literature. Before the commencement of ISST bar height was determined for each individual participant, based on seating position and maintenance of hip, knee and ankle joints at 90-degrees, in order to achieve the correct body position for each test. Seating position, rack bar, crocodile pin and bar position were recorded for protocol standardization ahead of scheduled testing. Procedures were identical between both testing sessions. Although there is no standardized warm up for the ISST, it
is apparent from other isometric tests that a derivative of the movement performed should be incorporated.\textsuperscript{15,16,19,20} Participants therefore completed a standardized warm-up beginning with a 10-minute of supervised stationary cycling 1.5 W kg\textsuperscript{-1}, cadence of 60 rpm on a cycle ergometer (Wattbike Ltd, Nottingham, UK), followed by five minutes of dynamic stretching, before advancing to two warm-up sets of IMTP soleus lifts at 50% and 75%.

The BTS-6000 force decks platform (VALD Performance, Newstead, Queensland Australia) were calibrated by the manufacturer to evenly distribute bodyweight across the two platforms. The participant was seated in a position of 90-degrees hip and knee flexion, feet hip-width apart and of equal distance from the center of the platform. While the use of a “self-selected” body position is likely to be advantageous for testing performance, it is not recommended without ensuring that the hip, knee, and ankle joint angles are at 90 degrees, due to the potential influence of varied body positions on force generation.\textsuperscript{19,21} An Airex (Airex AG Sins, Switzerland) cushion was placed on top of the participants’ thighs, with the bar placed on top. The individual was then asked to position the metal bar in line with their pre-recorded position, within the crocodile pins on the Sorinex XL racking system (Sorinex, Lexington, SC, USA), with the bar placed directly over the lateral malleolus. Participants were encouraged to maintain a vertical posture throughout the movement, with hands away from the bar due to interference previously recognized. Before each test, this position was ascertained, with the knee joint angle verified using a goniometer. The width of the participants’ foot position was measured using a standard measuring tape to ensure consistency between tests. After performing two warm-up efforts for the ISST at 50 and 75%, the participant performed three maximum efforts (three second hold with a one-minute rest between reps). Participants were advised to maintain a neutral foot position and minimal pre-tension on the bar until verbal instruction was given. Before each rep the athlete was guided by a countdown ("3, 2, 1") and instructed to push for three seconds up and against the bar as hard and as fast as possible.\textsuperscript{18}

DATA ANALYSIS

Initial data analysis was performed using Forcdeck software (VALD Performance, Newstead, Queensland Australia) and transferred to a spreadsheet program (Microsoft Excel, Microsoft Corp., Redmond, WA, USA). Data was recorded for each of the three maximum efforts of three seconds over the two sessions utilized to ascertain reliability of the test. An average was taken for each participant and relative reliability was calculated to identify the relationship for each limb. A Pearson’s correlation measured the relationship between the two testing sessions. The following criteria quantified magnitude of the correlation: trivial; >0.1 to 0.3, small; >0.3 to 0.5, moderate; >0.5 to 0.7, large; >0.7 to 0.9, very large; and >0.9, almost perfect, with statistical significance set at \(p \leq 0.05\). Reliability in units of measurement was calculated for the interpretation of group mean scores and the individual scores of Peak Force (PF) (N) including Standard error of measurement (SEM) and minimal detectable change (MDC). The formulas used for both SEM and MDC followed previous calculations described by Ransom et al.\textsuperscript{14} To analyze for levels of agreement a Bland-Altman method was completed.\textsuperscript{22} Prior to completing statistical analyses the distribution of data was assessed for normality using the Shapiro-Wilk Test and found to be suitable for parametric statistical testing. All statistical analysis was completed utilising SPSS software version 26.0 (SPSS, Chicago, IL, USA).

RESULTS

A significant correlation was demonstrated between tests (\(p<0.001\)). A very large correlation demonstrated for the ISST (Right: \(r = 0.89\); Left: \(r = 0.79\) (Table 1). Figure 1 highlights the linear relationship in the reliability data, bilaterally.

Figure 2 and 3 display the mean differences between the test-retest data for the ISST with the upper and lower 95% confidence intervals displayed for the measures taken.

Bilateral levels of agreement were found to be +/- 2 standard deviations (SD) of the interval of agreement bilaterally for ISST (Levels of agreement (LOA): Right: Upper 352.49 - Lower -494.76; Left: Upper 523.82 - Lower -591.30. No significant difference between the mean scores for the right \((p=0.09, CI: -153.21-10.95)\) or left \((p=0.52, CI: -139.81-72.33)\) test-retest mean scores were found, indicating that high levels of agreement were identified between the two tests bilaterally.

Table 1. Isometric Soleus Strength Test (ISST) strength measures (n= 30) and reliability statistics

<table>
<thead>
<tr>
<th>TEST</th>
<th>LIMB</th>
<th>Mean Test ± SD (N)</th>
<th>Mean Retest ± SD (N)</th>
<th>(95% CI)</th>
<th>(r) value</th>
<th>SEM (N)</th>
<th>SEM%</th>
<th>MDC (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISST</td>
<td>Right</td>
<td>1775.1±486.7</td>
<td>1846.27±391.6</td>
<td>(0.78, 0.96)</td>
<td>0.89</td>
<td>161.41</td>
<td>9.09</td>
<td>25.19</td>
</tr>
<tr>
<td>ISST</td>
<td>Left</td>
<td>1733.9±471.9</td>
<td>1767.6±327.0</td>
<td>(0.70, 0.93)</td>
<td>0.79</td>
<td>216.24</td>
<td>12.47</td>
<td>34.56</td>
</tr>
</tbody>
</table>

ISST, Isometric Soleus Strength Test, SD, standard deviation, Pearson’s correlation \(r\) value, CI, confidence interval, N = Newtons, SEM, standard error of measurement, MDC, minimal detectable change.
DISCUSSION

The aim of the current study was to evaluate the reliability of the ISST in an elite academy football population. It was hypothesised that reliability would be high for the ISST in this population. The primary findings from this study demonstrated high reliability in male academy footballers for the ISST. High levels of agreement were demonstrated between the two ISST tests bilaterally with 95% of differences demonstrated to be less than two standard deviations away from the mean. Indicating that the ISST can be utilized in an elite sporting environment to reliably quantify isometric strength of the soleus. The SEM (%) and MDC values indicated absolute reliability across measures suggesting changes in strength in an individual athlete can be determined from this test (Table 1).

Isometric strength testing is commonly used for identifying modifiable injury risk factors or assessing outcomes of performance enhancement programs. Confidence within the test in terms of repeatability is important for sports medicine and performance practitioners to consider. The ability to evaluate an athlete’s lower limb capacity to generate force is an integral part of strength profiling and evaluating the efficacy of training interventions. The strength of plantar flexors, notably the soleus muscle may be determined through the ISST. The test position in 80–90° knee flexion has been shown to inhibit the force generated by gastrocnemius, therefore primarily evaluating the strength of the soleus. Currently no standardised testing protocol exists for ISST. Recently Ransom et al. indicated the importance of repeatability in terms of detecting true changes in response to injury or load over time in order to enhance athlete profiling. Consequently, it is important to report both test-retest and absolute reliability. This provided assessment of variability between repeated measures as well level of agreement in PF data. Current results provide confidence in the measure of isometric soleus muscle strength through the ISST by highlighting normal variance and levels of agreement between testing sessions. Evidently, isometric soleus PF measures in the current study were reproducible both between sessions. Results from the current study on isometric soleus strength testing, support similar findings by De Witt and Haff et al. The current study offers further evidence that ISST PF is a useful metric for reliably quantifying maximum strength from isometric strength test protocols.

Medical and performance practitioners working within an elite performance setting may consider using the ISST to evaluate athletes’ optimum and PF capabilities due to the high reliability of the test identified in the current study. Practitioners may be reluctant to conduct maximal eccentric strength testing due to the potential risk of injury. Thus, prompting the need to consider the implementation of the ISST as an alternative measure to determine maximum strength and/or PF. The ISST being isometric in nature, decreases the risk of fatigue and subsequent risk of injury, thus providing a measure that can be utilized in fixture congested periods. Earlier researchers have advocated for in-depth analysis of players which should include isometric muscle strength (albeit in the hamstrings as an example) which may influence optimal training prescription.
functions such as acceleration, sprinting, distance jumping and directional changes. Reliable screening techniques such as the ISST may support the identification of at-risk or strength deficient players and consequently the adaptation of preventative interventions or programs targeting individuals can be derived from such information. This initial study only considered PF as a metric, due to its strong association to functional activities and movement patterns. Any future work in the area should consider other metrics, such as rate of force development (RFD).

SEM (%) and MDC data provided measurement error for absolute reliability (Table 1). Analysis of PF data before and after interventions may be assisted by the MDC data from the current study findings. For the ISST, SEM demonstrated 161.41–216.24N and a small relative index of 9.09 – 12.47%, with any individual PF changes above 25.19–34.56N being expected to be a ‘real’ change. Further investigation in other populations and ages within elite or normative populations may be beneficial to determine agreement. Although this type of data may provide sports medicine and performance practitioners with guidance on ‘real’ changes in strength that may occur, as presented in recent similar studies.

Due to the high reliability demonstrated within the present study the ISST for soleus this metric may be a useful objective marker for quantifying posterior lower limb function. Furthermore, the equipment allows for assessment between dominant and non-dominant legs through metrics derived from the Forceplate software (VALD Performance, Newstead, Queensland Australia). Future studies may consider further investigation of dominant or non-dominant limb through utilization of the ISST. For example, recovery of lower limb muscle strength in the dominant leg is reported to be compromised for up to 72 hours after competitive fixture. While a specific definition of muscle imbalance has yet to be agreed upon, debate continues as to the contribution of imbalance as a risk factor for professional football injury, to which the use of a measure such as the ISST may be a valuable addition.

Limitations require highlighting, despite the results of this study demonstrating high absolute and relative test-retest reliability. The sample utilized in the study was a convenience sample from a specific male, academy age elite football population. Data therefore may not be extrapolated to other genders, age groups, sports or non-sporting populations. Further investigation is required to determine whether equivalent findings exist. Because bilateral limb testing was utilized in accordance with Ransom et al. the authors acknowledge that bilateral limb deficit phenomenon may exist, but measures to minimize the likelihood were highlighted in the methodological approach.

CONCLUSION

The results of this study indicate that the ISST is a reliable method for assessing maximal isometric PF in the soleus musculature of male elite academy footballers. These results suggest that the ISST may be beneficial for performance practitioners for profiling soleus function of athletes.

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REFERENCES


Original Research


Jay Salerno, PT, DPT, Stephanie Tow, MD, Elizabeth Regan, DPT, PhD, Stephen Bendziewicz, PT, DPT, Matthew McMillan, PT, DPT, Shana Harrington, PT, PhD

1 Prisma Health Apex Athletic Performance, Lexington, SC, USA, 2 Department of Physical Medicine & Rehabilitation, University of Texas Southwestern Medical Center, 3 Department of Exercise Science, Physical Therapy Program, University of South Carolina, Columbia, SC, USA, 4 Jumpstart Pediatrics, Chapin, SC, USA, 5 Interim Healthcare of the Upstate, Greenville, SC, USA

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Background

Para swimming has experienced increased participation in recent years. Injury and injury prevention research on Para swimmers is lacking compared to swimmers without impairment.

Purpose

This study aimed to gather data in Para swimmers on typical injuries, injury prevention programs, and attitudes toward injury and injury prevention in this population.

Study Design

Cross-sectional, mixed-methods design evaluating injuries, injury management, and injury prevention in elite Para swimmers in United States (U.S.).

Methods

Para swimmers on the U.S. Paralympics Swimming National teams at multiple competition levels were invited to complete an online survey. Qualitative interviews with six U.S. Paralympics National team Para swimmers were conducted to provide detail on athlete experiences with injury and prevention.

Results

Twenty-one of 56 surveys were returned: 11 of 21 participants (52.4%) reported experiencing an injury that altered their weekly training. All (21/21) reported participating in strength training and 19 of 21 (90.5%) reported incorporating stretching into their training regimen, although strengthening/stretching regimens included routines that may not have been specifically targeted toward injury prevention. Six of 21 (28.6%) reported participation in an injury prevention program. Qualitative interview themes included the impact of swimmers’ compensated body mechanics on injury risk, the value of individualized injury prevention programs, and the importance of knowledgeable coaching and rehabilitation staff.

Conclusions

Injury prevention programs are important components in Para swimming training although they are underutilized based on responses in this study. These programs should be individualized to address swimming biomechanics and athlete-specific impairments. Increasing coaching knowledge and access to individualized programs may reduce injury prevalence among this at-risk population.

Corresponding author:
Shana Harrington PT, PhD
Department of Exercise Science, Physical Therapy Program, University of South Carolina, Blatt PE Center, 101G, Columbia, SC 29208, USA. Phone: 803-777-9112, Fax: 803-777-8422, Email: sharring@mailbox.sc.edu
INTRODUCTION

The Paralympic movement has gained significant momentum over the past century. The Paralympic Games includes athletes with various physical, visual, and intellectual impairments and have evolved into an elite level of competition.\textsuperscript{1,2} The International Paralympic Committee oversees the Paralympics, which has traditionally focused on elite sports performance or helping individuals with disabilities train in sports to become future elite athletes.

Classification systems were developed and have evolved for each sport intending to make the competition as fair as possible. The goal of classification is to group Para athletes who have a similar degree of sport-specific activity limitation from their impairment into a sport class.\textsuperscript{3} World Para Swimming governs Paralympic Swimming classification, and the classification process results in three separate sport classes per athlete evaluation: a S class for freestyle, backstroke, and butterfly, a SB class for breaststroke, and a SM class for individual medley. For physical impairments, sport classes range from S1 through S10 / SB1 through SB9 / SM1 through SM10, with the lower numbers representing more severe physical impairment/limitation in swimming.\textsuperscript{4} The visual impairment sport classes range from S11/SB11/ SM11 through S15/SB15/SM15, with the lower numbers representing more severe vision impairment.\textsuperscript{4} Within each sport class, Para swimmers may also have variability in their swimming performance, reflective of their training, experience, and inherent athleticism and not impacted by their impairment, similar to how swimmers without disabilities may have varying swimming performance within an age group. One may assume that certain sport classes experience greater functional limitations when injured due to their physical impairments, but this relationship remains unclear.\textsuperscript{5}

As the Paralympic movement gains increasing commercial support and media coverage, more generations of individuals with disabilities are inspired to participate in sports. With the growing population of Para athletes, there is an increased need to understand injury epidemiology and injury prevention strategies for Para athletes. A qualitative study conducted by Fagher and colleagues interviewed 18 Swedish Para athletes representing 10 different Para sports and revealed that Para athletes' views of their sports-related injuries experiences are complex, multifactorial, and distinct from the perspectives of athletes without disabilities in terms of injury causes, risk behavior, impacts on function after injury, psychosocial stressors, and overall consequences of injury.\textsuperscript{6} For instance, one Para athlete noted, "I'm often thinking, what will happen if I get an injury to my non-disabled side, I wouldn't be able to manage my daily life. That's what I'm afraid of."\textsuperscript{6}

Currently, most published Para sports injury epidemiology data have been from the Paralympic Games.\textsuperscript{5,7–11} Studies from the Rio 2016 and London 2012 Summer Paralympic Games reported 8.5% - 12.4% of Para swimmers had a current injury\textsuperscript{12} with the highest percentage of injuries being acute (47%), followed by overuse (37%), and then acute on chronic (16%).\textsuperscript{12} Past studies have reported higher injury rates in Para swimmers, Reynolds and colleagues found 69% of Para swimmers on the British team reporting injuries during the Barcelona 1992 Summer Paralympic Games.\textsuperscript{13} Outside of the elite competition, there is a lack of published studies that include Para swimmers and their injury patterns. To our knowledge, there have been no recent studies describing Para swimmers’ injury patterns outside of the Paralympic Games.

Due to the lack of published research on injuries and injury prevention specific to Para swimming outside of the Paralympic Games, Para swimmers often rely on current knowledge and evidence for injury prevention in swimmers without disabilities. Many injuries to swimmers without impairment are at the shoulder and are commonly a result of overuse.\textsuperscript{14} Risk factors for shoulder injuries in swimmers include high training volumes, muscle fatigue/overload (especially of the subscapularis and serratus anterior), rotator cuff tendinosis, shoulder laxity, and impingement positions during swim stroke.\textsuperscript{15} Injury prevention programs for swimmers should include strengthening, stretching, and endurance training. It should also include stroke-specific instruction on body mechanics such as decreasing internal rotation of the shoulder during recovery, breathing bilaterally, or shortening stroke follow-through.\textsuperscript{15,16} However, Para swimmers may have different risk factors for injuries compared to swimmers without disabilities due to Para swimmers’ underlying impairments. For instance, depending on the Para swimmer’s underlying medical condition(s) and impairment(s), they may have anatomical or functional differences that alter swimming biomechanics, compensatory biomechanics, and techniques to accommodate their impairments but also increase the risk of an overuse injury.

To better understand injuries, injury risk, and prevention in Para swimmers at all competition levels studies are needed outside of the Paralympic Games. Therefore, the purpose of this study was to investigate U.S. Para swimmers with physical or visual impairments at various competition levels and (1) describe injuries related to Para swimming, (2) understand athletes’ participation in injury prevention programs and the characteristics of those programs, and (3) evaluate athletes’ perceptions of injury risk, complications, and treatment.

METHODS

Design: A cross-sectional, mixed-methods approach evaluating injuries, injury management, and injury prevention related to Para swimming in U.S. National team Para swimmers was used for this study. The first part of the study consisted of a one-time online survey. A previous survey developed for Para athletes was used to help guide the development of the survey used in this study.\textsuperscript{17} Additionally, input from the U.S. Chief of Paralympic Sport and the U.S. Paralympics Swimming High-Performance Director was sought and the initial survey was piloted for any feedback...
and edits. An online survey (REDCap® version 7.6.0, Vanderbilt University, Nashville, TN) was utilized, hosted and distributed through University of South Carolina, (Appendix 1).

The second part of the study consisted of qualitative semi-structured interviews via an audiovisual communication platform (Skype™). The interview questions were developed by the student investigators (JS, MM, SB) as a result of the survey responses and through collaboration with a board-certified Physical Medicine & Rehabilitation and Sports Medicine physician (ST) with a specialization in Para Sports Medicine. The focus of the interviews was to gather comprehensive information on Para swimmers' perceptions and experiences with injuries, injury prevention, treatment, and the injury recovery process. The interview guide can be viewed in Appendix 2.

PARTICIPANTS:

Survey: Participants were recruited through emails distributed by the U.S. Paralympics Swimming High-Performance Director. Inclusion criteria consisted of: being able to complete the survey in English and being a member of the U.S. Paralympic Swimming National teams with either a physical or visual impairment. Participants were excluded if they were an athlete with an intellectual impairment given concern that they would not be able to appropriately complete the survey. Fifty-six participants were identified by the High-Performance Director for recruitment, the goal was to have a sample size of at least 17 responses (response rate 30.4%) since on average, online surveys yield a response rate between 20%-50%.18,19

Qualitative Interviews: Participants were selected through a convenience sample of U.S. Para swimmers on the U.S. Paralympics Swimming National teams. Researchers requested the U.S. Paralympics Swimming High-Performance Director provided purposeful sampling of Para swimmers representing diversity in regards to primary stroke, medical diagnoses, and impairments. Inclusion criteria were: current U.S. Para swimming National team members with either a physical or visual impairment under the direction of the director. Upon the director's review of the team roster and discussions with the athletes, six Para swimmers were selected based on the request in representing a diversity of Para swimmers, schedule availability, and willingness to participate in an interview. They were encouraged to also take the survey portion of the study but were not excluded if they did not complete the survey.

This study was reviewed and approved by the University of South Carolina Institutional Review Board (Pro00081813 and Pro00084553).

PROCEDURES:

Survey: Fifty-six participants on the U.S. Paralympic Swimming National teams were emailed the online survey. Email reminders were distributed after two weeks to remind participants of the study, and each week following for seven weeks, after which the survey was closed. The general definition used for injury history reporting in this study was "any injury related to swimming that altered weekly training or caused a Para swimmer to miss a competition, regardless of whether participants sought medical treatment for the injury."

Training: Student investigators were trained in qualitative interview techniques by author (ER), who is an experienced qualitative researcher, including open ended questions, follow up techniques and avoidance of leading questions. Student investigators practiced and were given feedback.

Interviews: After the survey was closed, each of the three student investigators contacted two of the six Para swimmers by email to arrange a one-on-one interview over an audiovisual communication platform (Skype™). Audiovisual interviews instead of audio-only were selected as this allowed for a more personal interview. The interviewers provided the Para swimmers with an explanation of the study and potential interview questions before conducting the interview. The interviews were conversational and semi-structured to allow for in-depth follow-up. Interviews lasted between 14 and 38 minutes.

DATA ANALYSIS:

Survey Analysis: Statistical analysis was performed using a statistical software platform (IBM® SPSS® Statistics for Windows, Version 26.0, Armonk, NY: IBM Corp). Descriptive statistics including means, minimum, maximum, standard deviations, and frequencies were calculated for the dependent variables.

Qualitative Analysis: Each interview was transcribed verbatim. De-identified transcripts from the interviews were input into qualitative data analysis software (QSR International Pty Ltd. (2019) NVivo, Version 12.3.0). Iterative thematic analysis20 was completed in a collaborative process by the three student investigators (JS, MM, SB) with support and review by author (ER) with qualitative research expertise. The first interview was coded by each of the three student investigators individually, then discussed as a group with author (ER) to ensure consistency between researchers in the coding process. Initial codes were completed inductively, remaining as close as possible to the participant's wording. Further iterations of the coding were completed as a group, with themes categorized both deductively into predetermined categories (demographics, injury, training, treatment) and inductively through emergent identified new themes through group consensus. Further thematic breakdown under resultant categories were reviewed and revised in several rounds by all three student researchers (JS, MM, SB) and author (ER), and the results were reviewed with authors (SH, ST). Trustworthiness was established through comparison to survey results (triangulation) and utilizing a mentor with qualitative expertise.21

RESULTS

PART I: SURVEY RESULTS

A total of 24 complete survey responses were received from the 56 surveys distributed to swimmers on the U.S. Paralympic Swimming National Teams (42.9% response rate). There were no incomplete survey responses. Three of the
Table 1. Survey Participant Demographics.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Number of survey participants (n=21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>6 (21.6%)</td>
</tr>
<tr>
<td>Male</td>
<td>15 (71.4%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age</th>
<th>Number of survey participants (n=21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 – 18 years</td>
<td>11 (52.4%)</td>
</tr>
<tr>
<td>19 – 25 years</td>
<td>6 (28.6%)</td>
</tr>
<tr>
<td>26 – 30 years</td>
<td>4 (19%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of years swimming competitively</th>
<th>Number of survey participants (n=21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5 years</td>
<td>3 (14.3%)</td>
</tr>
<tr>
<td>5-10 years</td>
<td>11 (52.4%)</td>
</tr>
<tr>
<td>&gt; 10 years</td>
<td>7 (33.3%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Highest level of competition in Para swimming</th>
<th>Number of survey participants (n=21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>International</td>
<td>19 (90.5%)</td>
</tr>
<tr>
<td>National</td>
<td>2 (9.5%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Impairment Type</th>
<th>Number of survey participants (n=21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical impairment*</td>
<td>18 (85.7%)</td>
</tr>
<tr>
<td>Hypertonia</td>
<td>2 (9.5%) (dystonic tetraplegia, multiple traumatic brain injuries)</td>
</tr>
<tr>
<td>Impaired muscle power#</td>
<td>3 (14.3%) (arthrogryposis amyoplasia, transverse myelitis, lumbar level incomplete spinal cord injury)</td>
</tr>
<tr>
<td>Impaired passive range of motion#</td>
<td>2 (9.5%) (arthrogryposis amyoplasia, Nager syndrome)</td>
</tr>
<tr>
<td>Limb deficiency</td>
<td>9 (42.9%) (lower extremity amputations including proximal femoral focal deficiency, upper extremity amputations, Nager syndrome)</td>
</tr>
<tr>
<td>Short stature</td>
<td>5 (23.8%) (dwarfism including achondroplasia, osteogenesis imperfecta)</td>
</tr>
</tbody>
</table>

Visual impairment 3 (14.3%)

24 survey responses (12.5%) were from swimmers with intellectual impairments and were excluded. Figure 1 demonstrates the recruitment process of participants.

PARTICIPANT INFORMATION

The mean age of survey participants was 19.4 years (range 14-30). Participants reported swimming competitively for a mean of 8.4 years (range 2-17). Demographics of survey participants are presented in Table 1. Only three (14.3%) swimmers reported competing in additional sports other than swimming (shot put, Para triathlon, and archery). The most common primary swimming stroke reported was freestyle (57.1%).

IN AND OUT OF POOL TRAINING INFORMATION

Participants reported swimming an average of 15.62 (SD 3.57) hours per week. All reported performing cross-training, with an average of 4.10 (SD 2.32) hours per week. When combining total hours of cross-training and swimming, participants averaged a total of 19.71 (SD 4.33) hours of total training per week. All of the survey participants reported using some type of resistance training outside of the pool (Table 2).
Table 2. Reported Strength Training Out of the Pool

<table>
<thead>
<tr>
<th>Type*</th>
<th>Number of Participants (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bodyweight exercise</td>
<td>20 (95%)</td>
</tr>
<tr>
<td>Dumbbells or free weights</td>
<td>18 (86%)</td>
</tr>
<tr>
<td>Medicine Balls</td>
<td>16 (76%)</td>
</tr>
<tr>
<td>Elastic bands</td>
<td>15 (71%)</td>
</tr>
<tr>
<td>Weight machines</td>
<td>10 (48%)</td>
</tr>
</tbody>
</table>

*Participants could select all that apply

Table 3. Reported Resistance Training In the Pool

<table>
<thead>
<tr>
<th>Type*</th>
<th>Number of Participants (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paddles</td>
<td>18 (86%)</td>
</tr>
<tr>
<td>Parachutes</td>
<td>17 (81%)</td>
</tr>
<tr>
<td>Fins</td>
<td>16 (76%)</td>
</tr>
<tr>
<td>Bungee cords</td>
<td>12 (57%)</td>
</tr>
<tr>
<td>Buckets</td>
<td>8 (38%)</td>
</tr>
<tr>
<td>Other (ie: swim socks or drag suits)</td>
<td>4 (19%)</td>
</tr>
</tbody>
</table>

*Participants could select all that apply

Approximately 91% of the participants were supervised during their resistance training. Supervision was most commonly provided by the swim coach (32%), athletic trainer or strength coach (26% each), a combination of both a swim coach and athletic trainer (11%), and a combination of a swim coach and physical therapist (5%). All 19 participants reported receiving correction of improper form during strength training. When determining the amount of weight used for strength training, 14 (67%) reported the amount of resistance was determined on an individual basis, nine (43%) reported the swimmer decides the amount of resistance, three (14%) reported using their body weight, two (9.5%) used a predetermined repetition maximum and one (4.8%) reported all swimmers on the team use the same amount of weight. All but one participant reported using some type of resistance training in the pool. The types of in-pool resistance reported by participants can be viewed in Table 3. Nineteen of 21 (90.5%) participants reported incorporating stretching into their training regimen. Strengthening/stretching programs reported by participants included routines that may not have been specifically targeted toward injury prevention since the interpretation of "injury prevention" was left up to the respondent.

**INJURY HISTORY**

Of the 21 survey participants, 11 (52.4%) reported experiencing an injury during their swimming career that altered their weekly training, with five (23.8%) reporting shoulder injuries as the cause of missed time. Six of the 21 swimmers (28.6%) reported missing competitions due to injury, with an average of 1.5 competitions missed. Of the swimmers who reported an injury that altered their weekly training, 8 trained 15-21 hours/week, 2 trained 8-14 hours/week, and one trained ≤7 hours/week. Freestyle (n=12) was reported as the most common primary stroke (57%). Eight (66.7%) who identified freestyle as their primary stroke reported an injury that altered weekly training, whereas four (33.3%) reported missing competition due to injury. Two swimmers (9.5%) reported having had previous surgery related to a swimming injury. Of the six male survey participants, two (33.3%) reported injuries that altered weekly training, while nine (60%) of the 15 females reported injuries that altered weekly training.

Any mechanisms of injury reported were classified as acute (defined as any injury that was caused by a specific, identifiable event related to Para swimming activities), chronic (defined as any injury that developed over days, weeks, or months and was not associated with an acute event), or unknown chronicity (if the participant did not provide enough information in their survey response to classify the injury as acute or chronic). Table 4 provides an overview of injury characteristics described by participants, categorized by the eligible impairment types of Para swimmers. Of the five respondents with short stature, four (80%) reported an injury that altered their weekly training and three (60%) missed competition due to their injury. The shoulder was the most commonly reported body area across multiple impairment categories.
<table>
<thead>
<tr>
<th>Impairment Categories</th>
<th>Hypertonia (n=2)</th>
<th>Impaired Muscle Power* (n=3)</th>
<th>Impaired Passive Range of Movement* (n=2)</th>
<th>Limb Deficiency (n=9)</th>
<th>Short Stature (n=5)</th>
<th>Visual Impairment (n=3)</th>
<th>Total Participants (n=21)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Participants reporting injury altering weekly training</strong></td>
<td>1 (50%)</td>
<td>1 (33.3%)</td>
<td>1 (50%)</td>
<td>2 (22.2%)</td>
<td>4 (80%)</td>
<td>3 (100%)</td>
<td>11 (52.3%)</td>
</tr>
<tr>
<td><strong>Participants reporting injury missing competition due to injury</strong></td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>1 (11.1%)</td>
<td>3 (60%)</td>
<td>2 (66.7%)</td>
<td>6 (29%)</td>
</tr>
<tr>
<td><strong>Chronicity of injuries reported</strong></td>
<td></td>
<td></td>
<td></td>
<td>3 (60%)</td>
<td>1 (33.3%)</td>
<td>---</td>
<td>4 (19%)</td>
</tr>
<tr>
<td>Acute injuries</td>
<td>---</td>
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<tr>
<td>Chronic injuries</td>
<td>1 (50%)</td>
<td>1 (33.3%)</td>
<td>1 (50%)</td>
<td>2 (22.2%)</td>
<td>1 (20%)</td>
<td>---</td>
<td>5 (23.8%)</td>
</tr>
<tr>
<td>Injuries of unknown chronicity</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>2 (66.7%)</td>
<td>2 (9.5%)</td>
</tr>
<tr>
<td><strong>Body part(s) reported to be injured (some participants reported multiple)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder</td>
<td>1 (50%)</td>
<td>1 (33.3%)</td>
<td>1 (50%)</td>
<td>2 (22.2%)</td>
<td>---</td>
<td>1 (33.3%)</td>
<td>5 (23.8%)</td>
</tr>
<tr>
<td>Knee</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>1 (20%)</td>
<td>---</td>
<td>1 (4.8%)</td>
</tr>
<tr>
<td>Lower leg</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>1 (20%)</td>
<td>---</td>
<td>1 (4.8%)</td>
</tr>
<tr>
<td>Ankle</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>1 (33.3%)</td>
<td>1 (4.8%)</td>
</tr>
<tr>
<td>Abdomen</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>1 (33.3%)</td>
<td>1 (4.8%)</td>
</tr>
<tr>
<td>Multiple fractures (location not specified)</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>2 (40%)</td>
<td>---</td>
<td>2 (9.5%)</td>
</tr>
<tr>
<td>Multiple tendon or muscle strains (location not specified)</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>1 (20%)</td>
<td>---</td>
<td>1 (4.8%)</td>
</tr>
<tr>
<td><strong>Reported</strong></td>
<td>Participated</td>
<td>1 (50%)</td>
<td>---</td>
<td>1 (11.1%)</td>
<td>---</td>
<td>2 (66.7%)</td>
<td>4 (19%)</td>
</tr>
<tr>
<td>Impairment Categories</td>
<td>Total Participants (n=21)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Hypertonia (n=2)</td>
<td>Impaired Muscle Power* (n=3)</td>
<td>Impaired Passive Range of Movement* (n=2)</td>
<td>Limb Deficiency (n=9)</td>
<td>Short Stature (n=5)</td>
<td>Visual Impairment (n=3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>in injury prevention and injured</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Description of injury prevention program</td>
<td>Prehab program prior to starting practice x10 min</td>
<td></td>
<td>Shoulder strengthening in physical therapy x1 hour weekly</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participated in injury prevention and NOT injured</td>
<td>1 (50%)</td>
<td></td>
<td>2 (22.2%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Description of injury prevention program</td>
<td>Stretching, shoulder and hip strengthening directed by strength coach x45 min every morning</td>
<td></td>
<td>1) Stretching, shoulder and hip strengthening directed by strength coach x45 min every morning 2) Exercises not specified x 1.5 hours weekly</td>
<td></td>
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</tr>
</tbody>
</table>
Table 5. Demographics of Interview Participants.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age (years)</th>
<th>Gender</th>
<th>Para Swimming Eligible Impairment(s)</th>
<th>Para Swimming Sport Class (S/SB/SM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26</td>
<td>Male</td>
<td>Visual</td>
<td>11/11/11</td>
</tr>
<tr>
<td>2</td>
<td>28</td>
<td>Female</td>
<td>Physical (limb deficiency and hypertonia)</td>
<td>8/7/8</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>Female</td>
<td>Physical (hypertonia)</td>
<td>3/3/3</td>
</tr>
<tr>
<td>4</td>
<td>23</td>
<td>Female</td>
<td>Visual</td>
<td>12/12/12</td>
</tr>
<tr>
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Eight of 21 participants (38.1%) reported having current pain with an average intensity rating of 3.4 (SD 0.89), (on a 0 to 10 numerical rating scale, with 0 representing no pain and 10 representing the most severe pain). Participants experiencing pain reported the location of their current pain as follows: 25.8% reported pain in the shoulder, 9.5% in the arm, 9.5% in the upper back and lower back, and 4.8% in the abdomen, elbow, hip, and knee.

INJURY PREVENTION PROGRAMS AND TREATMENT

Six (28.6%) of the 21 participants reported participation in an injury prevention program, with four of the six (66.7%) reporting injury. Seven (46.7%) of the 15 participants who did not participate in an injury prevention program reported having a history of an injury. Injury prevention programs (as interpreted by the participant) ranged from a program at a national team camp to an individualized program that included stretching and strengthening 45 minutes each morning to prevent shoulder and hip injury.

Nine (42.9%) of the 21 survey participants reported receiving physical therapy treatment due to injury, 9 (42.9%) reported receiving chiropractic treatment, 10 (47.6%) reported receiving a massage due to injury, and 4 (19%) reported receiving no treatment at all. Treatments included kinesiotape (n=9, 42.9%), cupping (n=7, 33.3%), ASTYM (n=4, 19%), electrical stimulation (n=8, 38.1%), massage (n=16, 76.2%), pneumatic compression (n=7, 33.3%), and manual therapy (n=8, 38.1%). Three (14.3%) participants responded to an open-ended question on the survey regarding any additional information on swimming and swimming injury as it pertains to their personal experiences and reported they had improvement of symptoms following the implementation of stretching and strengthening programs.

PART II. INTERVIEW RESULTS

Six Para swimmers who were U.S. Paralympics Swimming resident team members and at least 18 years old participated in the qualitative interviews, with demographics presented in Table 5.

Para swimmers interviewed represented both genders with diverse impairments and classification sport classes. The resultant themes from the interviews were categorized into four main topic categories: training, injury risk, injuries, and treatment and return to sport (Figure 2).

Training Theme*: Training is individualized and requires knowledgeable coaching and support personnel.* Interviewees noted the wide array of physical impairments makes the attitudes and beliefs towards training and injury vary between individuals in Para swimming. All 6 participants reported coaches, medical staff, and training personnel have an impact on their swimming career and that having access to a comprehensive, multidisciplinary team and resources was important for their training needs. As noted by Participant 06:

"Para athletes [need to] know that they’re on that same elite level [as athletes without disabilities] and they need those same ... recovery tools or ..., prevention techniques. ... That’s just something that I’ve realized since, ... making my first National team is I need those things just like an able-bodied athlete does, maybe just in a different way."

Para swimmers also recognized the value of having their training supervised by someone officially trained and experienced in working with athletes with disabilities who could recognize and understand the balance between allowing them to be resilient and push, but not overdo it to the point that risks injury. As per Participant 04:

"I’m very thankful to have coaches watching me and making sure I’m doing the proper technique. ... that was especially a big thing in therapy. I really had to
have somebody help me because I used a lot of compensation methods that I never realized that I did until I was in therapy and I was supposed to be doing isolated exercises and I would compensate a ton. So they had to work really hard with me and help me to, to not compensate.”

As is the case for all athletes, interviewees also noted it is important for Para swimmers to gradually return to their training regimens after a hiatus to avoid injuries. Some interviewees reported that time off from swimming may impact Para swimmers more than swimmers without disabilities, further emphasizing the importance of cross-training and participation in other activities.

Injury Risk Theme: Injury risk is unique in Para swimmers based on their underlying medical conditions, impairments, and adaptations to accommodate for their impairments: As per Participant 03:

“I think at the same time there was no real way for me to get the same range of motion or pull down my right arm in order to match my left arm, which would have led to another form of compensation injury.”

Some Para swimmers reported they learned to do their pre-habilitation or injury prevention programs based on their personal experience. Swimmers with visual impairment who require tappers also have to develop strong relationships with their tappers to anticipate the wall of the pool and prevent injury. However, most swimmers do not get a chance to practice with their tappers until the time surrounding a competition.

Injuries Theme: Para swimmers, compared to swimmers without disabilities, may experience a greater impact from their injuries on their daily lives: Interviewees reflected that Para swimmers, compared to swimmers without disabilities, may feel a more significant impact from injuries as some Para swimmers reported the water and swimming improved their function and everyday symptoms from their underlying disabilities. As per Participant 06:

“The water ... makes my body feel better and ... I don’t feel as stiff and ... don’t experience as many aches and pains as I do ... when I’m not in the water. So when there is an injury ... preventing me from being in the water, ... it definitely makes me upset. [...] sad. (because it affects me a lot and I feel like ... it affects me a lot more than it would [affect] an able-bodied swimmer.”

Interviewees also reported that their injuries can both be preventable and unpreventable due to unique risk factors from their underlying medical conditions. Injury symptoms and clinical presentation may be atypical due to some Para swimmers’ underlying disabilities and their subsequent increased resilience and pain tolerance.

Treatment Theme: Interviewees reported both mixed experiences with medical treatment of their injuries and return to sport recommendations, with negative experiences causing significant barriers in their Para swimming career: One interviewee noted that replacing swimming with another activity is sometimes more helpful when recovering from injury or taking time off. Interviewees also expressed how swimming itself aids in the recovery process and how it assists with strengthening. Injuries as severe as fractures were noted by one interviewee with osteogenesis imperfecta and were not enough to hold her out of the pool for more than 3 days. Interviewees reported both positive and negative experiences and inconsistencies with medical care of their injuries - times when all of their specific medical needs were met due to great communication, but also when conflicting staff opinions limited training unnecessarily. Participant 01 and 03 summarized:

Participant 01: “the staff at [location omitted] ...was sometimes more of an obstacle than a help ... their head of a Sports Medicine didn’t want me back in the pool after I had a pretty good attack. One day they called the ambulance, the whole 9 yards. ... And I [told] him [that] my neurologist cleared me, neurologist said ‘I’m fine, I’m cleared to go... I can remember that really hurt my training pretty bad.”

Participant 03: “Injuries that were not caught ... in time or misdiagnosed. So ... we’ve had to limit what we can and can’t do as far as strokes. ... We were doing the wrong rehab program for quite some time, so we were only aggravating that initial injury to begin with.”

DISCUSSION

This study utilized a mixed-methods approach producing valuable data and perspectives on injuries, treatment, training practices, and participation in injury prevention in elite U.S. Para swimmers with physical and/or visual impairments. These results indicate that Para swimmers experience injuries at similar rates to swimmers without impairments. Additionally, the results of this study show there is a lack of injury prevention programs being utilized by Para swimmers and that individual Para swimmers have unique needs due to their disabilities and impairments.

The most common site of injury in the athletes in the current study was the shoulder, which is consistent with other studies that focused on Para swimmers,22 Para athletes across a variety of sports,8,10,12 and swimmers without disabilities.16,23 The percentage of U.S. Para swimmers reporting injuries in our survey was higher than what has been reported in other studies.10,12 However, it is difficult to compare the present study to others because of differences in methodology, including data sources and how “injury” was defined. Derman and colleagues evaluated prospective cohort data from a total of 3657 athletes from 78 countries at the Rio 2016 Summer Paralympic Games.10 The authors reported that within the sport of Para swimming 42 of the 492 Para swimmers (8.5%) sustained injuries during the Rio 2016 Paralympic Games.10 Whether injuries were acute, acute on chronic, or chronic was not reported specifically for Para swimming. Willick and colleagues examined 62 injuries in Para swimmers (12.4% of all Para swimmers) during the London 2012 Paralympic Games.10 Of these injuries, 47% were reported to be “acute” and 16% were reported to be “acute on chronic.”12

The current study’s retrospective data was not specific to one event or time point, but rather across the participants’ careers as competitive Para swimmers. While studies conducted by Derman10 and Willick12 reported prospective data from a much larger sample size during the duration of
a single Paralympic Games, this present study is the first to report data exclusively from U.S. Para swimmers, specifically gathering data about injuries that impacted weekly training throughout the swimmer’s career. This present study focused on injuries that altered weekly training or competition participation, while studies conducted by Derman and Willick included injuries that may not have altered weekly training or competition participation.

The participants in the present study reported more chronic than acute injuries compared to the those included in Paralympic Games injury surveillance studies, which could be explained by gathering injury history data that may not have needed medical attention. Thus, the present survey may have been more sensitive in capturing chronic injuries compared to Derman and Willick studies. This is especially true if Para athletes are more likely to seek medical attention for acute injuries and not for chronic injuries at the Games, which may occur for multiple reasons. As reported by participants in this study, Para swimmers may have a complicated medical history and some have reported negative experiences when seeking medical care for symptoms leading to unnecessary training/competition restrictions. The qualitative interview discussion about injuries noted a common theme reflecting Para swimmers’ beliefs that time in the water improved their function in everyday life. Therefore, time away from the pool due to injury may be of greater detriment for Para swimmers than swimmers without disabilities. Fear of repeat negative experiences may discourage Para swimmers from seeking medical care until absolute necessary, such as in acute injuries causing significant pain or functional limitations, or only when chronic injuries have been exacerbated and come to a point where they are no longer tolerable. Further evidence is needed to understand the impact of an injury on various psychosocial, functional, and sports participation outcomes in Para swimmers compared to swimmers without disabilities.

Current guidelines proposed for injury prevention in swimmers without disabilities suggest that strength training be supervised by a certified strength and conditioning specialist, athletic trainer, or physical therapist to prevent injury. There are no published guidelines for those with impairments/disabilities. Most survey participants in our study (90.5%) reported supervision of their out of pool resistance training, with 61.9% being at least occasionally supervised by an athletic trainer, strength coach, or physical therapist, therefore meeting guidelines for best practice of strength training, at least according to literature for athletes without disabilities. The majority of survey participants (90.5%) also completed stretching as part of their regular training routine, which is in alignment with current recommendations for swimmers without disabilities. However, since both of these strengthening and stretching guidelines were created for swimmers without disabilities in mind, further research is needed to evaluate effective techniques for strengthening and stretching specifically in Para swimmers, with consideration of the broad spectrum of medical diagnoses, impairments, and functional abilities Para swimmers represent.

Although many of the survey participants reported performing resistance and stretching programs, while 15 (71.4%) reported they did not participate in a specific injury prevention program, half of this group reported an injury. Out of the remaining survey participants who did participate in an injury prevention program, 66.7% of these participants still reported an injury. In swimmers without disabilities, there are proposed algorithms for injury prevention, including careful monitoring of training volume, intensity, and duration by coaches and physicians while also looking out for stroke alterations that could represent compensation for pain or injury. It is also recommended that swimmers without disabilities in general work on endurance training (strengthening, stabilization, and flexibility) of core muscles to avoid excessive anterior pelvic tilt and lumbar lordosis, and also focus on scapular strengthening before primary rotator cuff muscles strengthening as part of their injury prevention program. However, due to the uniqueness of each Para swimmer, the results of the present study highlight that an injury prevention plan should include individual analyses of the Para swimmers’ biomechanics and a strong understanding of how their underlying medical condition impacts their movements in the water, fatigue, and risk of injury. Those that participated in the qualitative portion of this study also emphasized the value of having support from a multidisciplinary team well-experienced in working with Para athletes. In collaboration with the Para athlete, coach(es), and other healthcare specialists (e.g. sports psychologist, nutritionist, etc.), such individualized injury prevention programs could be prescribed by physiatrists, sports medicine physicians, physical therapists, and/or athletic trainers experienced in evaluating the needs of the Para athlete.

LIMITATIONS

The small sample size of this study limits the ability to generalize the results, and prevents detailed analysis by individual impairment types and sport classes for classification. Further limitations included the potential for response bias and having to rely on the participant’s understanding and interpretation of their injury diagnosis. Injury prevalence or incidence was not able to be calculated from the data as the survey did not define a time period for participants to report injuries. A specific definition for “injury” and “injury prevention program” also was not provided to survey participants, possibly leading to different interpretations of what entails an injury or injury prevention program, and over- or under-reporting of each. Moreover, the survey inquired about injuries that altered weekly training versus injury that caused the participant to miss a competition, but did not gather data about injuries that did not result in these consequences, thus potentially underrepresenting the injury history of Para swimmers in our study.

CONCLUSION

Injuries that alter weekly training are common in U.S. Para swimmers, although only a small number participate in injury prevention programs. Qualitative results revealed that many Para swimmers believe they experience injuries based on their specific impairments and compensations. Injury prevention programs should be specifically designed for in-
dividual Para swimmers due to the difference in training needs based on underlying medical conditions, impairments, and function. Future research should examine coaching knowledge and whether access to individualized, multidisciplinary programs can reduce injury prevalence among this at-risk population.

CONFLICTS OF INTEREST
None.

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REFERENCES


SUPPLEMENTARY MATERIALS

Appendix 1

Appendix 2
Medical management of the circus performer encompasses a wide variety of multicultural, transdisciplinary and multifaceted decision-making considerations. There is a paucity of research evidence investigating both the unique diversity of skill sets and cultural considerations in addition to injury patterns of performers within the circus environment. Since a previously established framework for supporting the health and well-being of the circus performer across various aspects of medical management does not exist in the literature, most recommendations in this regard must come from practical experience working with this highly specialized performance athlete population. The purpose of this clinical commentary is to provide the reader with a greater understanding of the unique challenges associated with the medical management of performance artists and acrobats as well as recommendations for developing an integrated approach for mitigating injury risk within a highly specialized, diverse athlete population.

Level of Evidence
5

INTRODUCTION

Circus performance encompasses a wide variety of disciplines, ranging from acrobats, artistic characters, former Olympic-level and professional athletes, and musicians, where unique skill sets are creatively integrated with artistic components and athletic ability to create show performance.1–3 Further, within performance acrobats, the individual performers are highly specialized with backgrounds which include ballet, dance, gymnastics, and acrobatic sport. As a result of these specializations and performance demands, the medical management of these performers requires an understanding of the complex interaction of both discipline specific considerations and performance act requirements. Despite the complexities and uniqueness of the circus performance environment, an established and evidence-supported framework for managing the health and well-being of this performance population does not exist. Therefore, recommendations and suggestions to the field in regards to implementation of a multi-faceted medical management program are primarily anecdotal and based upon practical experience. This commentary will focus on providing the reader with a greater understanding of the unique challenges associated with the medical management of performance artists and acrobats as well as recommendations for developing an integrated approach for mitigating injury risk within a highly specialized athlete population that is diverse in many aspects.

NEEDS ANALYSIS

Given the diversity of performer backgrounds within the circus environment, performance demands and functional capacities of each performer and their performance acts must be studied closely. Nomenclature specific to performance arts includes "artist" in place of "athlete", however performance artists include both acrobatic and non-acrobatic performers. For the sake of clarity, performance artists, or non-acrobatic performers, and performance acrobats (Figure 1) must be distinguished separately within the framework of this clinical commentary. Further, these disciplines have been previously characterized as either acro-
bats, non-acrobats or musicians.\textsuperscript{1}

In order to further distinguish between types of performers, a classification system of either sudden load performers, non-sudden load performers and musicians has also been used.\textsuperscript{4} Sudden load performers would be those who incur a sudden, substantial increase in physical compression or distraction loads as previously defined by Orlando et al.\textsuperscript{4} Skill sets such as diving, gymnastics, trampoline, partner lifting or catching, hand balancing, contortion (Figure 2), ballistic style dancing and aerial movements would be categorized as sudden load.\textsuperscript{1,4}

Non-sudden load performers may include jugglers (Figure 3), artistic image dancers and clowns, however features within the skill sets of these performers may also be dynamic and sudden load in nature, indicating a diversity in skill sets across all performer disciplines.\textsuperscript{1}

Beyond the primary act requirements specific to a performer’s discipline, a show performance also includes cue tracks, or minor performances such as brief dancing, character or image expression sequences specific to creating an artistic effect on stage for a particular act. While the cues required for each show may vary and generally have performer rotations, they do require specific movement demands which may or may not be similar to those of the performer’s specific act while contributing to overall performance workload.\textsuperscript{3} For example, a dancing animal cue which requires patterns of repeated lateral movement or sustained trunk flexion contrasts with the demands of overhead traction and torsion placed on the shoulder of a high bar acrobat who may be required to perform both in show performance. The ability to perform at a high-level within their discipline-specific act while also mastering artistically influenced movement patterns required of their cue track demands adaptability, continued refinement and versatility within the performer’s skill set. It is also important to recognize that no two acrobats have the same load demands within a performance act, despite similar backgrounds and disciplines, as implementation of their skill set within an act is greatly influenced by the timing of choreographic sequences, which are integrated for the sake of artistic expression.

INJURY RISK MITIGATION CHALLENGES

While one of the earliest studies on injuries in the circus performer population found injury rate to be lower in comparison to similar sport disciplines within the National Collegiate Athletic Association,\textsuperscript{1} research on this unique and diversified demographic has evolved.\textsuperscript{2,3} With show opportunities expanding and performers becoming more specialized, injury risk is more apparent and worthy of further discussion and investigation.\textsuperscript{2,3} Performance in circus requires high workloads through repetitive training and frequent show performance exposures which creates injury risk comparable to that in sports, with 7.3 to 9.7 injuries per 1000 artist performances.\textsuperscript{1–3,5} These injury rates in circus are comparable to those found in a study of practice injuries in NCAA sports, in particular Fall season sports which demonstrated injury rates of 7.4 injuries per 1000 exposures with the highest injury risk sport being women’s soccer at 9.3 injuries per 1000 exposures.\textsuperscript{5} The diversity of disciplines within both acrobatic and non-acrobatic performer profiles further influences a unique variety of injury conditions and presentations which require creativity while progressing an injured performer back to show performance.\textsuperscript{1–3} These high workloads within circus performance require frequent, repetitive movements and dynamically loaded patterns through extreme ranges of motion which contribute significantly to time-loss from training and performance due to a variety of acute, traumatic, and chronic injuries.\textsuperscript{1,2,6}

Show exposures may consist of 8–10 shows per week over
the course of 5-6 consecutive days, not including "off-days" that may require international travel by bus, air or train to the next tour city which can negatively influence sleep quality, recovery, performance and injury risk as shown in a variety of athletic populations. Fluctuating show performance times across various time zones within all seasons are variables that can negatively influence performance and recovery. Further, due to the nature of training sessions and show performances being held indoors across a variety of global venues at various times of year, lack of sun exposure and vitamin D deficits, especially during the winter and early spring seasons, must be considered as potential contributors to injury. Given the complexity of show performance and lifestyle demands, injury risk within the circus performer population is a constantly evolving variable that needs to be monitored and managed, especially within a highly specialized show performance environment where “backup performers” and shared allocation of show performance “minutes”, in load management vernacular, are not always available and possible.

Another unique challenge of mitigating injury risk as it relates to the volume and frequency of circus performance training and show exposure is the lack of a true "offseason" period. Unlike professional sport where offseason training commences following the conclusion of the competitive season, circus performances continue year-round with variable, brief show performance "breaks" ranging from a few weeks or longer and occurring between tour legs, which typically consist of a 9-12-week period of continuous touring and an intensive show performance schedule. Further, given the unique nature of what performers are required to do on stage as well as the specific equipment and technical aspects required within their acts, access to these apparatuses during these performance breaks is not always ensured which could contribute to injury risk when resuming training and show performance if there is a period of act specific "de-loading". These exposures to the potential risk factors of 1) fluctuations in act-specific training 2) decreased loading patterns both during and after sporadic tour and show performance breaks and 3) high volume training and show performance workloads over the course of a prolonged period of time can significantly, through workload spikes following periods of decreased training, contribute to injury risk in the circus performer as demonstrated in other athletic populations. Further, depending on performance group and entertainment company size, the exposure risk may be heightened when back-up performers are not available across the show and/or for a particular act which would then require the highly specialized performers to perform in their assigned role during each show, essentially compromising periods of relative rest where said performers would still perform but in a reduced capacity on a show-by-show rotation basis. In the presence of larger casts with built-in act and show performance rotations, the ability to implement these relative rest periods may potentially become more practical. However, even in this ideal situation, injuries across the show can alter line-ups and result in modifications to even the best planned rest-rotation schedule.

Given the diversity of cultures represented within circus performer disciplines, it is important for the practitioner to be sensitive to varying levels of understanding and interpretation of injury by the performer. In some cases, pain may be perceived as an acceptable or expected aspect of performing, a "badge of honor" in some respects, that is not deemed as threatening in the current moment. Some performers would attempt to perform through pain and disregard medical opinion rather than feel as if they "let down" the fellow members of their performance team or act. However, it is in these situations where the intersection of medical recommendations and emotional intelligence of the practitioner must be most robust and steadfast as prolonged injury conditions without proper medical evaluation can result in extensive time loss due to injury and potentially career threatening injuries. Guided by a collaborative decision-making approach which includes the coach and associate stakeholder who can assist with language translation as needed, education on the risk of career endangerment and harm potentially which can be caused to fellow performers within an act when a performer is not at full health should be broached in these discussions to ensure better understanding. Despite the existence of self-induced pressure to perform even with a significant musculoskeletal injury, show tracks and cues can be modified without creating increased risk to injured performers but still allowing them to perform in some capacity in show performances. These aspects of determining show performance status further illustrate the need for a collaborative, understanding and openly communicative decision-making structure within the circus environment.
As it relates to consultant-provided medical care, standards, systems and injury management recommendations vary significantly on a global scale. The interpretation of and recommended treatment interventions for a variety of injury conditions can vary greatly, with the heightened risk associated with circus acrobats in particular heavily influencing what may be perceived as more conservative timelines and restrictive recommendations.

Further influencing dynamics of the performer-practitioner healthcare relationship are the cultural expectations for what information relevant to their injury is expected, what is considered important in terms of how an injury is described and managed, and how involved the individual desires to be in the decision-making process while engaging with their practitioner. In some cultures, "less is more" in that minimal information is preferred as it relates to best understanding an injury condition and pathology.16,17 Misunderstandings or lack of awareness when educating and engaging the performer in their own healthcare can occur if the practitioner is not sensitive to cultural differences and language discrepancies, negatively influencing injury management outcomes and producing intercultural communication conflicts.17–20 Acknowledging and understanding potential differences in beliefs regarding health, injury or illness across a variety of ethnic groups is likely to reduce gaps in practitioner-performer communication and ensure a more positive outcome.19,20 For example, navigating the medical referral process for a Russian performer primarily speaking Russian and minimal English who sustained a shoulder dislocation injury on tour in Japan and is being seen by a local doctor who speaks neither English nor Russian will require linguistic diplomacy, planning, and level-headedness to ensure a desirable outcome. Certainly, the utilization of an established global medical referral network or telehealth services could meet the needs of the injured performer and provide diagnostic clarification in situations where language discrepancy or limited medical specialty services exist.

PSYCHOLOGICAL CONSIDERATIONS

Due to the unique interaction of both athletic ability and artistic expression required of the circus performance artist and acrobat, the emotional, social, and cognitive loads experienced by these performers needs to be considered.

Injuries as well as other critical circus situations such as on-stage accidents, show cancellations, and relationship issues can elicit a myriad of emotional responses which impact the health of artists. Furthermore, contrary to most sports, circus requires a deep level of emotional embodiment.21 Hence, providing an emotionally safe environment is paramount in supporting the creative growth and performance of the performers.22 In this regard, researchers have found that emotional regulation is integral to performing artist success and that it can reduce the occurrence of accidents and near misses in contemporary circus arts.22,23 It is thus essential for practitioners to address the emotional experiences of a significant event to help artists recognize, understand, label, express, and regulate emotional content attached to the experience. Active listening where the practitioner expresses curiosity by asking questions rather than making judgements can be a powerful tool. Processing emotional experiences, both verbally and through movement, is a crucial step towards enhancing psychological functioning and wellbeing in performing artists. In fact, the absence of emotional regulation support can result in long lasting emotional consequences thereby affecting the likelihood of developing a variety of health problems.24

Many circus acts are performed within a team environment and, therefore, optimal performance is influenced by the development of shared coordination and cohesion among teammates.25 Because safety at times depends on coordinated precision among artists as well as technicians, band leaders, and stage managers, it is thus important to stay attuned as practitioners to the quality of the social interactions experienced by artists. Lack of team cohesion and coordination increases social anxiety levels and mistrust within a team and could, for instance, reduce work enjoyment, slow down the reintegration process after an injury, and impede performance.22,26 In addition, there may be limited opportunities for socialization outside of the touring show environment, increasing the negative impact of poor social connections on artists’ overall wellbeing. Establishing team processes and support systems to foster trust, respect, and effective communication amongst artists is key.22,27

Improved awareness and understanding of socio-cognitive skills can favor best practice within a circus medical management program. For instance, it has been shown that artists with low self-efficacy are twice as likely to get injured compared to their higher self-efficacy counterparts. Specifically, a low level of either success or personal accomplishment may be predictive of injury.28 Lower self-efficacy is also associated with elevated anxiety and fear of failure and injury which has direct impact on motor performance because of its influence on attentional control.22 Specifically, elevated anxiety can make artists more inclined to reinvest their knowledge and overthink. This “paralysis by analysis” phenomenon disrupts movement automaticity resulting in a robotic performance and lower overall performance quality. In some cases, this disruption in automatic cognitive patterns can lead to Lost Movement Syndrome (LMS), a psychological condition in which athletes find themselves unable to perform a skill that was previously automatic. Research shows that this condition can negatively influence career potential.29 It is important to note that some individuals are more prone to performance deterioration under elevated anxiety. For instance, perfectionism, ruminating thoughts, and knowledge reinvestment have been identified as potential psychological mechanisms influencing motor performance decline. Hence, mental skills training can be highly effective within the circus community to enhance cognitive functioning.22,26,30

Contrary to sports where success is determined by an end-score regardless of spectator involvement, performing arts strive to immerse the audience into the performance of the artists. Hence, stage performance requires unique mental capacity to produce both captivating motor tricks and artistic display to evoke a crowd response which greatly influences how success may or may not be defined. Beyond what would be required on stage, the ‘circus life’ demands described through this commentary (e.g., frequently chang-
ing country, venue, and lodging environments) may naturally impose psychological demands and challenges on the performer which can influence fatigue, emotional wellbeing, on-stage performance, and injury risk and/or presentation.28

RECOMMENDATIONS

Given the diversity of skill sets and backgrounds possessed by the circus performer, the clinical examination, treatment, and return to performance decision-making processes must consider both the unique demands required of a highly specialized performance cohort in addition to the wide-ranging influence and vested interest of numerous stakeholders who are involved in ensuring an optimal performance environment for these performers. Successful medical management of the circus performer should thus account for a wide variety of considerations that influence injury mitigation, health and performance.3

COMMUNICATION AND COLLABORATION

Bolling et al. have thoroughly described and outlined the complex and dynamic interactions between circus stakeholders, ranging from technicians and wardrobe personnel to stage managers and the artistic team, as they relate to performer healthcare management.5 Namely, they highlighted that effective communication and collaboration strategies facilitate healthcare management when multiple, diverse professionals are involved. In the circus environment, it is advised to adopt a flexible mindset that is sensitive to the “when and where” aspects of effective communication. This requires an open-minded, ego-quiet, and understanding attitude. For example, as it would relate to understanding the perspective of a member of the wardrobe department, it may not be so relevant as to why a performer’s shoulder range of motion would need to be limited due to an acute acromioclavicular joint sprain but, rather, what modifications would be needed within the costume to protect this joint from possible compromise or what permissible color and style of supportive taping that can be applied by the medical department while still maintaining a certain required aesthetic on stage. On the contrary, it would be crucial for the act coach to know what range of motion limitations are present in order to possibly modify act sequences which still allows the performer to safely participate and not at the cost of aggravating the current condition further.

Internally, daily meetings and correspondence via medical reports with artistic directors, stage managers, and coaches provides a medium for open dialogue and feedback regarding medical management strategies on a case-by-case basis. Availability and open-mindedness are critical in not only strengthening communication with both the performer and stakeholders but allows the medical provider to seek out a greater understanding of the nuances and unique act specific demands relative to that performer’s particular role within the show performance. Robust communication practices between medical providers and coaching staff are likely to yield more favorable outcomes relating to injury and availability.31

Developing a global medical network external to the show can be a tremendous resource for accessing both local and international medical providers and should include a variety of practitioners, including, but not limited to, general medical doctors, orthopedic doctors, sports psychologists, nutritionists, chiropractors, and massage therapists. Given the unique demand of frequently moving show tours combined with the cultural aspects of circus performer medical management, it is important to integrate external medical providers who have either previously been exposed to managing circus performer injuries in the past or regularly consult with athletes in high performance sport to best comprehend the very unique set of skills and considerations when medical recommendations are provided to and for an injured performer. Virtual or telemedicine and translator services associated with these consultations with preferred doctors and specialized health providers present an opportunity to still access reliable and trusted medical care remotely when language differences and medical practice standards vary greatly on a global scale. Providing the consulting doctors with information in advance that is pertinent to the unique act demands and specialization of the performer, specifically through video of a particular act or injury episode, as well as relevant considerations for returning the performer back to full show performance in regards to cue track, act sequences and co-performer interactions, is recommended.

TRANSDISCIPLINARY APPROACH

The communication and collaboration styles described above are in line with a transdisciplin ary approach. According to Karol et al.,32 within this approach professionals that are part of the rehabilitation team defined patient needs collaboratively using their unique knowledge and experiences. It moves away from the “quantitative, typically reductionist and mono-disciplinary approaches to physiology, motor-learning, biomechanics, and psychology.”33 In sport, transdisciplinary rehabilitation teams are usually composed of physical, psychological, technical, and managing professionals plus the athlete.34 Including the athlete across the entire rehabilitation process is at the core of this athlete-centric approach as it was shown to increase athletes’ empowerment, engagement, and motivation in addition to decreasing burnout for sport medicine practitioners.35 Further, environments which foster collaboration and trustworthiness amongst staff while providing athletes with a positive vision, clear communication and continued support throughout training programs resulted in more favorable outcomes in regards to injury reduction and increased game availability.36

At a ‘micro-level’, adopting a transdisciplinary approach can translate into rehabilitation programs which integrate neurophysiologic and neurocognitive aspects of injury.37,38 In circus, such programs would entail educating the performer on information processing, perceptions, sensations, and emotions experienced during the task. Then, the performer and medical provider, with the collaboration of the strength & conditioning coach, mental performance specialist and artistic coach, can generate ideas to design in-
novative and engaging rehabilitation exercises that are representative of the physical, cognitive, affective, and social aspects of a particular skill or performance specialty. The rehabilitation program is thus more holistic in nature and not solely focused on the physical aspects of the healing process. Although promising, this approach deserves further empirical research to clearly highlight the depth of benefits.

At the macro-level, transdisciplinary processes consider the complex interactions of socio-ecological systems and could better support a health enhancement program. Bolling et al identified three injury prevention strategies in the realm of circus: safety, load management and preparation.3 While the strategies described were mainly physical (e.g., performing exercises) or organizational (e.g., adapting the schedule), expanding the load management and preparation strategies to include the cultural, social, cognitive, and affective aspects is also recommended.

Given what may be a condensed schedule during show weeks, training time for individual and group acts may either be limited or not readily available depending on the tour plan dynamics, facility lay-outs and technical inspection requirements which ensure proper safety of performance apparatuses. Therefore, traditional periodization and load management methods used in sports may not necessarily be applicable for the circus environment. It is important to consider that load demands in the circus population are not uniform, vary across disciplines and require varying management strategies across these disciplines. For example, a contortionist troupe may benefit from repeated, high volume static load exposures in both training and show performance to maintain soft tissue pliability whereas trampoline acrobats would require a more closely monitored and orchestrated training plan to ensure that training loads do not compromise their ability to recover and perform in shows given the ballistic, repetitive nature of their performance act.

In addition to the specificity of the task to be performed, contextual situations can also greatly impact the perceived load of a performance schedule. For instance, the cognitive load of learning new cues in the show can impact the level of fatigue of the artist, even if the cues are not physically demanding. Similarly, trying a high-risk trick for the first time might increase anxiety level, emptying the artist’s energy ‘tank’ faster. Finally, conflicts arising between team members or partners can be socially heavy to manage, which are also influenced by cultural background. Paying attention to the cognitive, affective, and social load/needs can help practitioners better design holistic preventive plans. By working in harmony with other specialists whom are both internal and external to the show, increased psychological support can be planned when the performance schedule involves high cognitive demands. Relaxation, meditation, or mindfulness sessions can be integrated to the daily schedule to help alleviate anxiety in addition to implementing a psychologically safe space to help artists communicate among themselves to avoid or manage social tension. According to the socio-ecological model of resilience35 “environments that provide resources to develop or maintain optimal psychological, social, and physical well-being facilitate the capacity of individuals to withstand, overcome, and adapt to adversity”.40 This type of community-based approach is relevant to professional circus contexts as it ensures the development of both internal and external resources, so the individual feels fully supported.41

The development of resources can also optimize preparation prior to show. Warmups which encourage artists to activate both their body and minds while synchronizing familiar performance sequences with each other is thus recommended. Although research is scarce about the impact of holistic warmups,42 the authors recommend providing performers with a wide variety of tools for them to build an individualized preparation for performance. Educational resources by way of infographics translated to a variety of languages spoken on tour and posted on-site, guest speakers, periodic group or “question and answer” sessions, and daily interactions during both ongoing injury management sessions and treatments can be provided to best inform artists. This knowledge can then influence prudent decision making on the part of the performer as it relates to adequate preparation as well as other important habits which influence sleep, recovery, emotional well-being, nutrition, and hydration while on tour to mitigate injury risk.9

Because injury prevention is considered to be a dynamic and complex system, one must consider how elements of this system interact and change over time.5 Hence, the use of a subjective wellness and preparation questionnaire, such as a multi-item Likert scale which provides ratings for general fatigue, muscle soreness, emotional states, coping resources, and sleep quality, can be used to assess perceived recovery from previous training as well as readiness for same-day participation.43–45 Training plans can be effectively developed and planned according to show volume and context, act and cue rotations, and “stage” or training area availability each week, rather than over the course of an entire tour plan due to the spontaneous and ever-changing nature of the circus environment. Input provided from a multidisciplinary team of stage managers, artistic coaches, performer-coaches, show directors, technicians and medical providers can promote a transdisciplinary approach in managing training and show load exposures not just within individual performance acts but across the performance cast as a whole.

Future research should focus specifically on the individual cohorts represented within this unique performance population to further investigate the needs analysis and mental performance demands as well as injury patterns which may vary between acrobats, artistic characters, and musicians. Cohort studies focused on these varying performance groups will allow for injury surveillance and treatment protocols to become more specialized and ideally both enhance performance and reduce injury risk.

CONCLUSION

Medical management of the circus performer requires a transdisciplinary, multicultural, and multifaceted approach. The skill sets and performance requirements of circus performers are diverse and highly specialized with a wide variety of injury conditions which present. Collaboration and establishing clear lines of communication between
and with non-medical essential stakeholders, such as stage managers, artistic directors, coaches, and technicians, is integral to managing the many aspects of circus life which influence the healthcare and wellbeing of the performer. Effective medical management should consider social and cultural perspectives as it relates to interpretation and coping strategies related to injury as well as the unique psychological and physical load demands placed upon the circus performer. An established global medical network and educational initiatives can be instrumental in guiding the understanding and managing of injury as well as fostering a pro-active approach for achieving optimal performance, health, and well-being of the circus performer.

ACKNOWLEDGMENTS

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Optimizing Performance in Return to Play After Sport-Related Concussion in Elite Ice Hockey Players: A Sports Physical Therapy and Athletic Trainer Perspective

Mario Bizzini, PT, PhD

1 Human Performance Lab and Swiss Concussion Centre, Schulthess Clinic; Swiss Sports Physiotherapy Association

Keywords: sport-related concussion, return to play, ice hockey

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INTRODUCTION

In the last two decades, sport-related concussion (SRC) has received growing attention within the sporting world. High SRC incidence rates have been reported for contact team sports such as rugby, American football and ice hockey, whereas men's football (soccer) is associated with the lowest concussion incidence.1 Furthermore, higher rates of SRC were found in female football and ice hockey players during competition and training.

Since 2017, the Concussion in Sport Group (CISG) consensus statement has set the benchmark for physicians, athletic trainers, sports physical therapists and other healthcare providers involved in athlete care at any level of sport.2 Sport-related concussion is defined as a subset of mild traumatic brain injury without structural anomalies on conventional neuroimaging. Headache and dizziness are the most common acute symptoms of SRC that usually resolve after 7 to 10 days, although 10% to 15% of symptoms may persist for a longer period. The CISG statement describes 11 "Rs" of clinical SRC management: recognize, remove, re-evaluate, rest, rehabilitation, refer, recover, return to sport, reconsider, residual effects and sequelae, and risk reduction.2 After an initial period of 24 to 48 hours of physical and cognitive rest, a gradual return to sport (RTS) strategy is recommended.

Feddermann-Demont et al.3 recently presented a systematic approach for the initial examination, diagnosis, and management after SRC for high-level football (soccer) players, which includes a detailed RTS program. To date, this procedure is the only example of a sport-specific comprehensive strategy available for team physicians and healthcare personnel to treat SRC athletes.

In elite ice hockey, concussion protocols of the National Hockey League (NHL)4 and International Ice Hockey Federation (IIHF)5 exist and are consistent with the CISG consensus and RTS guidelines. While the CISG-RTS guideline entails generic activity descriptions (Table 1), the NHL protocol provides an example of a graded return to play progression for ice hockey players after SRC.

This clinical commentary presents a detailed RTS program for high-level ice hockey, which is based on the most recent recommendations as well as clinical and practical experience. The proposed comprehensive protocol specifically aims to optimize performance in elite male and female ice hockey players after SRC.

RETURN TO SPORT

While the team physician (or designee) supervises the RTS protocol,2,3 sports physical therapists, athletic trainers, and conditioning coaches closely cooperate to monitor the injured player throughout the various RTS stages.

Based on CISG guidelines, SRC players are progressively exposed to training activities (known as graduated RTS progression) that do not provoke or worsen symptoms (Table 1). There should be a period of at least 24 hours (or longer) for each progression step. If any symptoms worsen during exercise, the athlete should return to the previous stage.2 The process from one phase to the next should be individualized based on the current signs and symptoms, and on the unique characteristics (i.e. age, experience and skills) of each player.

The 2016 consensus statement on RTS defines three elements of the "RTS continuum": return to participation, return to sport and return to performance.6 While the ultimate aim of returning to pre-injury performance level is ideally reached after complying with the consensus RTS process, the goal of the supporting staff is to safely and optimally guide the athlete through the "training to perform" regimen. In a recent editorial, Reinhold7 highlighted that sports physical therapy should aim to optimize performance: the key concept (or the "performance spectrum continuum") not only involves helping the athlete to restore

ORCID # 0000-0002-4161-9163
Tel: +41 44 3857585
Email: mario.bizzini@sportfisio.ch
Table 1. Graduated Return to Sport (RTS) Strategy of the Concussion in Sport Group (CISG)

<table>
<thead>
<tr>
<th>Stage</th>
<th>Aim</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Symptom-limited activity</td>
<td>Daily activities that do not provoke symptoms</td>
</tr>
<tr>
<td>2</td>
<td>Light aerobic exercise</td>
<td>Walking or stationary cycling at slow or medium pace. No resistance training</td>
</tr>
<tr>
<td>3</td>
<td>Sport-specific exercise</td>
<td>Running or skating drills. No head impact activities</td>
</tr>
<tr>
<td>4</td>
<td>Non-contact training drills</td>
<td>Harder training drills, e.g. passing drills. May start progressive resistance training</td>
</tr>
<tr>
<td>5</td>
<td>Full contact practice</td>
<td>Following medical clearance, participate in normal training activities</td>
</tr>
<tr>
<td>6</td>
<td>Return to sport</td>
<td>Normal game play</td>
</tr>
</tbody>
</table>

Consensus adapted from McCrory et al.2

their baseline function(s), but also requires working with them to improve, enhance and optimize performance.

OPTIMIZING RETURN TO PERFORMANCE

From a sports physical therapy and athletic trainer perspective, there is a need to be more actively involved in the RTS process rather than passively guiding the athlete.

While it is paramount to closely monitor SRC symptoms (i.e. before/during/after exercising), the inclusion of additional individual-adapted training activities can help the athlete in their "training to perform" at the different stages of the RTS program (Table 2). Table 2 outlines an example of a suitable RTS program for elite ice hockey players with SRC: the athlete should not only progress through the RTS stages, but also work on any deficits linked directly (i.e. balance abilities) and/or indirectly (i.e. reactive capacities) with the SRC.

In Stages 2 and 3 of the recommended program, the player is often supervised by the sports physical therapist or athletic trainer: while the focus is set on aerobic exercise (initially using a stationary bike or elliptical trainer to avoid neck/head impact) and initiating light resistance training, further elements can be added to facilitate player recovery.8–10 In the gym, the player may use skates and a stick for balance and coordination drills, and the slide board for (controlled) agility drills (Figures 1, 2, 3). While the player is still far away from the ice, the additional neuromuscular training—which should be role-specific depending on whether the affected athlete is a player or goalkeeper—enhances sport-specific reactive stabilization strategies and promotes a positive psychological attitude within the overall training regimen.

If symptoms persist for more than 10 to 14 days, the athlete should be referred to a healthcare professional with concussion management expertise.2,11 In particular, this is the case for players dealing with vestibular and/or oculomotor deficits (the topic of which is beyond the scope of this commentary), who often require comprehensive and targeted management.11–13

Deficient (or insufficient) activation of the deep cervical muscles is a common clinical observation in athletes after SRC,14 and it is therefore recommended to implement a neck stabilization/strengthening scheme in the RTS program usually during Stage 3 when SRC symptoms gradually resolve (Figure 4, 5). Despite the controversy surrounding this aspect of cervical involvement, a stable and stronger neck may contribute to a lower risk of further injury in athletes post-SRC.15–19

Within Stage 3, SRC players can begin with easy skating (while respecting the sub-symptom threshold) and before engaging in non-contact training (Stage 4.1), a basic set of on-ice drills is recommended (Stage 3.2). The assumption that a symptom-free player in the gym will remain symptom-free on the ice should be avoided; for example, if dizziness caused by head and/or body rotations has resolved with specific vestibular exercises,20 turning and pivoting on the ice may invoke renewed symptoms of head pressure or dizziness. Therefore, by allowing the player to proceed through a set of simple drills, where linear and circular/rotational moves (forward and backward) with simple and dual tasks (i.e. adding puck control, focusing on a fixed/moving target) are performed, the player is then able to feel...
<table>
<thead>
<tr>
<th>STAGE</th>
<th>AIM(S)</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Symptom-limited activity</td>
<td>Daily activities that do not provoke symptoms (e.g. 10 min of slow walking)</td>
</tr>
</tbody>
</table>
| 2     | Light aerobic exercises (unspecific) | a. Cardiovascular exercise on stationary bike; 25-40 min including warm up and cool down; controlled activities, low to moderate intensity (ca. 70% HR max); control for stable head/neck position while exercising  
   b. Mobility/stretching, stabilization and controlled balance (double and single stance) exercises |
| 3     | 3.1 Aerobic exercise (progression) | a. Introduce interval training on stationary bike (or elliptical, treadmill not first choice because of head/neck impacts); 25-40 min including warm up and cool down; controlled activities, moderate intensity (ca. 70-80% HR max); control for stable head/neck position while exercising  
   b. Body training (no resistance/light elastic resistance)  
      - Mobility and stretching exercises  
      - Neck stabilization exercises (no resistance)  
      - Trunk strength/stabilization exercises (no resistance; no explosive movements)  
      - Basic lower/upper extremities strength exercises (light elastic resistance) in the 3 planes of movement  
      - Balance exercises (double and single stance) on unstable surfaces |
|       | 3.2 Ice hockey-specific exercises | a. Warm up - free skating - for 10 min at low/moderate intensity  
   b. Basics skating with rotation/changing of direction  
      - Skating forwards, backwards, sideways, stop & go (not explosive)  
      - Skating in the face-off circle, figure of 8 between the two face-off circles  
   c. Technical training with the stick/puck (1:1)  
      - Basics: stickhandling, short/long passing; easy shooting on targets |
| 4.1   | Non-contact ice hockey training drills | a. Cardiovascular training on the ice  
      - Warm up - free skating - for 10 min at moderate intensity  
      - Interval skating at higher intensities (ca. 90% HR max) with sufficient breaks  
      - Cool down for 5-10 min at low intensity  
   b. Technical training (with small group of players)  
      - Small size game  
      - Short/long passing  
      - Shooting on goal  
      - Selected drills with passing/shooting  
      - Agility and reactive quickness drills  
   c. Body training (incl. elastic resistance)  
      - Mobility and stretching exercises  
      - Neck stabilization exercises (elastic resistance)  
      - Trunk strength/stabilization exercises (incl. free weights)  
      - Basic lower/upper extremities strength exercises (elastic resistance; free weights)  
      - Balance exercises (double and single stance) on unstable surfaces  
      - Agility and reactive quickness drills  
   d. Strength training  
      - Keep resistance below about 80% 1RM, no classic weight lifting or exercises with head below the level of the hips (e.g. back extensions on a bench)  
      - Progressively increase external resistance for multi-joint exercises |
| 4.2   | Ice hockey training drills with controlled contact | Participation in team training with controlled contact situations (checks on players, checks on boards)  
   Progressively increase intensity in all training drills  
   For goalkeepers: all movements; drills with players shooting (incl. slapshots) on goal from different angles |
| 5     | Full contact practice (team) | Following medical clearance, participate in normal team training  
   a. Cardiovascular training; to be continued |
(and the coaches can observe) whether they are experiencing symptoms during these movements on the ice or not (Figure 6). The ability to master these drills on the ice without symptoms improves the player’s confidence and raises the chances that they will be able to resume non-contact team practice efficiently.

Ice hockey is a fast-paced, contact team sport that requires high levels of reaction time and decision making, and athletes after SRC need to master motor and cognitive skills concurrently. Affected players usually experience difficulties with quickness and reactivity drills, which confirms recent findings on impaired reaction times during sports-related movement tasks.21,22 The inclusion of cognitive reactive agility drills with dual or multitasks (e.g. visuomotor reaction time training with the FITLIGHT® system) is therefore an important element in the "training to perform" part of Stage 4 and beyond (both in the gym and on ice).23,24 (Figure 7, 8) In addition to strength and conditioning training, these cognitive reactive agility drills are also necessary to minimize subsequent injury risk.25,26

At Stage 5 of our proposed RTS strategy, the player needs, on average, 4 to 5 full team training practice sessions (including unrestricted contact) before they can be considered completely mentally and physically ready for participation in competition games. As previously mentioned, this process is highly individual and should be based on both the athlete’s response and staff judgement of the athlete’s performance during training. The psychological readiness for competition is crucial, and the use of the Injury-Psychological Readiness to Return to Sport (I-PRSS) tool is helpful to assess the player’s confidence in performing at the last stages of the RTS scheme.27,28 Neurocognitive testing (not discussed here) should also be used as part of the RTS decision-making process.11 Depending on the position, role and importance of the player within the team, the coaching staff often plan a number of games with increasing ice time (usually with the farm team) to allow the progressive return of the player to competition. With appropriate monitoring of the player’s training progression and close interaction with the player, the medical and technical staff can best support the athlete in the "training to perform" stage of the RTS program, which should ideally be a shared decision-making process among these stakeholders.6 Ultimately, RTS after SRC should only occur with medical clearance from a licensed healthcare provider who is trained in the evaluation and management of concussion.15

CONCLUSION

Sport-related concussion is a severe and complex type of injury requiring specific rehabilitation management and a

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Figure 2. Balance/stabilization on board with stickhandling and moving the puck between two plates (duration/sets to be adapted)

RTS protocol following the CISG guidelines. While respecting these principles, the supporting team comprising a sports physical therapist and athletic trainer should work with the athlete to restore function as well as optimize and enhance their performance. The athlete is constantly supervised by the medical team during this process. Elite ice hockey players post-SRC should not only be symptom-free and able to participate in unrestricted practice and games, they should also be optimally ready at both physical and mental levels to perform with minimal re-injury risk. This clinical commentary has described a comprehensive RTS ice hockey program, which can help injured elite players in reaching this goal.

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Figure 3. Moving on the slide board with an oculomotor task (fixing objects at various distances) (duration/sets to be adapted)

Figure 4. Isometric neck stabilization (lateral muscles) against a Swiss ball (duration/sets to be adapted) – Stage 3 (Table 2)
Figure 5. Reactive neck stabilization against elastic resistance, on an instable surface (duration/sets to be adapted) – Stage 4 (Table 2)

Figure 6. Scheme of basic moves on ice: 1) Bully circle, skating one/other directions; 20-30 sec per each direction; 2-3 sets with increased speed (stick only/ stick & puck) 2) Figure 8 skating, ½ forwards & ½ backwards; 20-30 sec per each direction; 2-3 sets with increased speed (stick only/ stick and puck) 3) A: circling 2x => B) accelerate to the boards, stop and back => A) + C) accelerate to boards, stop and back => continue (stick only) (duration/sets to be adapted)
Figure 7. Visuomotor reactive training on the “Speed Court” (GlobalSpeed GmbH, Hemsbach, Germany). The player moves quickly from plate to plate reacting to the given signal on the screen placed on the wall in front of him. Drills of about 20-30-40 sec duration (sets to be adapted). Photo courtesy of Steven Lingenhag (Hockey Club Davos).

Figure 8. Several cones on the bully circle line and one in the middle. Player skates quickly and randomly between cones (stick/stick and puck). Progression: Fitlights are placed on the cones, and the player skates quickly to the cones reacting to the given light signal (stick only). Drills of about 20-30 sec duration (sets to be adapted)
REFERENCES


7. Reinold MM. Performance physical therapy is sports physical therapy: why our profession needs to progress. *Int J Sports Phys Ther.* 2021;16(2). doi:10.26605/001c.21556


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