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EDITORIAL:
TWO STEPS FORWARD
Michael M. Reinold, PT, DPT, ATC, CSCS
President, American Academy of Sports Physical Therapy

Each January, I have always enjoyed looking back at the last year and reflecting on all that occurred the previous year. It is a rewarding and productive activity that ensures I remain focused on the big picture. It’s often too easy to get caught up in the day-to-day wins and losses and lose focus on the season ahead.

I do this for my personal and professional areas of life, and I recommend you consider a similar process.

As President of the American Academy of Sports Physical Therapy (AASPT), it’s part of my duty to you to perform this activity for the Academy. Looking back at all that the Executive Committee, home office, and volunteer leadership have accomplished, I can’t help but smile and feel so proud and honored to serve the membership.

While change is never easy in a leadership position, neither is becoming stagnant. I believe that each new President of the AASPT should take a step back and look at the Academy with fresh eyes. It’s an honor to walk in the footsteps of the past Presidents of the AASPT and build upon all the past successes. I look forward to the next President doing the same. This process will ensure that our incredible Academy continues to evolve. Sometimes, you need to take one step back to take two steps forward.

That’s how I feel my presidency has evolved.

During my first year, we took a step back to re-evaluate our mission, vision, and success path for members. We took a deep look at the structure and function of the Academy in an attempt to ensure we are meeting the needs of all our members.

As we pass the halfway point of my second year as President, we’ve already made tremendous progress and a first step forward. We’ve restructured our existing committees and established new committees in areas that needed attention. We’ve listened to feedback from our members and are starting to refresh our approach to educational opportunities for members. We’ve continued to grow our collaborations with other organizations, like AOSSM, AANA, and OSET, to provide our members with as many opportunities as possible.

In addition, we are excited to announce a renewed partnership with IJSPT. Since the journal’s inception as a publication of the AASPT back in 2005, IJSPT has always been one of the benefits that membership has ranked highest in our surveys. We look forward to partnering with IJSPT again on several educational, research, and publication opportunities for our members.

While the leadership of the Academy has worked hard, much of this has occurred in the background. Sometimes, things seem incomplete when small pieces of the puzzle are viewed without the context of the entire plan.

As I prepare for the start of my third year as President this summer, I look forward to seeing all this progress come together and the membership start to reap the benefits of all this hard work: The second step forward. This will become apparent with the return of our AASPT Annual Meeting.

We’re incredibly excited to announce the new AASPT Annual Meeting in Las Vegas, which will be held on June 13-14th, 2024. The AASPT Annual Meeting should be the premier event for all Sports Physical Therapists, from students to late-career professionals. It will be an exceptional educational experience with cutting-edge concepts and the latest research evidence that sports physical therapists can apply to the clinic immediately. Plus, as always, amazing social and networking events!

Thank you to all the members for your continued support; it’s been an honor to serve! I can’t wait for that second step forward. I hope to see you at the Annual Meeting!
One of the most important milestones of the International Federation of Sports Physical Therapy (IFSPT), a specialty group of the World Physiotherapy (WP) group, was the creation of the Sports Physiotherapy Competencies and Standards document. This statement, finalized by an international panel of experts almost twenty years ago, under The European Union-funded Sports Physiotherapy for All (SPA) project, describes effective professional behaviours and integrates specific knowledge, skills and attitudes in the context of practice. These competencies provide a basis for policy development, enable quality assurance activities and facilitate individual professional development.

**OVERVIEW**

In August 2022 at the Fourth World Congress of Sports Physical Therapy, the IFSPT research committee held a meeting with interested member organizations (MOs) to discuss the future of sports physiotherapy. During the meeting, the attendees suggested updating the sports physiotherapy (SPT) competencies through an international project, based on a global need for expanding the role of the sports physiotherapist. This project would also support each MO by providing educational opportunities to its members. Thanks to the vision of the IFSPT research committee and under the guidance of its members, Ben Waller (Finland), Jo Verschueren (Belgium), Maria Constantinou (Australia) and Luciana De Michelas Mendonça (Brazil, IFSPT President) the IFSPT established an international consortium tasked with building a strong Erasmus+ application to the European Union to support its goal.

**CONSORTIUM**

The project consortium consists of five organisations: Jamk University of Applied Sciences (Jamk, Finland), University of Tartu (UT, Estonia), Vrije Universiteit Brussel (VUB, Belgium), University of Thessaly (UTH, Greece), and the International Federation of Sports Physical Therapy (IFSPT, Switzerland).

In September 2023, the new consortium announced that the Erasmus+ Cooperation
Partnership Project, Higher education to improve competency in Sports Physiotherapy (SportsComp), was granted funding for an international project lasting three years.

As stated by the assessors, “...the involvement of and the role of the IFSPT (CH) is pivotal in bringing the results of the project to a broad range of international institutions to use, and could impact sports physiotherapy education and the profession globally.” It continued “…The project has very good potential to positively impact its participants and participating organisations, as well as their wider communities…”. In addition, thanks to the credibility of the other partners, they also stated that “…The profile, experience and the activities of the participating organisations are relevant for the field, the application is clear and very well presented. Participants have significant experience in the field(s) as well as strong evidence-based competencies and skills. The applicants are strong groups with the clear ability to translate research-based approaches to practical level solutions…”.

The SportsComp project, coordinated by Jamk, began on 1 September 2023, and is divided into five Work Packages (WPs), which focus on the long-term competence development of the academia, students, and professionals by updating sports physiotherapy competencies. The project enhances international collaboration in sports physiotherapy, and lifelong learning, and supports the digital competencies of the project target groups.

**PROJECT WORK PACKAGES (WPs)**

**The Work Package 1 (WP1), “Project Management and Coordination,”** is led by the project Coordinator, Jamk. WP 1 includes the Project Management Group (PMG), which coordinates and monitors the activities across the WPs and solves any possible challenges, which may influence project implementation. The Quality Assurance Team (QA Team) is also part of this WP and its work focuses on quality planning, assessment, monitoring and follow-up. The Project Implementation Plan and the Quality Assurance Plan are the two most important outputs of this WP, which help the project experts to implement the project according to set quality standards, timeline and settled objectives.

The consortium has recently turned its focus to the **Work Package 2 (WP2),** led by VUB. This WP, “Updating the sports physiotherapy competencies”, began in September 2023. Part 1 of this WP is a Delphi study survey, which aims to update the current international sports physiotherapy competencies using input from all global member organisations of the IFSPT and to align them with the competency profile of WP and the CanMEDS competency framework. Part 2 is a focus group, which is planned to comprehensively understand the role and significance of different competencies of modern sports physiotherapists. The interview data of Part 2 will come from at least three main groups: athletes, athlete support personnel, sporting or national healthcare organizations that use the services of sports physiotherapists. Stakeholders will include National Olympic committees, international sport federations, para-athlete organizations, and athletes and support staff representing different socioeconomic statuses.

**Work package 3 (WP3), “E-learning courses in sports physiotherapy”,** led by UTH, focuses on developing three (3) sports physiotherapy e-learning courses based on the competencies from WP 2 to ensure continuous sports physiotherapy competence development of the target groups in the long term at European Qualifications Framework (EQF) level 7.

The second objective of the WP 3 is to support different learners and learning scenarios in sports physiotherapy by creating learner-centered, innovative teaching, and learning materials based on current evidence and findings utilizing digitalization. Developed courses also support blended learning and hybrid learning, including other teaching and learning scenarios supporting the strengthened role of sports physiotherapists according to the working life needs.

The main objective of the **Work Package 4 (WP4), “Implementation of e-learning courses”** led by Jamk, is to assess the quality of the devel-
oped courses in practice. The quality check is done by implementing (piloting) two of the developed e-learning courses from WP 3, and amending one e-learning course based on course feedback. This is to ensure that the courses match with the updated competencies in WP 2 and that the developed contents contribute to long-term competence development. WP 4 collates the key outputs and findings from the implementation WPs into a Tutor Guide, which is published at the end of the WP.

The objective of Work Package 5 (WP5), “Communication and Dissemination,” guides the communication and dissemination activities of the project. WP 5 is led by IFSPT, and it aims to offer information on the project and ensure that the project outputs and results are communicated to stakeholders and wider audiences in a timely, accessible and quality manner. On-going updates regarding project activities, documentation and reached results are published on social media, project website and partners’ websites.

Communication and Dissemination activities are guided by the Dissemination Plan. WP 5 provides global visibility of the project contributing to enhanced knowledge regarding sports physiotherapy and continuous competence development. WP 5 will produce two physical results: a) two publications (a consensus paper and a paper on the role of the sports physiotherapist); and, b) a strategic plan for long-term collaboration.

**EXPECTED PROJECT RESULTS**

- Updated competencies of sports physiotherapy based on the EQF level 7, and the redefined role of the sports physiotherapist according to the CanMEDS model. This is in line with the WP educational framework.
- Three innovative e-learning courses in sports physiotherapy at EQF 7 level (3 x 5 ECTS credits). Courses will be integrated to partner higher education institutions’ curricula once finalised. The courses will be developed based on the newly-established core competencies, which will be globally applicable, irrespective of context in sports physiotherapy. Two of the courses are to be piloted with feedback and assessment, with one course updated. Courses will be promoted forward to students, academia and clinical professionals to ensure on-going competence development.

- Digital teaching and learning materials and content to support lifelong learning and professional development of different target groups and learners.
- A Tutor Guide to support competence development, learning and teaching for the academia, professionals, and learners to be used in different environments and settings to facilitate the developed skills and knowledge towards end-users and beneficiaries.
- A report on the competency update and e-learning materials, which includes two publications: the update in competency, and roles of sports physiotherapy around the world.

**MEETINGS**

To support sustainability and green transition, most of the project activities and tasks are carried out by on-line means. However, the committee has scheduled five face-to-face meetings over the project duration of three years.

The project Kick-off meeting was held at Jamk, Finland, 25-27 October, 2023. Over the three days, experts focused on building the implementation details for the five WPs with the finalisation of administrative, communication and dissemination actions to be carried out throughout the project duration. In addition, experts began discussing the creation of e-learning courses in sports physiotherapy and continued co-developing the ongoing activities to update the sports physiotherapy competencies at EQF level 7, which is due to be finalised in summer 2024. The next project consortium meeting is planned in Brussels, hosted by VUB in April 2024. The following consortium meetings will be hosted by the UTH in autumn 2024, by UT in summer 2025, and by IFSPT in summer 2026. The last project face-to-face meeting held by IFSPT will be the project Final Seminar focusing on disseminating project results
to different stakeholders and wider audiences internationally.

**IN SUMMARY**
The SportsComp project increases the quality of sports physiotherapy education and professionalism through competence development. The Project enhances the excellence of sports physiotherapy, physiotherapy, and rehabilitation education, and supports the improvement of European and global health care and sport systems. The SportsComp project experts know the relevance of the final aims, and are enthusiastic and honored to work on achieving them. It is known that the SportsComp project will generate untold advantages to the global sports physiotherapy world.

**For further information on the project...**

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Clinical Viewpoint

An Apparent Achilles Heel of the NFL: Have Achilles Tendon Injuries Significantly Increased to Unacceptably High Incidence Levels in the NFL and if so, why? A Clinical Insight

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Keywords: NFL, achilles rupture, football injuries

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Many if not most of us watched in utter disbelief and horror last September 11th as Aaron Rogers, the newly acquired $75 million dollar quarterback with the New York Jets just 4 snaps into the new season, suffered an Achilles Tendon ruptures (ATR) in his inaugural game on nationally televised Monday Night Football with his new and excited team and demanding fanbase. With cell phones in hand, we watched as our X apps lit up with claims of an excess of ATRs in the NFL in recent years and much of the blame placed on the new rubberized turf surfaces in place in most of the NFL stadiums. That first week of the NFL season the NFL Players Association, the NFLPA, put out a statement to this effect that demanded removal of rubberized turf surfaces throughout the NFL! With Kirk Cousins devastating ATR a few weeks later, amongst 21 others this season, and Aaron Rogers return to practice after a mere seven to eight weeks post-injury, this conundrum remains foremost in our hyper-questioning minds!

Interestingly, Achilles Tendon ruptures in the NFL have been tracked with relatively high fidelity over the last 25 years, though the NFL is not always totally forthcoming with the injury reports. The Achilles tendon is the largest, strongest, most powerful spring in the human body that experiences enormous loads, especially during eccentric calf contractions, and requires large loads to rupture.1 Prior studies reported an average of 4 Achilles tendon ruptures (ATRs) per NFL season between 1980 and 2001 and approximately five Achilles tendon ruptures per year between 1997 and 2002, approximately 45 to 21 years ago.2 Our research group reported a large increase in the prevalence of Achilles tendon ruptures in the NFL in the season following the 2011 season lock-out, especially in the preseason, in which 12 ruptures occurred. The latest peer-reviewed reports that ranged between 2009-2016 showed a significantly increased prevalence to between 13 and 16 ruptures per year.3 Since then, social media reports over the last 3 seasons have average 17 per year and the current 2023 season 22 ATRs have occurred in NFL. There is no doubt that the prevalence of ATRs in the NFL has increased between 3 and five-fold and that this 300-500% increase is both clinically and fiscally significant.

With regard to the second relevant question, the answer is likely not as simple as the NFLPA purports it to be. One must ask: what are the primary potential contributors?
Similar to other sports medicine injuries there are both modifiable and nonmodifiable risk factors. Here is the current synopsis based on evidence-based hypotheses and historic injury risk modeling in order of relative potential predictive power:

1. Demographic and anthropometric factors are always important and come out of nearly every injury risk profile assessment: age, activity level, height, body mass, and BMI may play significant roles. With the exception of age, all are increasing in the NFL. These are examples of non-modifiable factors.

2. The absence of sufficient preparatory training, such as heavy eccentrics. This has likely increased due to the new collective bargaining agreements between the NFL and NFLPA, which restrict team access to players during the off-season.

3. Surface (newer generation rubberized turf versus grass) shoe, rigid ankle taping, and bracing.

4. The use of anabolic and corticosteroids. The unknown and upregulated use of these drugs is unknown but have likely increased.

5. There are other potential contributors that are possible as well.

Treatment for ATRs has historically revolved around open treatment, but newer minimally invasive treatments such as the “speed bridge procedure” may have improved the recovery and post-operative course. We all will continue to follow Mr. Rogers’ progress with very high levels of interest! Future randomized trials looking at earlier return to play will be vital with regard to these newer technologies.

In conclusion, there is absolutely no doubt that the prevalence of ATRs has increased over the last half to quarter century 3 to 5-fold. The questions that remain are which are the greatest contributors to this highly impactful and expensive problem and what interventions can be instituted to reduce the risk of these devastating injuries? For example, Aaron Rogers and Kirk Cousins, what characteristic do they share as NFL quarterbacks may be the common predictive factors and most important determinants of not only recovery time but of the length of their future careers?

The NFL and the sports medical community must address this issue before next season and the next oncoming round of ATR injuries in 2024. As outlined above the modifiable risk factors should be examined in detail and attention to improving those factors as much as possible.

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REFERENCES


Original Research

Sport-Specific AMCaMP: New Modular Tools for Measuring Adolescent Self-Confidence In Sport-Specific Movement

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¹ Sports Medicine, Children’s Healthcare of Atlanta, ² Children’s Healthcare of Atlanta, ³ George Mason University
Keywords: Adolescent, Self-Confidence, Return to Sport, Reliability, Validity
https://doi.org/10.26603/001c.92012

International Journal of Sports Physical Therapy

Background
Despite increasing interest in psychological factors that affect the impact of self-efficacy on readiness to return to play, few clinical tools are available to assess self-confidence in performing sports-specific movement patterns in the pediatric/adolescent population.

Hypothesis/Purpose
The purpose of this study was to test the psychometric properties of sports-specific modules to supplement a general measure of movement self-efficacy, the Adolescent Measure of Confidence and Movement Performance (AMCaMP).

Study Design
Quasi-experimental cross-sectional validation.

Methods
After preliminary testing for readability and ease of administration, one of 12 sport-specific modules pertinent to the individual’s sport (baseball, softball, basketball, football, gymnastics, cheerleading, soccer, ballet, swimming, lacrosse, tennis, and cross country) were administered to 14,744 patients, 11-18 years of age, drawn from 12 pediatric sports physical therapy facilities in a single health care system. Respondents completed the assigned sport-specific self-report questionnaire at initial visit and conclusion of the episode of care.

Results
Based on sample sizes, Bartlett’s Test of Sphericity, and Kaiser-Myer-Olkin measures, nine modules (baseball, softball, basketball, football, gymnastics, cheerleading, soccer, ballet, and swimming) were deemed suitable for factor analysis. Each module sample was divided into test validation samples. Exploratory factor analysis revealed an underlying structure ranging from one to three factors depending upon the module. Subsequent confirmatory factor analyses fully supported the hypothesized factor structures for each module except swimming. Additional analyses to determine coefficient alpha (range=0.8-0.976), Standard Error of Measurement (range=1.12-2.33), and Minimum Detectable Change (range=3.1-6.47) confirmed the reliability of each of these modules.
Conclusion

AMCaMP sport-specific modules are reliable and valid self-report tools to capture self-confidence in performing sport-specific movements to supplement AMCaMP's evaluation of self-efficacy in performing the general movements of everyday life. The results of this study support using these modules as part of the overall clinical evaluation of psychological readiness to return to sport.

Level of Evidence

Level 3b.

INTRODUCTION

The decision to return an athlete to sport is a complex clinical judgement requiring careful and deliberate consideration of both physical and psychological factors. Physical factors (e.g., range of motion, strength, coordination, and agility) are objectively quantified, and often can be compared to the individual's contralateral side as well as the norms generated from standard objective measures. All this clinical information is used to judge physical readiness from a purely physiological perspective. However, there is increasing interest in the psychological aspects of rehabilitation within the physical therapy community and throughout sports rehabilitation, most notably among these, fear and self-confidence.

Moreover, there is ample evidence that psychological factors also make a critical contribution to motor learning to support this growing interest relative to return to sport.

Psychological components are often considered to be difficult to quantify due to their "subjective" nature. However, there are multiple objective measures that have been developed and used across the professions concerned with patient readiness for returning to sport, including the Injury-Psychological Readiness to Return to Sport Scale, and ACL-Return to Sport after Injury (ACL-RSI) scale. While these measures have clinical utility and are certainly appropriate to use based on their psychometric properties, they are limited either by encompassing all sports generically (IPRSS) or targeting diagnostic-specific conditions based on the anatomical site of injury (ACL-RSI). Without reference to a specific sport and the particular movements required to be ready to return to that sport, these instruments are helpful but ultimately insufficient to support clinical decision-making. The present study reports on the development of a suite of self-report modules for selected sports to address these limitations and enhance the process of making clinical judgments about adolescent athletes.

The parent instrument from which these modules were developed is the Adolescent Measure of Confidence and Musculoskeletal Performance (AMCaMP). The AMCaMP is a 22-item self-report instrument, which was developed as a "core" measure for individuals ages 11 to 18 years of age, characterizes an adolescent's confidence in the ability to perform general movements (sitting, standing, walking, running, etc.) that are essential to daily life irrespective of sport. Similar to the assessment for adults on which it was based, the AMCaMP is rooted in the self-efficacy theory developed by Bandura. This theory proposes that the situation-specific beliefs which a person holds about the capability to perform specific tasks help to determine what tasks the individual will choose to do, the energy and attention that will be devoted to doing it, and the perseverance that will be displayed in order to execute a specific level of performance when confronted by barriers to success. This theory can be summarized by the familiar saying, "If you think you can, then you can, and if you think you can't, you're right." The psychometric validation of the reliability and validity of the AMCaMP indicated it demonstrated acceptable internal consistency and established a minimal detectable change threshold for documenting clinical progress and outcomes in adolescents. The purpose of this study was to test the psychometric properties of sports-specific modules to supplement a general measure of movement self-efficacy, the Adolescent Measure of Confidence and Movement Performance (AMCaMP). These modules were developed to assist the overall clinical determination of readiness to return to play.

METHODS

INSTRUMENT

The sports-specific AMCaMP is designed to be an adjunct to the core AMCaMP questionnaire. It is a patient-centric measure to assess confidence in sport-specific movement patterns. The questionnaire presents items on a Likert-type array of five response levels progressively ranging from "no confidence" (1 point) to "fully confident" (5 points). The array of items was selected to explore self-confidence in performing movement patterns particular to each of 13 sports: soccer, baseball, softball, basketball, football, gymnastics, cheerleading, lacrosse, swimming, volleyball, tennis, cross country, and dance (See Appendices 1-6). For example, full court backpedaling is a particular movement that might regard as essential to returning to basketball. The sports were chosen based on high rates of participation and on the volumes of participants at the survey test sites. A "not applicable" option was available for any item that would be unnecessary for an athlete to have confidence as it is not a requirement of their performance. For example, a baseball pitcher would not need to assess his confidence in the movements essential playing the catching position.

STUDY SITES AND PARTICIPANTS

Data were gathered from patients who were referred to physical therapy for sports-related injuries from 14 outpatient clinics in the Children's Healthcare of Atlanta system. The institutional review board at Children's Health-
care of Atlanta deemed the study exempt. Traditionally the onset of puberty is accepted at the beginning of adolescence, which the authors operationalized as 11 years of age. All therapists at each site were instructed on who was eligible to participate in the study and how to collect the data. Any new patient was eligible to participate in the study if the patient was: 1) 11 to 18 years of age; 2) spoke and read English; and 3) had the cognitive ability to complete the questionnaire independently. Demographic data were also collected on the first visit.

ITEM SELECTION AND DEVELOPMENT

An expert group of eight physical therapists with an average of 11 years of experience (range 5-20 years) and at least two years of sports therapy experience participated in providing items. Of these, four were board certified in sports physical therapy and all 11 played competitively in high school, club, or collegiate sports. A board certified pediatric orthopedic surgeon and a board-certified primary care sports medicine physician with a combined 50 years of experience were consulted as well. Suggestions on critical movements for each sport and in some cases for specific positions within the sport were solicited. Consensus was reached when 6 out of the 8 panel members deemed a movement critical. Additional consideration was given to panel members with expertise in a specific sport (e.g., if a panel member played college football). The final item count was as follows: 17 for soccer, 16 for baseball/softball, 16 for basketball, 16 for football, 15 for ballet, 14 for gymnastics/cheerleading, 10 for swimming, 10 for volleyball, 9 for lacrosse, 9 for tennis and 7 for cross country.

STATISTICAL METHODS

DATA PREPARATION

A total of 14,744 patients were potentially available for study aggregating the data from all sports. Each sport was separated into its own individual cohort and each of these datasets were evaluated independently for the analysis reported below. Observations were not dependent because there was only one questionnaire per patient.

OUTLIER ANALYSIS

Outliers were assessed using the Mahalanobis Distance. This distance corresponds to the distance between an observation and the centroid of all observations in the space of questionnaire items. If this distance exceeded the threshold outlined by the α=.001 significance level, we excluded the observation. Because quality of response is also an issue of concern when analyzing response data, the Intra-Individual Response Variability (IRV) was used to exclude patients. Patients with an IRV value in the 99th percentile or above were judged as having haphazard/random response patterns and were subsequently dropped from the study.

Additionally, responders with zero variance in their responses (ex: responded all 5’s for all items) were dropped.

COLLINEARITY DIAGNOSTICS

Because collinearity/multicollinearity violates key assumptions of factor analysis, collinearity diagnostics were conducted to determine if there was potential redundancy amongst survey items primarily using condition index and the determinant of the response matrix. A condition index above 50 was used as an indicator of collinearity, but an index above 20 was still scrutinized. In addition to the condition index, this function provides variance decomposition proportion associated with each condition index. Items that both had a proportion of over .5 for the same index were considered candidates for deletion. Once collinearity was no longer deemed a problem, patients who did not have at least two responses in the remaining items were dropped.

DATA ANALYSIS

An exploratory factor analysis (EFA) was conducted to identify a hypothetical latent variable structure among questionnaire items and confirmatory factor analysis (CFA) to verify this structure. Not all sports had a sufficient sample size for factor analysis. A minimum of 400 participants and 10 participants per item were required for each sport (200 for EFA and 200 for CFA).

Factor analysis suitability was assessed using Bartlett’s Test of Sphericity and the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO). Bartlett’s Test examines the correlation matrix of all questionnaire items under the assumption that there is no relationship between the items. Rejecting this assumption suggests the data is suitable for factor analysis. The KMO Measure represents the proportion of variance among items that may be common variance with values above 0.7 suggesting factor analysis would be appropriate (where 1 is the best possible score).

A set of plausible number of factors for each sport was then determined by using the Kaiser Criterion (KC), the Scree Test, Parallel Analysis (PA) and the Hull Method. Finally, sed unweighted least squares and a promax rotation when applicable for the EFA were used. The metrics of success for a hypothetical model were strong loadings on an items primary factor (> 0.6), weak cross-loadings for an item’s secondary factors (< 0.3), and a high proportion of the total variance explained by the model (> 60%).

Participant data that were used in the EFA were not used in used in CFA. Model validity was assessed using the fit indices Root Mean Square Error of Approximation (RMSEA), the Standardized Root Mean Square Residual (SRMR), the Comparative Fit Index (CFI), and the Tucker-Lewis Index (TLI). The RMSEA is the difference between the observed covariance matrix per degree of freedom and the hypothesized covariance matrix with an acceptable value being below 0.08. The SRMR is the average of the standardized residuals between the observed and hypothesized covariance matrices with acceptable values being below 0.06. TLI and CFI are not especially sensitive to sample size with high values > 0.97 indicating the hypothesized model is better compared to the independence model. Although the chi-square test can be used to evaluate model fit but is not in-
Table 1. Sample size by sport for each module.

<table>
<thead>
<tr>
<th>Sport</th>
<th>Final Sample Size (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseball &amp; Softball</td>
<td>1147</td>
</tr>
<tr>
<td>Cross Country</td>
<td>277</td>
</tr>
<tr>
<td>Basketball</td>
<td>1228</td>
</tr>
<tr>
<td>Gymnastics &amp; Cheerleading</td>
<td>787</td>
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<tr>
<td>Tennis</td>
<td>230</td>
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<tr>
<td>Football</td>
<td>905</td>
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<tr>
<td>Swimming</td>
<td>526</td>
</tr>
<tr>
<td>Lacrosse</td>
<td>318</td>
</tr>
<tr>
<td>Ballet</td>
<td>429</td>
</tr>
<tr>
<td>Soccer</td>
<td>1167</td>
</tr>
<tr>
<td>Volleyball</td>
<td>366</td>
</tr>
</tbody>
</table>

Table 2. Appropriateness of testing each module.

<table>
<thead>
<tr>
<th>Sport</th>
<th>Bartlett</th>
<th>KMO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseball &amp; Softball</td>
<td>Reject</td>
<td>0.904</td>
</tr>
<tr>
<td>Basketball</td>
<td>Reject</td>
<td>0.908</td>
</tr>
<tr>
<td>Gymnastics &amp; Cheerleading</td>
<td>Reject</td>
<td>0.871</td>
</tr>
<tr>
<td>Football</td>
<td>Reject</td>
<td>0.919</td>
</tr>
<tr>
<td>Swimming</td>
<td>Reject</td>
<td>0.798</td>
</tr>
<tr>
<td>Ballet</td>
<td>Reject</td>
<td>0.820</td>
</tr>
<tr>
<td>Soccer</td>
<td>Reject</td>
<td>0.924</td>
</tr>
</tbody>
</table>

Barlett = Bartlett’s Test of Sphericity; KMO = Kaiser-Meyer-Olkin Measure of Sampling Adequacy

included because when fitting ordinal factor analysis models, this test can have inflated and/or unreliable Type I error rates.22

Lastly, the reliability of the factor scales using Cronbach’s alpha, Standard Error of Measurement (SEM), and Minimum Detectable Change (MDC) was assessed. Cronbach’s alpha was used as a proxy for internal consistency and is considered to be a scale of reliability. Values above 0.8 were set to be considered acceptable. The SEM examines the spread of measured test scores around the estimated true score. The MDC measures the minimal amount of change in score that rules out measurement error.

RESULTS

Based on the tests for sample size, seven sports had a sufficient sample size to proceed: baseball/softball, basketball, gymnastics/cheerleading, football, swimming, ballet, soccer (Table 1). All of these sports passed Bartlett’s Test, and the minimum KMO among the sports was 0.798 (Table 2).

The analysis of the candidate number of factors using all four methods ranged from 1 to 4 depending upon the sport (Table 3). Each sport was evaluated under the same conditions for all plausible numbers of factors.

Based upon the criteria that had been set to determine a successful model, and the pragmatic considerations of clinical utility (i.e., information that most assists clinical decision making and carries a low response burden), a factor structure for each sports module was selected based on strong primary loading, weak cross loading, and percent of variance explained. Results indicated that two factor structures were optimal except for baseball (one factor) and soccer (3 factors). The proportion of variance, interfactor correlation, and breakdown of the items contained within a factor for each sport module are found in Table 4.

Although the football, ballet, and soccer modules failed at least one of the criteria we had set a priori for the EFA, these deficiencies were not sufficient violations to exclude these item groups from CFA. Out of all sports modules tested, only swimming did not have a model that met all a priori requirements. While all fit indices were satisfactory for the two-factor swimming model, the RMSEA was slightly higher for this sport module than the recommended 0.06 cutoff value (Table 5).

The summary of reliability testing (Cronbach’s alpha, SEM, and MDC) are displayed in Table 6.

DISCUSSION

Confirmatory factor analysis was used to determine valid scales for items to be grouped. The reliability metrics suggest that most factors provide adequate measures and could be used to detect improvement over time. While these findings provide a latent variable structure for each sport, it does not provide information on what these latent variables actually are. Although all the items grouped in a factor for each sport demonstrated acceptable psychometric properties, a potential trade-off between statistical performance and clinical utility must be acknowledged. While a different set of items might have performed statistically better, such items might be most informative to clinicians making decisions. The methods by which we included items generated by clinicians and set a priori statistical requirements that were met in all but one scale suggests that this trade-off was successfully negotiated.

In the process of identifying the latent variable structure of these sport specific questionnaires, our approach filtered out several potential problems. Eliminating collinearity helps to ensure that each item is measuring a unique component of its respective construct. Eliminating items that load weakly helps ensure all items are relevant to the constructs of interest. The remaining items are then able to give a much clearer reference point of the construct they are measuring. Additionally, the high Cronbach’s α suggests the psychometric property of reliability for each sport module is strong.

An athlete’s body must be prepared to handle all the stressors of the sports to which they will return, physical and psychological. Given the growing awareness of the impact of self-efficacy and other psychological constructs on rehabilitation and recovery, the need for objectives measures of what was traditionally regarded as unmeasurably “subjective” has also grown. However, a common limitation of existing instruments was the inability to capture the mental readiness of the athlete in the critical context of the
Table 3. Plausible number of factors for each sport.

<table>
<thead>
<tr>
<th>Sport</th>
<th>KC</th>
<th>Scree</th>
<th>PA</th>
<th>Hull</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseball &amp; Softball</td>
<td>1 factor</td>
<td>2 factors</td>
<td>1 factor</td>
<td>3 factors</td>
</tr>
<tr>
<td>Basketball</td>
<td>2 factors</td>
<td>3 factors</td>
<td>2 factors</td>
<td>4 factors</td>
</tr>
<tr>
<td>Gymnastics &amp; Cheerleading</td>
<td>1 factor</td>
<td>2-3 factors</td>
<td>1 factor</td>
<td>2 factors</td>
</tr>
<tr>
<td>Football</td>
<td>2 factors</td>
<td>2-3 factors</td>
<td>2 factors</td>
<td>2 factors</td>
</tr>
<tr>
<td>Swimming</td>
<td>1 factor</td>
<td>3 factors</td>
<td>2 factors</td>
<td>2 factors</td>
</tr>
<tr>
<td>Ballet</td>
<td>1 factor</td>
<td>2 factors</td>
<td>1 factor</td>
<td>3 factors</td>
</tr>
<tr>
<td>Soccer</td>
<td>2 factors</td>
<td>3 factors</td>
<td>2 factors</td>
<td>3 factors</td>
</tr>
</tbody>
</table>

KC=Kaiser Criterion; Scree=Scree Test; PA=Parallel Analysis; Hull=Hull Method.

specific movement requirements of an athlete's particular sport, which is essential to rendering sound clinical judgments tailored to the individual's goals. The Sport-specific AMCaMP modules are patient-centric tools that capture the patient's point of view (See Appendices 1-6). Furthermore, because self-efficacy is highly predictive of what an athlete actually will do once leaving clinical care, the modules yield highly relevant data on the specific requirements which will be the criteria for determining the success of rehabilitation to achieve to sport. Together, the Sports-specific AMCaMP and its parent the AMCaMP can provide a broader array of data to support clinical decisions.

LIMITATIONS

Sport specialization is a limitation with this analysis that was not present in the original AMCAMP publication. Because all items were related to basic movements/functions in the original AMCAMP questionnaire, they were likely to be relevant to all patients. However, in sports, team sports in particular, certain players may specialize in a certain kind of role that is only applicable to players of their position/specialty. Future instrument construction should consider developing separate position-specific modules for each sport to address this limitation.

CONCLUSION

The psychometrically validated modules of the Sport-specific AMCaMP offer distinct advantages in evaluating an adolescent's confidence in readiness to return to a specific sport. Combining a more complete understanding of the psychological context of each athlete's confidence in performing specific movement requirements with more traditional physical data will better enable clinicians to assist adolescent athletes in successfully transitioning back to their sports.

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Table 4. Proportion of variance, interfactor correlation, and items contained within a factor for each sport module.

<table>
<thead>
<tr>
<th>Sport</th>
<th>Proportion of Variance Explained</th>
<th>Interfactor Correlation</th>
<th>Items by Factor</th>
</tr>
</thead>
</table>
| Baseball & Softball  | .69                              | --                      | Factor 1:  
• Catch ground balls  
• Catch fly balls  
• Slide feet first  
• Slide headfirst  
• Run bases  
• Swing live  
• Bunt  
• Catch for 1 inning |
| Basketball           | .75                              | .67                     | Factor 1:  
• Run full court suicide  
• Change direction quickly  
• Defensive stance  
• Scrimmage for 30 min  
• Backpedal full court  
Factor 2:  
• 10 post feeds  
• 10 layups (right hand)  
• 10 layups (left hand)  
• Shoot 10 jump shots  
• Shoot 10 free throws  
• Shoot 10 three pointers |
| Gymnastics & Cheerleading | .71                          | .71                     | Factor 1:  
• 5 jump/leap series  
• 5 springboard impacts  
• 5 dismount landings  
• 5 layouts  
• 5 back tucks  
Factor 2:  
• 5 front walkovers  
• 5 vault tabletop impacts  
• 5 stunts  
• 5 back handsprings |
| Football             | .79                              | .69                     | Factor 1:  
• Backpedal 10 yards  
• Change direction quickly  
• Kick 10 kick-offs  
• Kick a 30 yd field goal  
• Punt 10 balls  
Factor 2:  
• Snap 10 balls  
• Catch 10 passes 25 yards  
• Hit the sled with 100% effort 10 times  
• 10 tackles  
• Get tackled 10 times  
• 10 up/downs  
• Maintain 3-point stance for 10 seconds |
| Swimming             | .71                              | .71                     | Factor 1:  
• Swim standard warmup  
• Swim main set backstroke  
• Swim main set butterfly  
Factor 2:  
• Start off the block  
• Perform dry land routine  
• Perform a flip turn  
• Swim main set breaststroke |
| Ballet               | .75                              | .70                     | Factor 1:  

<table>
<thead>
<tr>
<th>Sport</th>
<th>Proportion of Variance Explained</th>
<th>Interfactor Correlation</th>
<th>Items by Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soccer</td>
<td>.80</td>
<td>.58 (F1:F2)</td>
<td>• If en pointe: full rise onto platform of pointe shoe in 1st</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.55 (F2:F3)</td>
<td>• Sauté or changement jumps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.81 (F1:F3)</td>
<td>• Releve in 1st position</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Pirouette</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Grande jete</td>
</tr>
<tr>
<td></td>
<td>Factor 2:</td>
<td></td>
<td>Factor 2:</td>
</tr>
<tr>
<td></td>
<td>• Stand in 2nd position</td>
<td></td>
<td>• Stand in 4th position</td>
</tr>
<tr>
<td></td>
<td>• Demi plie in 1st position</td>
<td></td>
<td>• Grande plie in 1st position</td>
</tr>
<tr>
<td></td>
<td>• Grande plie in 1st position</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Factor 1:</td>
<td>10 cross balls in a game</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 10 shots from the 18-yard line in a game</td>
<td>10 corner kicks in a game</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 10 volleys in a game</td>
<td>• 10 punts in a game</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 10 goals kicks in a game</td>
<td>• 10 touch passes in a game</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Backpedal 10 yards</td>
<td>• Dribble the ball around 10 cones</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Sprint 10 yards</td>
<td>• 10 goalkeeper punches in a game</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Quickly change direction</td>
<td>• 10 goalkeeper saves in a game</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Dribble the ball around 10 cones</td>
<td>• 10 goalkeeper dives in a game</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 10 throw-ins down the line in a game</td>
<td>• A header in a game</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Factor 3:</td>
<td>• 10 goalkeeper punches in a game</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 10 goalkeeper saves in a game</td>
<td>• 10 goalkeeper dives in a game</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 10 throw-ins down the line in a game</td>
<td>• A header in a game</td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Fit indices for each module.

<table>
<thead>
<tr>
<th>Sport</th>
<th>RMSEA</th>
<th>SRMR</th>
<th>CFI</th>
<th>TLI</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseball &amp; Softball</td>
<td>0.038</td>
<td>0.042</td>
<td>0.998</td>
<td>0.997</td>
<td>20</td>
</tr>
<tr>
<td>Basketball</td>
<td>0.057</td>
<td>0.058</td>
<td>0.994</td>
<td>0.992</td>
<td>53</td>
</tr>
<tr>
<td>Gymnastics &amp; Cheerleading</td>
<td>0.052</td>
<td>0.055</td>
<td>0.994</td>
<td>0.991</td>
<td>26</td>
</tr>
<tr>
<td>Football</td>
<td>0.053</td>
<td>0.058</td>
<td>0.995</td>
<td>0.994</td>
<td>53</td>
</tr>
<tr>
<td>Swimming</td>
<td>0.069</td>
<td>0.063</td>
<td>0.990</td>
<td>0.984</td>
<td>13</td>
</tr>
<tr>
<td>Ballet</td>
<td>0.037</td>
<td>0.059</td>
<td>0.997</td>
<td>0.996</td>
<td>26</td>
</tr>
<tr>
<td>Soccer</td>
<td>0.028</td>
<td>0.043</td>
<td>0.999</td>
<td>0.998</td>
<td>101</td>
</tr>
</tbody>
</table>

RMSEA=Root Mean Square Error of Approximation; SRMR=Standardized Root Mean Square Residual; CFI=Comparative Fit Index; and TLI=Tucker-Lewis Index.
Table 6. Reliability of each module.

<table>
<thead>
<tr>
<th>Sport</th>
<th># Items</th>
<th>Alpha</th>
<th>SEM</th>
<th>MDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseball/Softball F1</td>
<td>8</td>
<td>0.95</td>
<td>2.33</td>
<td>6.47</td>
</tr>
<tr>
<td>Basketball F1</td>
<td>5</td>
<td>0.95</td>
<td>1.83</td>
<td>5.08</td>
</tr>
<tr>
<td>Basketball F2</td>
<td>7</td>
<td>0.95</td>
<td>2.05</td>
<td>5.68</td>
</tr>
<tr>
<td>Gymnastics &amp; Cheerleading F1</td>
<td>5</td>
<td>0.93</td>
<td>2.08</td>
<td>5.78</td>
</tr>
<tr>
<td>Gymnastics &amp; Cheerleading F2</td>
<td>4</td>
<td>0.80</td>
<td>1.64</td>
<td>4.54</td>
</tr>
<tr>
<td>Football F1</td>
<td>5</td>
<td>0.95</td>
<td>1.89</td>
<td>5.24</td>
</tr>
<tr>
<td>Football F2</td>
<td>7</td>
<td>0.94</td>
<td>2.31</td>
<td>6.42</td>
</tr>
<tr>
<td>Swimming F1</td>
<td>3</td>
<td>0.88</td>
<td>1.67</td>
<td>4.63</td>
</tr>
<tr>
<td>Swimming F2</td>
<td>4</td>
<td>0.84</td>
<td>1.82</td>
<td>5.04</td>
</tr>
<tr>
<td>Ballet F1</td>
<td>5</td>
<td>0.92</td>
<td>2.04</td>
<td>5.65</td>
</tr>
<tr>
<td>Ballet F2</td>
<td>4</td>
<td>0.92</td>
<td>2.14</td>
<td>3.92</td>
</tr>
<tr>
<td>Soccer F1</td>
<td>6</td>
<td>0.98</td>
<td>1.57</td>
<td>4.34</td>
</tr>
<tr>
<td>Soccer F2</td>
<td>5</td>
<td>0.96</td>
<td>1.19</td>
<td>3.31</td>
</tr>
<tr>
<td>Soccer F3</td>
<td>5</td>
<td>0.91</td>
<td>1.12</td>
<td>3.10</td>
</tr>
</tbody>
</table>

F1=factor 1; F2=factor 2; F3=factor 3; Alpha=Cronbach’s α; SEM=standard error of the mean; MDC=minimum detectable change.
REFERENCES


SUPPLEMENTARY MATERIALS

Appendix 1

Appendix 2

Appendix 3

Appendix 4

Appendix 5

Appendix 6
Original Research

The Effect of Joint Hypermobility Syndrome on DOMS and Recovery Time

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1 Physical Therapy, New York Institute of Technology

Keywords: soreness, physical therapy, muscle pain, eccentric exercise, hypermobility

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Background

Previous research has reported that people with Joint Hypermobility Syndrome (JHS) and Ehlers-Danlos Syndrome (EDS) generally experience a high rate of muscular injury and pain. However, there is limited research comparing the recovery times and length of Delayed Onset Muscle Soreness (DOMS) in individuals with JHS to non-hypermobile individuals in response to exercise.

Hypotheses/Purpose

The purpose of this study was to investigate JHS and its effects on DOMS and its recovery time.

Study Design

Quasi-experimental, observational comparison

Methods

Two groups including a hypermobile group (score >4 on Beighton Scale) and a non-hypermobile group all took part in five-second long standing eccentric bicep curls based using their one-repetition maximum (1-RM) of their dominant arm to failure in order to induce DOMS. Visual analog pain scale (VAS), McGill pain scale, resting arm angle, girth, and the pressure pain threshold, all domains of DOMS, were measured over a five-day period. Results were analyzed using ANOVA with time as the repeated factor.

Results

Both groups experienced DOMS following the eccentric exercise. However, VAS reporting was significantly greater in the hypermobile group compared to the non-hypermobile group and there was a significant difference over time. However, other variables did not reveal any other significant findings between groups.

Conclusion

Individuals with JHS may experience greater DOMS and require more time to recover between treatment sessions. Therapists need to be aware that patients with hypermobility may experience higher pain levels related to exercise, and they need to adjust treatment parameters appropriately.

Level of Evidence

2b

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INTRODUCTION

Joint Hypermobility Syndrome (JHS) is defined as a condition in which an individual exhibits relatively increased or an abnormally large range of motion around a joint and/or joints.\(^1\) JHS is quantified by patients having a score of \(> 4\) on the Beighton Score.\(^1,2\) The Beighton Score has been shown to be an accurate measure for confirming hypermobility in patients.\(^2\) Each point in the Beighton Score represents one of nine possible joints that can present with hypermobility. Research has found that individuals with hypermobility disorders, in particular Ehlers-Danlos Syndrome (EDS), have defective and/or abnormal healing,\(^3\) with a high rate of fatigue.\(^4,5\) Previous authors have reported that people with JHS and EDS experience high rates of muscular injury and pain due to exercise.\(^6\) However, there is limited research comparing the recovery times and length of delayed onset muscle soreness (DOMS) symptoms in individuals with JHS to individuals without JHS in response to exercise. DOMS is defined as muscle pain and soreness that occurs post-exercise which may peak and last for several days after the exercise.\(^7\) It has been documented that the prevalence of JHS was 12.5% overall in college-aged students, 16.2% for women and 8.7% for men.\(^8\)

JHS has been associated with many debilitating features including increased risk for injury, centralized fatigue, centralized pain, inhibition of surrounding muscles, and decreased strength/performance when compared to non-hypermobile individuals.\(^1,6\) Lee et al.\(^7\) investigated the laxity of the anterior cruciate ligament (ACL) and muscle soreness post exercise comparing men and women. They stated that the women reported greater DOMS and the women’s ACLs had significantly greater elasticity following exercise when compared to the men. They concluded that women may require more time for musculoskeletal recovery in response to heavy exercise.\(^7\) To et al.\(^9\) studied central vs. peripheral fatigue in participants with JHS and participants without JHS. The participants received electrical stimulation to their biceps to invoke muscle fatigue. Both central and peripheral fatigue was measured in all participants. The control group did not experience central or peripheral fatigue; however the experimental group (JHS) experienced centralized fatigue. This study suggests that individuals with JHS may experience fatigue differently. It has been reported that the transverse abdominis muscle can be inhibited by the surrounding hypermobile vertebrae.\(^10\) The study concluded that decreased muscle activity and increased muscle inhibition exists in muscles surrounding hypermobile joints.\(^10\) Di Stefano et al.\(^11\) investigated on how central sensitization could be the underlying mechanism causing pain in people with JHS and EDS. They stated that pain is a common symptom in patients with the connective tissue disorder, JHS, but the mechanism of why and how are unclear in previous studies. Their study included patients with JHS/EDS that participated in a detailed clinical exam to investigate the somatosensory nervous systems and central sensitization in this population. The authors discovered there was no damage to the somatosensory nervous system of these participants. However, they concluded that most of the subjects experienced widespread pain due to persistent nociceptive input due to joint abnormalities which probably triggers central sensitization in the dorsal horn neurons. Alternatively, Igharno et al.\(^12\) compared the small fiber peripheral nerve fibers and autonomic nervous system of hypermobile EDS subjects to healthy controls. They confirmed that small nerve neuropathy and autonomic nervous dysfunction is a common feature of hypermobile EDS as an underlying pathomechanism of joint pain and dysfunction.

DOMS refers to heightened muscle soreness and pain that peaks and lasts several days after exercise.\(^7\) The intensity of DOMS increases within the first 24 hours post exercise, peaks between 24 to 72 hours, and subsides and eventually disappears in 5 to 7 days.\(^3\) Although resistance exercise has been proven to be an effective intervention for reducing pain and joint instability in hypermobility,\(^14\) individuals with JHS may respond differently to resistance exercise as compared to individuals with normal range of motion due to differences in their nervous system, joint morphology, muscular and ligamentous attachments. The purpose of this study was to investigate JHS and its effect on DOMS and recovery time. The authors’ hypothesized that individuals with JHS would experience increased DOMS when compared to non-hypermobile individuals in response to exercise. The results of this study may assist and add to the body of knowledge regarding treating and exercising patients with JHS, as special considerations can be important when treating this population. Patients with JHS may experience greater DOMS and require more time to recover between treatment sessions.

METHODS

PARTICIPANTS

Participants had to be physically active and participate in recreational exercise. Participants were recruited from the greater university community. Participants were selected according to the inclusion/exclusion criteria. The inclusion criteria included: Age range: 18-35 years; Good overall health; Regularly participate in recreational exercise. The exclusion criteria included: Individuals with Ehlers-Danlos Syndrome; Any major musculoskeletal injuries in the prior six months; Any recent traumas that could have led to acute hypermobility or instabilities; Any known disorders that impede recovery/healing time (i.e. Lupus, Rheumatoid Arthritis, Scleroderma); Current elbow pain; Any other health issues that would risk the safety of the subject. The study was approved by New York Institute of Technology Institutional Review Board (BHS # 1636) and the study was registered at www.ClinicalTrail.gov (NCT04934267). The participants were informed of the methods, procedures, risks and were asked to sign the approved consent form prior to starting the study.

PROTOCOL

The research design was a quasi-experimental, observational comparison. Group 1 was the non-hypermobile group and Group 2 was the hypermobile group. The inde-
pendent variables were the two groups and the dependent variables were girth, resting arm angle (RANG), Pain 1-10 Visual Analogue Scale (VAS), Short Form McGill Pain Questionnaire (SF-MPQ 2), and pressure pain threshold (PPT) using an algometer. This battery of measures was utilized to quantify the domains of DOMS because there does not exist a single outcome measure to define it and has been previously utilized in the literature. All participants took part in an exercise session with eccentric bicep curls based on their 1 repetition maximum (1-RM), which was the highest amount of weight that they could lift concentrically once, using their dominant arm. Both groups performed one set of standing eccentric bicep curls based on their 1RM to failure in order to induce DOMS. Each rep included a timed five second long eccentric component with a metronome and without a concentric component, as the research conductors lifted the weight up concentrically for the participant. The exercise stopped when the participant could not volitionally keep up with the five second count lowering the weight or their form was disrupted. This procedure was previously utilized by Douris et al. Participants were asked to refrain from self-treatment of their DOMS by taking pain medication, using massage or other pain or edema reducing modalities, as well as refraining from any upper extremity exercises during the duration of the study. Prior to exercise, baseline measurements were taken for girth, pressure pain threshold, and RANG. Starting day 2, all measures (including girth of dominant brachium, PPT, VAS, McGill Pain Questionnaire, and RANG) were taken every day at the same time of day, for the following four days. VAS and the McGill Pain Questionnaire were not taken because the subjects were without pain prior to starting the protocol according to the exclusion criteria. Each dependent variable and change in measurements from baseline or day 2 to day 5 post exercise were recorded and used for subsequent data analysis.

MEASUREMENT

Girth: Girth was the measurement of the circumference of a limb (in this study, the midline of the dominant brachium) in centimeters, using a standard tape measure, measuring swelling and/or edema, which commonly occurs during DOMS. A standard tape measure was utilized.

RANG: Resting Arm Angle (RANG) is a ROM measurement in degrees, using a standard goniometer, of the dominant arm (elbow joint) while resting. A standard goniometer was utilized.

VAS Numeric Pain Distress Scale: The 0-10 point VAS Numeric Pain Distress Scale is a commonly employed self-completed scale for the assessment of pain in adults. The scale is marked with 10 equal intervals starting with 0 and ending in 10, to quantify the level of self reported pain. The anchor (0/10) is marked "no pain", the middle (5/10) is marked "moderate pain", and the end (10/10) is marked as "unbearable pain". Greater distances are associated with increased pain levels. In the absence of a gold-standard for pain assessment, the VAS has demonstrated high correlation with a 5-point verbal descriptive scale and a numeric rating scale for pain (r = 0.71-0.78 and r = 0.62-0.91, respectively).

SF-MPQ 2: The SF-MPQ 2 is a shorter version of the original McGill Pain Questionnaire. It is a multidimensional measure of pain, consisting of two subscales, one for sensory change and one for affective change. The SF-MPQ 2 has been shown to be valid when compared to VAS (r = 0.926) with strong test-retest reliability (ICC = 0.941) when assessing adult populations. The SF-MPQ 2 score is the sum of the 22 pain descriptors.

Algometry: Algometry is the assessment of load-dependent tenderness at a specific anatomical site. Tissue tenderness has been conventionally measured by subjecting myofascial structures to external pressure. Algometers serve to quantify pressure pain thresholds and have been shown to be valid up to 80N (r = .990) when compared to force plate output. Additionally, interrater and intrarater reliability were 0.92 (r = 0.87-0.95) and 0.84 (r = 0.75-0.90), respectively. Research suggests algometry may be useful in the assessment of treatment efficacy (14). The Force Ten™ FDX Pressure Algometer (Wagner Instruments, Greenwich, CT 06836) was utilized. The procedure for algometric measurement was adapted from Park et al and was standardized according to the following: continuous ascending pressure was at a constant rate, to the midline of the anterior brachium, in order to quantify the individuals pain pressure threshold, measuring in kilogram-force (kgf). Pressure was increased at a rate approximately 1 kg/cm²/s. The participant indicated increased pain by saying the word "ouch," the test was then concluded, and the measurement recorded. The procedure was repeated for a total of three trials; average scores were calculated and recorded.

STATISTICAL ANALYSIS

All values are reported as mean ± standard deviation. Statistical analyses were performed utilizing SPSS for Windows (version 27.0, Armonk, NY). The independent variables consisted of two groups, an experimental group (hypermobile individuals), and a control group (individuals that were not hypermobile with normal ranges of motion). The dependent variables were girth, resting arm angle (RANG), Visual Analogue Scale (VAS), McGill Pain Questionnaire, and pressure pain threshold using an algometer. In order to test the hypothesis, a mixed design ANOVA was performed for each dependent variable with time as the repeated factor. The two main effects were the two groups and time and the interaction effect was the interaction of time and group. The assumption of sphericity was tested using Mauchly’s test. In the event that sphericity was violated, a Greenhouse-Geisser correction factor was applied. A priori sample size calculation revealed that 10 subjects were required in each group in order to detect observed differences at a power of 80%. A p value<.05 was accepted for statistically significant differences.
Table 1. Subject Characteristics (n=24)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGE (yrs)</td>
<td></td>
<td>25.7 ± 4.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HEIGHT(cm)</td>
<td></td>
<td>169.4 ± 10.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WEIGHT(kg)</td>
<td></td>
<td>68.0 ± 13.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

RESULTS

This study included 24 men and women participants. Group 1 included 12 subjects, 10 men and 2 women with normal ranges of motion (score of <4 on Beighton Scale). Group 2 included 12 subjects, 10 women and 2 men, with increased ranges of motion (score of ≥ 4 on Beighton Scale and hypermobile in the elbow. The subject characteristics of the twenty four participants are presented in Table 1.

The means and standard deviations for all dependent variables are reported in Table 2.

There were significant main effects for time for VAS, McGill, RANG, and PPT with no interaction effects. Both groups responded similarly, with significant changes over the five-day period (main effect of time) which reflects the response to DOMS. The main effect of group was also significant for the dependent variable of VAS (p=0.015) and girth (p=0.057). However, post hoc analysis with independent t-tests between the groups revealed that only the VAS scores were significantly greater in the hypermobile group compared to the non-hypermobile group on Day 2 (p=0.005) with a large effect size (d=1.50) and Day 4 (p=0.057), also with a large effect size (d=0.93). The results of the mixed design ANOVA for all dependent variables are presented in Table 3.

DISCUSSION

The results of the study demonstrated that individuals with JHS may experience and complain of more pain than individuals without JHS as a result of unaccustomed eccentric exercise. It appears from this data that both groups experienced DOMS over the five-day period following the eccentric exercise. The study revealed no evidence of significant differences in the level of DOMS between the two groups except for the VAS scores. The McGill scores, RANG measurements, and PPT measurements were all significantly changed over time for all subjects, which is the expected response to unaccustomed or eccentric exercise, and appears to be unrelated to the level of hypermobility of the participants. The results of this study may be explained by Distefano et al. who demonstrated increased perceived pain in hypermobile participants when compared to non-hypermobile participant, as the hypermobile group experienced increased perception of pain as compared to the non-hypermobile group (VAS scores), with no other dependent variables showing a significant difference between the groups. Girth was the only variable that was not significantly changed over time; however, was significantly different between groups, with a higher girth for the non-hypermobile group on average compared to the hypermobile group. The authors of this study are attributing this to a potential gender effect. The hypermobile group included more women and the non-hypermobile group included more men. The current results compare favorably to Lee et al. after inducing muscle soreness through intense squatting, women reported significantly greater VAS scores compared to men. The study also found that women have greater elasticity in their knee joint and should have more time for musculoskeletal recovery. Although they reported differences between the men and the women, they did not take into account of possibility of increased hypermobility prior to exercise in the knee joint in the women as compared to the men which can be inferred by their reporting greater elasticity of the women’s anterior cruciate ligament of the knee joint after exercise.

Table 2. Variables Days 1-5

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAS (0-10)</td>
<td>1</td>
<td>2.3±1.5</td>
<td>3.6±1.8</td>
<td>1.9±1.8</td>
<td>0.3±0.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4.7±2.2</td>
<td>4.7±1.8</td>
<td>3.9±2.5</td>
<td>1.4±1.8</td>
<td></td>
</tr>
<tr>
<td>McGill</td>
<td>1</td>
<td>72.3±61</td>
<td>86.7±109.9</td>
<td>68.6±182</td>
<td>18.2±46.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>54.2±40.8</td>
<td>86.4±65.1</td>
<td>62.9±75.9</td>
<td>19.3±36.6</td>
<td></td>
</tr>
<tr>
<td>PPT (kg)</td>
<td>1</td>
<td>2.7±0.9</td>
<td>1.8±0.8</td>
<td>1.4±0.7</td>
<td>1.7±0.8</td>
<td>2.0±0.8</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.6±0.8</td>
<td>1.5±0.8</td>
<td>1.0±0.8</td>
<td>1.4±1.0</td>
<td>1.9±1.1</td>
</tr>
<tr>
<td>RANG (deg)</td>
<td>1</td>
<td>23.8±5.7</td>
<td>30.4±7.9</td>
<td>33.0±13.5</td>
<td>31.0±11.8</td>
<td>25.8±6.2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>22.9±3.8</td>
<td>35.8±5.5</td>
<td>36.2±7.5</td>
<td>36.4±12.8</td>
<td>28.2±4.6</td>
</tr>
<tr>
<td>Girth (cm)</td>
<td>1</td>
<td>31.0±4.5</td>
<td>31.6±4.6</td>
<td>32.2±4.5</td>
<td>31.6±4.5</td>
<td>31.5±4.6</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>27.7±3.4</td>
<td>28.6±3.4</td>
<td>28.7±3.6</td>
<td>26.3±8.4</td>
<td>28.8±3.5</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation. VAS: Visual Analog Scale for Pain, McGill: Short Form McGill Pain Questionnaire, PPT: Pain Pressure Threshold, RANG: Resting Arm Angle.

Group 1- non-hypermobile group, Group 2- hypermobile group

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Table 3. Results of Mixed design ANOVA

<table>
<thead>
<tr>
<th>Variable</th>
<th>Factor</th>
<th>F</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAS</td>
<td>Time</td>
<td>$F_{3.66} = 33.87$</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>Group</td>
<td>$F_{1.22} = 6.89$</td>
<td>.015</td>
</tr>
<tr>
<td></td>
<td>Interaction</td>
<td>$F_{3.66} = 1.84$</td>
<td>.148</td>
</tr>
<tr>
<td>McGill</td>
<td>Time</td>
<td>$F_{3.66} = 8.58$</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>Group</td>
<td>$F_{1.22} = .047$</td>
<td>.830</td>
</tr>
<tr>
<td></td>
<td>Interaction</td>
<td>$F_{3.66} = .200$</td>
<td>.659</td>
</tr>
<tr>
<td>PPT</td>
<td>Time</td>
<td>$F_{4.88} = 29.77$</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>Group</td>
<td>$F_{1.22} = .469$</td>
<td>.429</td>
</tr>
<tr>
<td></td>
<td>Interaction</td>
<td>$F_{4.88} = .452$</td>
<td>.771</td>
</tr>
<tr>
<td>RANG</td>
<td>Time</td>
<td>$F_{4.88} = 13.812$</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>Group</td>
<td>$F_{1.22} = 1.44$</td>
<td>.243</td>
</tr>
<tr>
<td></td>
<td>Interaction</td>
<td>$F_{4.88} = 9.78$</td>
<td>.424</td>
</tr>
<tr>
<td>Girth</td>
<td>Time</td>
<td>$F_{3.66} = 33.87$</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>Group</td>
<td>$F_{1.22} = .49$</td>
<td>.037</td>
</tr>
<tr>
<td></td>
<td>Interaction</td>
<td>$F_{3.66} = 1.84$</td>
<td>.148</td>
</tr>
</tbody>
</table>

Bold font denotes a significant difference (p<0.05)

ple living with JHS report higher levels of pain, fatigue, and repeated episodes of injury. Their study also indicated that people with JHS report and experience greater anxiety about getting injured or trying to "fit in" and that acceptance by medical professionals help with their long term recovery. Thus, there may be a psychological component to the higher perceived pain levels in the JHS population as well.

There were several limitations of the current study. As mentioned previously, a gender effect was at play, as the non-hypermobile group in the current study mostly consisted of men and the hypermobile group consisted primarily of women. This was especially evident with girth measurements, as the men, on average, had larger arm girths than the women. As previously discussed, there are physiological differences between females and males that affect recovery and pain perception as well. Future studies may attempt to study men or women separately to control for the confounding effect of gender. Some participants reported they were not fully recovered by the end of the five days, and therefore the time limit of five days for assessment in the current study served may be a limitation. Additionally, the authors of this study believe the SF-MPQ 2 may not have been the best outcome measure to include as it incorporates many different pain types that may have not been the most appropriate for this particular study. This study was heavily reliant on many subjective outcome measures as is true of most studies on DOMS. More expensive and objective outcome measures such as ultrasound imaging and blood markers of muscle damage may be warranted.

CONCLUSION

The results of this study indicate that individuals with JHS may experience greater DOMS and require more time to recover between treatment sessions. Therapists need to be aware that hypermobile patients may experience higher pain levels, and so may need to adjust treatment parameters appropriately. This also means that therapists need to listen to their hypermobile patients’ feedback carefully regarding their pain levels when prescribing interventions. Resistance exercise has been proven to be an effective intervention for reducing pain and joint instability in hypermobility, but therapists need to monitor and progress it individually for hypermobile patients.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

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REFERENCES


The Convergent Validity of the SWAY Balance Application to Assess Postural Stability in Military Cadets Recovering from Concussion

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Keywords: Concussion, SWAY balance, return to play

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Background
Concussions are often accompanied by balance disturbances. Clinically accurate evaluation systems are often expensive, large, and inaccessible to most clinicians. The SWAY Balance Mobile Application (SWAY) is an accessible method to quantify balance changes.

Purpose
To determine the known groups and convergent validity of the SWAY to assess balance after a concussion.

Study Design
Case-Control Study.

Methods
Twenty participants with acute concussion and twenty controls were recruited. At initial, one-week, and final return to activity (RTA) evaluations, all participants completed the Sports Concussion Assessment Tool (SCAT-5), and balance control measured by SWAY mBESS and NeuroCom Balance Master Sensory Organization Test (SOT). Mixed model ANOVAs were used to detect differences in SWAY mBESS and NeuroCom SOT scores with time (initial, one-week, final RTA) as the within-subjects factor and group (concussed, healthy) as the between-subjects factor. Spearman’s Rho correlations explored the associations between NeuroCom SOT scores, SWAY scores, SCAT-5 symptom scores, and time in days to final RTA.

Results
The sampled population was predominantly male and age (20 ± 1), and BMI differences were insignificant between groups. The SWAY did not detect differences between healthy and concussed participants and did not detect change over time [F(2,40) = .114, p = 0.89; F(2,40) = .276, p = .60]. When assessing the relationship between the SWAY and the SOT, no correlation was found at any time point (r = -0.317 to -0.062, p > 0.05). Time to RTA demonstrated a moderate correlation with both SCAT-5 symptom severity score (r = .695, p < .01) and SCAT-5 total symptom score (r = .611, p < .01) at the one-week follow-up.

Conclusion
The SWAY mBESS does not appear to be a valid balance assessment for the concussed patient. The SWAY mBESS in patients with concussion failed to demonstrate convergent...
validity and did not demonstrate an ability to validate known groups. When assessing the
time to final RTA, the one-week post-initial assessment SCAT-5 symptom severity and
total scores may help determine the length of recovery in this population.

**Level of Evidence**
Level 3

**INTRODUCTION**

Concussions cause a range of symptoms and can be challenging to diagnose. Over 450,000 military personnel have sustained some type of traumatic brain injury (TBI) since 2000, most of which were mild traumatic brain injuries (mTBI), also known as concussions. However, this is likely an underestimate as over 50% of military concussions go unreported, similar to civilian sport-related concussions. Concussions in collegiate athletes may be more common than in the general population, and their incidence may be even higher within a military cadet population due to the demands and risks taken. Understanding these individuals’ symptoms better may help manage the concussed individual with the appropriate return to activity.

Decreased balance is one impairment that is often identified in patients after a concussion. This is especially true for an acute traumatic event that needs to be diagnosed in military return-to-duty or athletic return-to-play scenarios. Unfortunately, the evaluation of concussion symptoms in most cases is rudimentary and consists of using non-instrumented tools to assess static balance. The Balance Error Scoring System (BESS) is one of the most commonly used tests to evaluate impaired balance within the sports population. This test requires the patient to maintain their balance in different test positions while the clinician tallies technical “errors” for the duration of the test. Clinician-assessed BESS testing has demonstrated moderate to good reliability in the assessment of static balance; however, clinicians may lack detection of subtle changes in postural sway that do not result in visible errors scored in the BESS or may simply miss errors because of the multitude of movements occurring simultaneously.

Objective and instrumented assessments of static balance uses force plates or reflective markers. One of these quantitative methods is the NeuroCom sensory organization test (SOT). However, this method and other similar devices are neither practical for an on-field assessment nor cost-effective for most clinicians and first-line providers to implement.

Static balance may also be assessed in a portable and affordable manner through the use of mobile technology. The Sway Balance Mobile Application (SWAY) can be accessed on most smartphones or tablets. The SWAY Modified Balance Error Scoring System (mBESS) may be more clinically feasible, can be completed without significant training, and may be used in austere environments. In healthy participants, the SWAY mBESS demonstrated good test-retest reliability. Many youth and college athletic programs use the SWAY for concussion baseline testing. However, no research has examined healthy young individuals after experiencing a recent concussion.

The primary purpose of this study was to determine the known groups and convergent validity of the SWAY to assess balance after a concussion. An additional objective was to determine the relationship between reported concussion symptoms and time to return to full activity.

**METHODS**

**PARTICIPANTS**

Twenty participants that suffered a recent concussion and a group of 20 matched healthy, non-concussed controls were recruited prospectively through convenience sampling within a military physical fitness center and physical therapy clinic. The study was approved by the Regional Health Command-Atlantic Institutional Review Board, and all participants provided written informed consent prior to participation.

**INCLUSION/EXCLUSION CRITERIA**

Participants in the concussed group were cadets within three days of a concussion diagnosed by a medical provider. Participants in the healthy group were cadets without any recent concussion or lower extremity injury that would affect their balance. Participants who reported a history of lower extremity surgery involving the foot or ankle, concussion within the prior six months, or any disorders known to affect balance (Parkinson’s, BPPV, etc.) were excluded from both groups.

**STUDY DESIGN**

This study was a case-control design separated into three aims. The first aim was to assess the ability of the SWAY application to detect differences in static balance between participants with a concussion as compared to a group of healthy controls (known groups validity). The second aim was to determine the relationship between the SWAY application and other established clinical measures, such as the NeuroCom SOT (convergent validity). The third aim explored relationships between assessed outcomes (SCAT-5, SWAY mBESS, NeuroCom SOT) and the time to final RTA.

**PROCEDURES**

All participants completed an initial assessment including self-reported symptoms using the SCAT-5 and static balance using the SWAY and Neurocom SOT. The average duration of the assessment was approximately 30-45 minutes. Participants in the concussion group and control group completed the same assessments again at a one-week fol-
low-up and final RTA follow-up. The final reassessment (RTA) was completed at the time the patient was cleared by their medical provider to return to full activity. Control participants attended a return to activity time point evaluation equivalent to their concussion-matched participant.

OUTCOME MEASURES

**Static Balance: SWAY Modified Balance Error Scoring System (mBESS).** The SWAY mBESS protocol consisted of five test positions. Each position was performed for ten seconds with the participant’s eyes closed. The positions in order are feet together, tandem left foot forward, tandem right foot forward, single leg right, and single leg left, all with the participant holding the mobile device to their chest.30,32 (Figure 1) A proprietary algorithm is used by the app to calculate a SWAY balance score. The score is derived from information collected within the mobile device's inertial sensors. The SWAY mBESS scores can range from 0 to 100, with greater scores indicating better balance.

**Static Balance: NeuroCom Sensory Organization Test.** The participant is presented with six conditions of varying sensory input, including eyes open, eyes closed, sway surround, and sway support. This test is used to evaluate the participant’s use of somatosensory, visual, and vestibular input to maintain their balance. The NeuroCom SOT Balance Master is equipped with two 9- x 18in (23- x 46-cm) force plates.33 The visual surroundings and the support surface rotate in the sagittal plane.35 The primary outcome of the SOT is the equilibrium score, which ranges from 0-100. An equilibrium score is calculated based on how effectively the participant can maintain their theoretical limits of stability (established as a total of 12.5 degrees in the anterior-posterior direction).35 Greater postural stability is indicated by decreased postural sway in the anterior-posterior direction and results in a higher equilibrium score.35 The participant receives an equilibrium score of 0 for a trial if they fall or receive a negative value (sway more than the theoretical limit of 12.5 degrees).35

Subjective Symptoms: The Sports Concussion Assessment Tool (SCAT-5). The SCAT-5 is a multi-item questionnaire used in the sports and athletic setting to assist in evaluating cognitive, sleep, affective, and physical symptoms.34 The SCAT-5 is a responsive instrument that distinguishes normal baseline levels of neurocognitive function from a concussive injured athlete.35,36 There is also evidence to suggest the SCAT-5 may be used as a mental health screening tool after a baseline concussion screen.34 The SCAT-5 consists of an on-field and off-field assessment. The on-field assessment has four steps, some of which include evaluation of red flags, observable signs, memory assessment (Maddocks questions), and examination that includes a Glasgow Coma screen. The off-field screen consists of a six-step assessment that includes a subjective assessment of 22 symptoms to a final decision matrix after performing the multi-step process.

STATISTICAL ANALYSIS

Descriptive statistics for age, height, body mass, prior history of concussion, number of concussions, and time from concussive event to time of evaluation were analyzed with means and standard deviations calculated. T-tests and chi-square tests were used to compare differences between groups as appropriate with continuous and categorical data. Mixed model ANOVAs were used to detect differences in SWAY mBESS and NeuroCom SOT scores with time (initial, one-week, final RTA) as the within subjects factor and...
group (concussed, healthy) as the between subjects factor. Paired and independent t-tests, with Bonferroni corrections for multiple comparisons, were used for post hoc testing. Cohen’s d effect sizes were calculated, with 0.3 indicating a small, 0.5 indicating a medium, and 0.8 indicating a large effect. Normality and skewness were assessed, and Spearman’s Rho correlations were used to explore the associations between NeuroCom SOT scores, SWAY mBESS scores, SCAT-5 severity / total symptom scores, and time to final RTA. Correlation coefficients were interpreted as low-fair (r = 0.25 - 0.49), moderate-good (r = 0.50 - 0.74), and strong (r > 0.75). The significance level for all analyses was set at α = .05, and all tests were two-tailed. All statistical analyses were completed using SPSS (version 28; IBM Corp, Armonk, NY, USA).

RESULTS

Forty cadets consented to participate in this study, 20 with a recent concussion and 20 healthy matched controls. The groups were equivalent at baseline, except that the concussion group reported a significantly greater frequency of prior history of concussions (Table 1). One participant in the concussion group did not complete their final data collection, and these data were carried forward with the last values recorded by the clinic. The same participant was cleared and returned to activity by an outside provider; that date was used as the final RTA date. Age, BMI, height, weight, and race distribution were not significantly different p>0.05 between groups, indicating successful matching (Table 1).

Table 1. Participant demographics

<table>
<thead>
<tr>
<th></th>
<th>Total (N=40)</th>
<th>Post-concussion (mean ± SD)</th>
<th>Control (mean ± SD)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>32</td>
<td>16</td>
<td>16</td>
<td>na</td>
</tr>
<tr>
<td>Female</td>
<td>8</td>
<td>4</td>
<td>4</td>
<td>na</td>
</tr>
<tr>
<td>Age, mean (mean ± SD)</td>
<td></td>
<td>20 ± 1</td>
<td>20 ± 1</td>
<td>p=0.60</td>
</tr>
<tr>
<td>Weight, lbs (mean ± SD)</td>
<td></td>
<td>174.60 ± 29.04</td>
<td>172.75 ± 31.71</td>
<td>p=0.69</td>
</tr>
<tr>
<td>Height, in (mean ± SD)</td>
<td></td>
<td>69.67 ± 3.53</td>
<td>69.70 ± 3.61</td>
<td>p=0.97</td>
</tr>
<tr>
<td>BMI, Kg/cm²</td>
<td></td>
<td>25.19 ± 3.10</td>
<td>24.88 ± 3.48</td>
<td>p=0.53</td>
</tr>
<tr>
<td>Time from the concussive event to the evaluation, days (mean ± SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial evaluation</td>
<td></td>
<td>1.8 ± 1.1</td>
<td>na</td>
<td></td>
</tr>
<tr>
<td>One week</td>
<td></td>
<td>8.15 ± 1.3</td>
<td>na</td>
<td></td>
</tr>
<tr>
<td>Final follow-up (RTA)</td>
<td></td>
<td>38.30 ± 43.3</td>
<td>na</td>
<td></td>
</tr>
<tr>
<td># of prior concussions</td>
<td></td>
<td>*1.4 ± 1</td>
<td>*0.4 ± 0.75</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>% of prior history of concussion</td>
<td></td>
<td>24 (60%)</td>
<td>18 *(90%)</td>
<td>6 *(30%)</td>
</tr>
</tbody>
</table>

PC, Post-concussion; SD, standard deviation; lbs, pounds; in, inches; BMI, body mass index; cm², centimeters squared; Kg, kilograms; RTA, return to activity
*statistically significant differences noted between group demographics

KNOWN GROUPS VALIDITY

A mixed-model ANOVA examined the effect of a recent history of concussion on balance scores at three different times: initial, one-week follow-up, and final RTA. For the SWAY mBESS there were no significant main effects for time [F(2,40) = .121, p = 0.87]) or group [F(2,40)= .296, p =0.59]). There was also no significant group-by-time interaction [F(2,40)= 1.284, p =.28] (Table 2, Figure 2).

There was a significant main effect of time [F(2,40) = 34.59, p < 0.01] and group [F(2,40)= 8.25, p < 0.01] for the NeuroCom SOT. However, there was no group-by-time interaction [F(2,40)= 1.915, p =0.16]. In both groups, post-hoc testing revealed that scores increased significantly from the initial evaluation to one-week follow-up (p<0.01) but did not change significantly from the one-week follow-up to the final RTA (p=0.08). (Table 2, Figure 2) The control group scored greater at all time points except at the final RTA (Initial evaluation p<0.01, one-week follow-up p=.02, final RTA p=0.07).

CONVERGENT VALIDITY

No significant correlations were found between the SWAY mBESS and the NeuroCom SOT at any time point in the concussed group (r = -0.517 to -0.062, p > 0.05) and the control group (r = 0.275 to 0.387, p > 0.05).

RELATIONSHIPS WITH RTA

Time to full return to activity was positively correlated with both SCAT-5 symptom severity score (r = .695, p < 0.001) and SCAT-5 total symptom score (r = .611, p = 0.004) at the one-week follow-up. Time to full return to activity was
Table 2. Group Means for SWAY & NeuroCom SOT

<table>
<thead>
<tr>
<th></th>
<th>Post-concussion (mean ± SD)</th>
<th>Control (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SWAY</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial evaluation</td>
<td>83.49 ± 14.03</td>
<td>78.25 ± 14.73</td>
</tr>
<tr>
<td>One-week</td>
<td>80.73 ± 13.61</td>
<td>79.46 ± 13.50</td>
</tr>
<tr>
<td>Final (RTA)</td>
<td>80.41 ± 17.17</td>
<td>80.15 ± 13.13</td>
</tr>
<tr>
<td><strong>NeuroCom SOT</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial evaluation</td>
<td>70.90 ± 9.86*</td>
<td>78.05 ± 5.88*</td>
</tr>
<tr>
<td>One-week</td>
<td>77.25 ± 11.67*</td>
<td>84.50 ± 4.94*</td>
</tr>
<tr>
<td>Final (RTA)</td>
<td>81.85 ± 6.95</td>
<td>85.25 ± 4.01</td>
</tr>
</tbody>
</table>

SD, standard deviation; SWAY, Sway Mobile Application; RTA, Return to Activity
SOT, Sensory Organization Test; RTA, Return to Activity
*statistically significant differences noted between group scores

Figure 2. Group Balance Mean Scores for SWAY and NeuroCom SOT.

SOT, NeuroCom Sensory Organization Test; RTA, Return to Activity
* statistically significant difference noted between concussed and control group
* statistically significant difference noted between initial and one-week follow-up

not related to SCAT-5 symptom severity score (initial- \( r = .239 \), RTA- \( r = .114 \)) or SCAT-5 total symptom score (initial- \( r = .196 \), RTA- \( r = .132 \)) (Table 3).

DISCUSSION

This study aimed to determine the SWAY’s ability to identify differences in static balance between participants with a recent concussion and matched healthy controls (known groups validity). Additional objectives were to determine the relationship between other commonly used clinical measures (SCAT-5, NeuroCom SOT) and the SWAY (convergent validity). The SWAY mBESS detected no differences in static balance in participants after a recent concussion when compared to healthy controls. SWAY mBESS scores also had no significant correlation with static balance clinical assessment tools such as the NeuroCom SOT, suggesting it may not be a valid assessment to interpret balance disturbances within a concussed population. Total symptoms and symptom severity at one-week (SCAT-5) were associated with time to final return to activity.

Previous authors within the literature have suggested that the SWAY application may be able to detect balance deficits in patients with diagnoses known to cause balance problems. In Parkinson’s patients, postural sway differences were identified using accelerometers similar to the SWAY.38,39 Alkathiry and colleagues observed that accelerometers were a precise method to measure postural sway among adolescents with concussions.40 Conversely,
Table 3. Correlations between time to RTA and SCAT-5 Total Symptom/Symptom Severity Score

<table>
<thead>
<tr>
<th></th>
<th>Time to RTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCAT-5 total symptoms</td>
<td>.196</td>
</tr>
<tr>
<td>Initial Evaluation</td>
<td></td>
</tr>
<tr>
<td>SCAT-5 total symptoms</td>
<td>*.611</td>
</tr>
<tr>
<td>One-week evaluation</td>
<td></td>
</tr>
<tr>
<td>SCAT-5 total symptoms</td>
<td>.132</td>
</tr>
<tr>
<td>Final RTA</td>
<td></td>
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<tr>
<td>SCAT-5 symptom severity</td>
<td>.239</td>
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<tr>
<td>Initial Evaluation</td>
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<td>SCAT-5 symptom severity</td>
<td>*.693</td>
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<tr>
<td>One-week evaluation</td>
<td></td>
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<tr>
<td>SCAT-5 symptom severity</td>
<td>.114</td>
</tr>
<tr>
<td>Final RTA</td>
<td></td>
</tr>
</tbody>
</table>

SCAT, Sports Concussion Assessment Tool; RTA, Return to Activity. * = Statistically significant correlation noted.

in this study, the SWAY could not distinguish between patients with concussion and healthy controls. These conflicting observations may be due to different accelerometer placements that do not account for differences in balance strategies; the accelerometer was placed on the low back at the level of the sacrum in the Alkathiry study versus the sternum for this study. Some participants in this study may have used an alternate postural control strategy or accelerometer stabilization method that made the sensor unable to detect changes but it could have possibly been detected with a placement similar to Alkathiry’s study.40

Other authors have found that increased sway and potentially the SWAY application itself can discriminate between injured patients with neurological and musculoskeletal conditions and healthy controls.58,39,41,42 When assessing Parkinson’s disease progression, Mancini et al. observed a progressive increase in the acceleration excursions for the Parkinson Diseased participant.58,39 The Sway application score is correlated with increased postural sway in older participants (aged 50-71).42 The results of this study do not align with the findings of Mancini and other authors, which may be due to the participant’s ability to employ different balance strategies as suggested above. The SWAY application may not help discriminate balance deficits in patients with concussions.

Multiple studies have attempted to validate the SWAY compared to other valid and responsive balance tests.53–58 One comparison was made between the BESS, BioDex and SWAY balance, in which no significant correlation was found.46 Another study that compared the SWAY and the modified BESS observed a strong negative correlation indicating ability to determine balance deficits in healthy older adults.48 The SWAY application has also been compared to the Neurocom VSR sport in which a moderate inverse correlation was reported, but testing was also performed in a different manner than what is normally performed with the modified BESS test.47 However, the SWAY has not been previously compared to a clinical gold standard balance assessment like the NeuroCom SOT and within the other-wise healthy and young concussed population. In contrast to the SWAY mBESS, this study did find that the NeuroCom SOT could accurately discriminate between patients with concussions and healthy controls. These findings supplement the available research supporting the NeuroCom SOT as a valid and reliable tool that assesses static balance and postural sway.19,49,50 As other authors have noted, this research observed a learning effect using the NeuroCom SOT, suggesting that the healthy and concussed participants in this study improved similarly in this balance assessment over time as those in existing literature.49,51,52 This learning effect is not unique to the NeuroCom SOT, as other authors have reported improvements on the BESS are observed with repeated balance testing up to 60 days after initial testing.53,54 Overall, these findings align with previously published research and support the Neurocom’s continued value in discriminating between a healthy and a balance-challenged population.

Prior authors have suggested that the SWAY application may offer a valuable means of providing objective evaluations on the sidelines or in emergency departments.55 Prior authors have also reported moderate to strong correlations between the traditional mBESS and the SWAY mBESS in healthy participants.55,56 In this study of patients with a concussion, SWAY mBESS scores were not significantly correlated with the NeuroCom SOT scores. This aligns with one other published instrumented assessment balance study that found little to no relationship between the SWAY mBESS scores, BESS scores, and Biodex balance systems in a similar healthy college age population.46 Contrary to the results found within this study, Mackenzie et al. observed that the NeuroCom VSR sport demonstrated a moderate inverse relationship with the SWAY balance assessment in older adults.47 However, these participants performed a special assessment using the Modified Clinical Test of Sensory Interaction and Balance (mCTSIB). Due to the conflicting evidence concerning the convergent validity of the SWAY mBESS and other measures, caution should be taken when using the SWAY mBESS in a post-concussed population.

In this study, total number of concussion symptoms and greater symptom severity scores on the SCAT-5 at one-week post-concussion were associated with longer recovery times. This finding is in alignment with Ademan et al., reporting that those who had elevated SCAT-5 (≥ 2) total symptoms at the initiation of return to activity had 22% longer recovery times.11 These results suggest a longer recovery for patients with concussion who have increased SCAT-5 total symptom and symptom severity scores at one-week. This may have some relationship to the implementation timeline of return to activity programming, and further research into matching the optimal exercise intensity to one-week SCAT-5 symptoms may be warranted.

LIMITATIONS

This study has several limitations. The population assessed was a relatively young, healthy, and active population, which may not generalize to other population groups. Contrary to the recommendations put forth by Bret et al., the
CONCLUSION

These findings do not support the use of the SWAY mBESS for assessing static balance control as part of the acute assessment of and during the recovery from a concussion. The SWAY mBESS did not discriminate between healthy controls and patients with a concussion and was not correlated with a validated measure of balance in patients with a concussion. This may be due to the SWAY’s inability to detect balance strategies due to the proximal placement of the accelerometer. One-week follow-up assessment SCAT-5 total symptom and symptom severity scores may help determine the length of RTA in this population. More research is needed to determine the best clinical measure of balance in patients with a concussion and the optimal exercise intensity based on symptom severity at RTA.

DISCLAIMER

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.

CONFLICTS OF INTEREST AND SOURCE OF FUNDING

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ETHICS APPROVAL

Study was approved by the Naval Medical Center Portsmouth Institutional Review Board (RHC-A-20-051).

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REFERENCES


Original Research

Workload Comparison of Contemporary Interval Throwing Programs and a Novel Optimized Program for Baseball Pitchers

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Background

In the rehabilitation of injured baseball pitchers, there is lack of consensus on how to guide a player back to pitching. It is unknown how different contemporary interval throwing programs (ITPs) progress in the amount of throwing workload.

Purposes

To 1) evaluate three prominent ITPs commonly employed in baseball pitcher rehabilitation and assess whether these ITPs produce training loads that increase in a controlled, graduated manner and 2) devise an ITP that produced training loads which increased steadily over time.

Study Design

Cross-sectional study

Methods

Three publicly available ITPs from prominent sports medicine institutions were analyzed. Elbow varus torque per throw was calculated from a 2nd order polynomial regression based upon a relationship between recorded torque measurements and throwing distance measured from a database of 111,196 throws. The relative rate of workload increase was measured as an acute:chronic workload ratio (ACWR). For each ITP, throw counts, daily/acute/chronic workloads, and ACWR were calculated and plotted over time. Finally, an original ITP was devised based upon a computational model that gradually increases ACWR over time and finished with an optimal chronic workload.

Results

Each ITP exhibited a unique progression of throwing distances, quantities, and days to create different workload profiles. The three ITPs had throwing schedules ranging from 136 days to 187 days, ACWR spiked above or fell below a literature-defined "safe" range (i.e. 0.7 – 1.3) 19, 21, and 23 times. A novel ITP, predicated on a 146-day schedule and with a final chronic workload of 14.2, was designed to have no spikes outside of the safe range.

Conclusion

Existing ITPs widely utilized for rehabilitation of baseball pitchers exhibit significantly inconsistent variation in the rate of throwing load progression. Computational modeling may facilitate more incremental workload progression in ITPs, thereby reducing injury during rehabilitation and more efficiently condition a pitcher for return to competition.

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Level of Evidence

3b

INTRODUCTION

Despite continued improvements in the understanding of the overhead throwing motion, injuries to the upper extremities of baseball pitchers continue to rise across all levels of play.1-4 Efforts to return pitchers to their pre-injury level of performance remains a critical, yet challenging task for sports medicine physicians, physical therapists, athletic trainers, and other rehabilitation specialists. Successful rehabilitation of baseball pitchers relies on a gradual building of strength, flexibility, and endurance to meet the demands of competition. With or without surgical intervention, an interval throwing program (ITP) remains the cornerstone by which throwing athletes systematically return.5 Once a pitcher is cleared by medical staff, he may then pursue his competitive training (long-toss, weighted balls, bullpen sessions, etc.) and pitching in games.

Traditional ITPs have relied on a generic, standardized prescription of throwing activities that change in volume, distance, and effort exerted over a fixed timeframe.6 The distance, volume, and intensity of throws are progressively overloaded to gradually expose the pitcher to mechanical stress, resulting in tissue adaptation to the increased demands of throwing.7 In general, an ITP is comprised of a flat-ground (sometimes referred to as long-toss) progression with increasing distances starting somewhere from 30 ft to 60 ft out to 120 ft. After completing the flat-ground progression asymptotically, the pitcher transitions to pitching from the mound at regulation distances (60.5 ft) with graduated intensities, often starting at 50% effort. Some ITPs have prescribed pitchers to throw off the mound at reduced distances of 45 ft before transitioning to the full 60.5 ft.

Recent advancements in the assessment of throwing biomechanics have scrutinized how factors such as throwing distance and ball velocity impact stresses experienced at the shoulder and elbow.8,9 Biomechanical metrics, such as elbow varus torque, offer objective and potentially more accurate data about training loads in which pitchers experience. For example, Melugin et al10 demonstrated that a reduction in perceived effort did not correlate with the same percent reduction in ball velocity and elbow varus torque causing variability in predicted workloads. Metrics, such as the acute:chronic workload ratio (ACWR), employ biomechanical parameters to evaluate whether training loads experienced by a rehabilitating athlete occur in a graduated manner.11,12 Previous research investigating ACWR has reported increased injury risk occurs when the workload ratio either exceeds 1.5 or drops below 0.7.13-16 Together, biomechanical data and objective metrics for training loads afford an opportunity to optimize ITPs to avoid excessive variations in training loads and, potentially, avoid setbacks and recurrent injury during rehabilitation.

The purpose of this study was to evaluate three prominent ITPs frequently utilized among rehabilitating baseball pitchers and assess whether contemporary ITPs produce training loads that increase in a controlled, graduated manner. It was hypothesized that ITPs commonly employed by baseball pitchers would have excessive variation in training workloads that sometimes produce ACWR outside the safe range of 0.7 - 1.3. Therefore, a secondary aim of the study was to devise an ITP that produced training loads which increased steadily over time, thereby reducing the potential risk of re-injury during rehabilitation and more efficiently condition a pitcher for return to competition.

METHODS

INTerval THROWING PROGRAMS (ITPS)

Interval throwing program protocols were identified at three sports medicine institutions affiliated with Major League Baseball. Individual ITPs were selected based on their public and academic prominence pertaining to the treatment of professional baseball pitchers.17,18 The selected ITPs are among the most utilized in the rehabilitation process for return to throw for pitchers. The three throwing programs were from the American Sports Medicine Institute (Program A, Supplement 1), the Kerlan-Jobe Institute (Program B, Supplement 2), and Hospital for Special Surgery (Program C, Supplement 3), respectively.

CALCULATION OF ELBOW VARUS TORQUE AND WORKLOAD

In order to determine elbow varus torque with each throw, data were mined from Motus Global’s MotusBaseball sensor (now Driveline Pulse; Driveline Baseball, Kent, WA) database. Previous research has shown that the Motus sensor’s measures correlate well with 3D motion capture laboratory measures19,20 and provides precise and reproducible data.10,21 A total of 238,611 anonymized flat-ground throws were extracted from one NCAA-Division 1 level team over the course of two years. These throws were taken by healthy college pitchers (n=54, 186.02 ± 7.5 cm, 89.4 ± 10.8 kg). Of these, 111,196 flat-ground throws were tagged by distance, ranging from 30 ft and 300 ft. Distance categories with over 1,000 throws per distance were used in the model. A 2nd order polynomial regression created a relationship between throwing distance (x in ft) and peak elbow varus torque (Nm) (Equation 1).

\[
\tau_{\text{varus}} = -0.000579x^2 + 0.194x + 36.230; \\
\tau^2 = 0.986
\]  

(1)

The workload of each throw \((WL_{\text{Throw}})\) was computed by exponentially weighting the elbow varus torque value to 1.3 (Equation 2). This exponential weight was chosen based on NASA’s ‘Daily Load Stimulus’ research regarding mechanical load and gravity.22

\[
WL_{\text{Throw}} = \tau_{\text{varus}}^{1.3}
\]  

(2)

Daily workloads \((WL_{\text{Day}})\) were computed as the total sum of workload of each throw (Equation 3).
Acute workloads (\(WL_{\text{Acute}}\)) were computed as a rolling 7-day average of daily workload (Equation 4).\(^\text{13}\)
\[
WL_{\text{Acute}} = \frac{1}{7} \sum_{\text{day}=7}^{\text{day}=1} WL_{\text{day}}
\]

Chronic workloads (\(WL_{\text{Chronic}}\)) were computed as a rolling 28-day average of daily workload (Equation 5).\(^\text{13}\)
\[
WL_{\text{Chronic}} = \frac{1}{28} \sum_{\text{day}=28}^{\text{day}=1} WL_{\text{day}}
\]

Finally, the ACWR was computed as the acute workload divided by the chronic workload (Equation 6).
\[
ACWR = \frac{WL_{\text{Acute}}}{WL_{\text{Chronic}}}
\]

Workloads (i.e. daily, acute, chronic, and ACWR) were built from the prescribed throwing for each program. Previous research investigating ACWR has reported increased injury risk occurs when the workload ratio either exceeds 1.5 or drops below 0.7.\(^\text{13-15}\) Therefore, the ACWR ‘safe’ range was coded as anything between 0.8-1.3.

Each ITP consisted of various sequential phases; a pitcher must complete each phase pain-free before progressing to the next phase. In Program A, pitchers were instructed to throw every other day and perform each phase two times before advancing to the next phase. Program B instructed pitchers to throw three to four times per week. To account for this, one week was coded throwing three times and the next week was throwing four times; this alternated between the two for the whole program. Additionally, phases in Program B were separated by month without specifying how many times each phase should be repeated, therefore it was assumed four weeks of throwing for each month. Program C instructed players to throw every three days and to complete each phase three times before progressing to the next one.

While an ideal ITP would explicitly state which days to throw, the number of throws per day, and clearly defined distances, this exact information was not available in each of the three programs. Program C was the only program to explicitly state the number of throws to perform at each phase with specific distances. Program A provided a range of throws starting at 75 ft and varied 5-15 throws at each phase after. Program B had a range of throws for each phase and varied 5-20 throws and a range of throwing distance (i.e. 40-45 ft, 60-70 ft). To standardize the number of throws for each phase in the programs that did not have an exact number, the median of the provided range was used. For example, if the program stated to throw 20-25 times at a given distance, the throws coded were 23. In order to standardize Program B that used distance ranges, the distance closest to the 15 ft increments used in the two other programs was used (i.e. 40-45 ft, 45 ft distance was used).

For all ITPs, throws in the flat-ground progression were instructed to be thrown as ‘catch’ and not meant as maximal effort throwing. These flat-ground throws were not to be thrown with a pitching motion and all were programmed using the flat-ground polynomial regression torques. All programs allowed crow-hop/shuffle at longer distances (starting at 75 ft), which was accounted for in the polynomial regression. Program C did not prescribe warm-up throws. Program A stated warm-up throws should start at 30-45 ft and then progress to the starting distance for the phase, but the quantity of throws was not provided for these ‘warm-ups’. Program B prescribed 10 throws at 40 ft as a ‘warm-up’ and ‘cool down’. In order to standardize across Program A and C, it was assumed ‘warm-up’ throws to be 5 throws at each distance – increasing by 15 ft until reaching the starting throwing distance for that day. Additionally, if a program stated throws could be taken if the athlete desired, then 5 throws at that distance (similar to warm-up throws) were coded. Program C provided an optional three weeks of flat-ground (phases 15-16), this was not coded as they were considered optional.

All three programs delineated throwing intensity during the mound phase (e.g., 20 throws at 75%). Asking pitchers to throw with graded effort is a difficult and sometimes inaccurate task. Previous research has shown that there was not a proportionate decrease in ball velocity or elbow varus torque to perceived effort when pitching off the mound.\(^\text{23, 24}\) Melugin et al\(^\text{10}\) reported that when pitchers were asked to throw 50% effort, elbow varus torque was 86% of maximum torque and when throwing 75% effort, elbow varus torque was 95% of maximum torque. In order to codify for mound intensity, the average 100% effort torque from Melugin et al’s study (\(T_{\text{maximum}} = 74 \text{Nm}\)) was used and a linear regression model was built using the three efforts and resulting torques (Equation 7). This allowed for the differentiation of prescribed intensity and to build the resulting torque for each program.
\[
\tau_{\text{actual}} = \frac{T_{\text{maximum}}(0.28 \times \text{perceived intensity}) + 72)}{100}
\]

Lastly, two programs (Program A and B) prescribed off-speed pitches when the pitcher was close to resuming game throwing, whereas Program C did not specifically differentiate between pitch types. Previous research has shown that resultant loads in the throwing arm are similar for the fastball and curveball in pitchers.\(^\text{25-27}\) Thus, pitch types were not differentiated and fastball elbow varus torque was used for the workload calculations.

MODEL ITP FOR OPTIMIZING WORK LOAD PROGRESSION

Using the results of the three ITPs, a novel computationally-optimized workload ITP model was created (Supplement 4). This model was developed to maintain an optimal ACWR, while also steadily increasing the chronic workload throughout the throwing program. The novel model utilized non-linear throw count increments, while steadily increasing throw counts and distances with variability in the daily amounts. In current programs, cyclic loading and consistent off-days in the protocols (i.e. throwing every other day) led to detrimental ACWR. To address this, variable off days were implemented with throwers not throwing on consecutive days over what would be considered a "weekend" until week 16 where a light throwing day was implemented. Throwing volume was gradually built up along with increased throw distance, until 120 ft throwing distance was
reached; then the protocol transitioned into throwing from the mound. The mound progression was gradually built up with pitch counts to reach an optimal chronic workload of 13.8. The last week of the program's mound days were delineated as live pitching sessions where players were allowed to pitch to a hitter but still have constrained pitch counts.

RESULTS

Each ITP exhibited a unique progression of throwing distances, quantities, and days to create different workload profiles. The chronic workload in the denominator of ACWR increases during the first 28 days, causing all four programs to have large spikes in ACWR early in this initial period.

Program A consisted of a 156-day schedule. The first 72 days were the flat-ground phase and included 24 days of throwing (Figure 1). The final 64 days were the mound phase and included 22 days of throwing. The program finished with a chronic workload of 15.0. During the program, there were 19 times the ACWR spiked above or below the safe range.

Program B consisted of a 157-day schedule (Figure 2). A total of 56 out of 111 days were spent throwing in the flat-ground progression. The mound progression consisted of 23 throwing days out of 46 total days. The program finished with a chronic workload of 15.0. During the program there were 21 times the ACWR spiked above or below the ‘safe’ range.

Program C consisted of a 187-day schedule (Figure 3). There were 36 throwing days in the 106 days of the flat-ground progression. The mound progression consisted of 28 throwing days out of 81 total days. The program finished with a chronic workload of 8.4. During the program there were 23 times the ACWR spiked above or fell below the ‘safe’ range.

NOVEL INTERVAL THROWING PROGRAM TO OPTIMIZE WORKLOAD PROGRESSION

The newly modeled optimized ITP consisted of a 146-day schedule (Figure 4). The features of the optimized ITP were reverse-engineered using computational modeling to derive a graduated increase in ACWR. There were 53 days of throwing within the 77 days of the flat-ground progression. The mound progression consisted of 37 throwing days out of 70 total days. The program finished with a chronic workload of 14.2. The program was built so there were no spikes in ACWR once 28 days of throwing was accomplished.

DISCUSSION

There are a plethora of ITPs circulating in the baseball community, as orthopedic surgeons often utilize unique ITPs for their recovering pitchers. ITPs have traditionally not been based on relevant physiologic metrics like workload (acute, chronic, and ACWR) and instead on anecdotal, clinician-directed experiences. The principal finding from this study is that several prominent, contemporary ITPs utilized by injured baseball pitchers confer inconsistent progression of throwing workloads.

A recent study emphasized the dramatic variability in rehabilitation and throwing programs after ulnar collateral ligament reconstruction (UCLr) surgery. Each program varied in its instructions, number of days to complete the program, distance, volume, intensity, mechanics, and pitch type. In a more recent study, Griffith et al reported significant variability between 717 professional pitchers undergoing rehabilitation after UCLr and the timing of throwing progressions varied widely. Accounting for individual variability, pain, recovery, and adherence to the exact program is virtually impossible for all programs. The variability found in these studies, as well as in the present analysis, highlights the potential for optimizing rehabilitation programs based on objective metrics. In turn, a newly devised ITP modeled to reduce the variability in workload may reduce the risk of set-back or recurrent injury by providing a steady incremental increase of tissue loading during throwing rehabilitation.

This study’s findings rely upon ACWR as a surrogate marker for evaluating how ITPs progress baseball pitchers in their rehabilitation. Increased ACWR has been linked to increased risk of suffering a time loss injury across a variety of sports. Moreover, Gabbett et al demonstrated that the correlation between higher ACWR and injury risk was consistent across multiple methods of calculating ACWR.

The present study’s application of ACWR builds upon prior work assessing performance progression in other sports including soccer, rugby, gymnastics, and cricket, all of which advocate for maintaining consistent ACWR ranges. When building the ACWR, this study used the assumption that at the beginning of the ITP, no throws had been completed for the previous 28 days. However, because of large variations in rehabilitation protocols for UCLr before throwing a baseball even takes place, this assumption may or may not be correct. There has been a recent emphasis for pitchers to perform plyometric training in rehabilitation which can result in added elbow varus torque to the throwing arm before starting their ITP. If plyometric training is being performed during rehabilitation, then it is possible that throwers are not starting at 0 for workload on Day 1 of the ITP and the ACWR would be altered at the beginning stages of throwing. However, the only true way for the throwing arm to experience the same forces and torques during the throwing motion is to actually throw a ball; therefore, this assumption is reasonable. It is hard to know if this ‘skyrocket’ in ACWR during the first 28 days of throwing is useful or accurate; but caution should be taken during the first month of throwing.

Within baseball, higher ACWR has been associated with increased injury risk among varsity high school pitchers. In a cohort of 18 high school pitchers, whose throws were tracked for six months using a wearable MotusTHROW sensor, five out of six throwing-related injuries occurred in pitchers whose ACWR exceed 1.27. Pitchers whose workload exceeded this threshold value exhibited an injury risk nearly 15-times that of those below this value. In our study, a pitcher who simulated Programs A, B, and C exceeded this...
ACWR threshold 18–23 times starting from Day 28; while our optimized program was created to not deviate from the safe ACWR range of 0.7–1.3. Extrapolation from prior data of ACWR threshold values on varying levels of baseball pitchers is needed and further study is necessary to delineate optimal ACWR values in baseball pitchers. Nonetheless, the present data align with the available literature suggesting that existing ITPs are not optimized to load the throwing arm of a rehabilitating pitcher.

Gradual building of the chronic workload throughout an ITP is vital to help mitigate spikes in ACWR when there are high acute workload days. In this way, high chronic workloads are thought to be protective. In middle-school aged athletes, it was reported that high chronic workloads were associated with reduced risk of injury.\textsuperscript{35} This protective effect of chronic workload has also been reported in both rugby and cricket.\textsuperscript{31,33} However, limited studies in baseball link workload based off each throw and injury. In high school players, Mehta et al.\textsuperscript{36} reported players with higher chronic workloads were associated with increased risk of injury compared to players with lower chronic workloads. In-season chronic workloads have been reported in high school pitchers to be between 12–15.\textsuperscript{36} This is similar in college and professional pitchers, as reported by Motus Global (unpublished). Programs A and B had chronic workloads when the programs finished between 13–15; similar to the Optimized program (Program D) that was built. Program C finished well below the targeted average at 8, even though this program also had the greatest duration of days (187).

Appropriate timing in the implementation of an ITP is crucial to ensure the safe return of a throwing athlete to competition. For example, the minimum duration of time and rehabilitation required before an athlete can safely re-

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Throwing workload characteristics of interval throwing Program A.}
\end{figure}
Figure 2. Throwing workload characteristics of interval throwing Program B.

(A) Acute:Chronic workload ratio over the 157-day program; (B) Calculated chronic throwing workload; (C) Daily number of throws performed in ITP

The colors on the graphs represent the deviations away from the optimal chronic workload of 1.5 (green), ±1 standard deviation (yellow), ±2 standard deviation (orange), and ±3 standard deviation (red). The grey band on figure A represents the ACWR 'safe' range of 0.7-1.3.

Many factors can influence the ideal time course for initiating an ITP, such as time from surgery, level of competition, time of season, surgeon's preference, and successful progression through physical therapy. In a recent review, Griffith et al. included 14 studies tracking return to sport (RTS) after UCLr and reported time from surgery was the most common RTS criterion used and was reported in 100% of the studies. However, there was no consensus on how much time was adequate for rehabilitation before returning, with time frames ranging from 4-16 months. Conversely, in a separate systematic review the most common return to play criterion was completion of an ITP (87%; 13 out of 15 studies) and found players started the ITP on average 16.7 weeks after surgery (range 12-18 weeks). The optimal wait period following injury or surgery to initiate an ITP is likely highly individualized. We believe objective testing is vital to proper progression into starting a throwing program. In a recent study, 25% of competitive pitchers did not pass an objective return to throw protocol at the time of clearance by their surgeon. The study also reported lack of plyometric exercises in the rehabilitation process as the most common reason for failing their return to throw protocol. Measures such as range of motion, grip strength, arm strength, and endurance should be used to properly progress a pitcher into throwing; however, further investigations can help elucidate specific attributes of injury, surgery, and/or objective benchmarks to better guide athletes on when to initiate an ITP.

Interval throwing programs use distance as a measure of intensity in lieu of prescribed efforts, radar guns, or wearable technology. While some programs explicitly state to throw with a certain amount of intensity or effort, others do not. Pitchers are frequently unable to accurately assess
their throwing effort or intensity, particularly when they are rehabilitating from an injury. This becomes more of an obstacle once a player gets to the mound progression as some programs instruct players to throw with as little as 50% effort. This is not a feasible, or even an easy, task for a pitcher to do. When pitchers were asked to throw with decreased intensity, they did not decrease elbow varus torque or ball velocity at the same rate as their perceived intensity. Anecdotally, players do not like throwing at dramatically reduced efforts and find it difficult to get the ball to the desired target. Reduced efforts also cause deleterious changes in throwing mechanics and timing of the throw. The Optimized Protocol was created so that pitchers throw with 'intent' and build up their workload during the flat-ground progression, so that once they step on the mound during the second part of the program, their effort does not need to be decreased.

Concern for potentially volatile changes in tissue stress among prevailing ITPs stimulated the design of a novel ITP aimed to deliver appropriate, progressive workloads to the rehabilitating pitcher. In this model, throwing variables such as throwing frequency, throwing distance, and throwing effort were generated based upon calculated ACWR. The ITP's design is compatible with emerging biofeedback technologies that allow for real-time monitoring of torques experienced by an individual athlete. Applying such technology can enable rehabilitation specialists to individualize these programs by modifying quantities of throws, arm speeds, distances, and the relative amount of flat-ground versus mound-based throwing to titrate actual workload. The Optimized Protocol, along with other new rehabilitation tools, require long-term evaluation to determine whether they result in meaningful reductions in injuries as well as effectively prepare the pitcher for return to

Figure 3. Throwing workload characteristics of interval throwing Program C.

(A) Acute:Chronic workload ratio over the 187-day program; (B) Calculated cumulative throwing workload; (C) Daily number of throws performed in ITP. The colors on the graphs represent the deviations away from the optimal chronic workload of 15 (green), ± 1 standard deviation (yellow), ± 2 standard deviation (orange), and ± 3 standard deviation (red). The grey band on figure A represents the ACWR ‘safe’ range of 0.7–1.3.
Figure 4. Throwing workload characteristics of interval throwing Optimized Workload Protocol.

(A) Acute-Chronic workload ratio over the 146-day program; (B) Calculated chronic throwing workload; (C) Daily number of throws performed in ITP. The colors on the graphs represent the deviations away from the optimal chronic workload of 15 (green), ±1 standard deviation (yellow), ±2 standard deviation (orange), and ±3 standard deviation (red). The grey band on figure A represents the ACWR ‘safe’ range of 0.7-1.3.

sport. Nonetheless, the ITP was conceptualized as an individualized and proactive form of rehabilitation that is responsive to objective, real-time biometric data. Future innovations in throwing rehabilitation will likely benefit from aiming at this objective.

This study must be considered within the context of its limitations. Rehabilitation of the baseball pitcher following injury is a highly individualized process and the current analyses of both existing and proposed ITPs do not account for how such protocols are implemented and tailored to an individual pitcher. The absolute values of elbow varus torque and workloads calculated in the present analysis were determined using data reported by Melugin et al. and therefore may vary for pitchers of different size, throwing mechanics, prior injury, etc. Nonetheless, despite increased emphasis on dynamic, interactive rehabilitation that respond to athlete biofeedback, formalized throwing programs remain a cornerstone of modern rehabilitation and merit further optimization. The provided computational model of throwing workload was predicated on biomechanical studies of elbow varus torque experienced by pitchers at varying distances, effort level, and field surface (flat-ground vs. mound) and may therefore be most applicable to pitchers recovering from elbow-related injuries. However, further study is needed to evaluate the impact of ITPs on other biomechanical variables, such as shoulder distraction forces and the addition of various pitch types. Interval throwing programs are supposed to enable a pitcher to return to proper throwing mechanics upon completion of the program; however, measuring proper kinematics of the throw are beyond the scope of this study. While the Optimized Protocol was designed to safely ramp pitchers up and maintain ACWR within a safe range, rehabilitating pitchers commonly experience one or more set-
backs during the return-to-throw process, causing them to stop throwing or repeat a subset of an ITP. For all programs, the rehabilitation team must recognize and accommodate an ITP to an individual pitcher. In attempts to simulate a set-back, we changed the Optimal Program to have a week repeated once, twice, and three times and there was no change in the ACWR; however, the final chronic number was greater. Additionally, while the codified workload was specific for the throwing arm, other factors such as rate of perceived exertion from previous throwing day, recovery, sleep, nutrition, cumulative physical and mental stress, and hydration likely influence perceived effort and workload in the pitcher. Future investigation is needed to characterize and quantify such variables for implementation into a computational-based ITP. The time intervals for acute (7 days) and chronic (28 days) workloads might be inaccurate for a baseball pitcher starting on a 5-day rotation. There is also concern for the conceptual basis of ACWR and the statistical faults that arise from these calculations.  

CONCLUSION

Existing ITPs utilized for rehabilitation of baseball pitchers exhibit wide and inconsistent variation in the rate of throwing load progression. Computational modeling may facilitate more incremental workload progression in ITPs, thereby reducing the risk of injury during rehabilitation and more efficiently condition a pitcher for return to competition.

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REFERENCES


SUPPLEMENTARY MATERIALS

Supplement 1

Supplement 2

Supplement 3

Supplement 4
The Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) Performance in Elite Team Handball Players Playing with Shoulder Pain, Previous Pain, or No Pain

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Keywords: Handball, Shoulder injuries, CKCUEST, Overhead athlete

Background
Physical therapists use tests that could determine strength and weaknesses of the shoulder for overhead throwing athletes to enhance performance, prevent injury, and safely progress rehabilitation. The Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) has been proposed to assess muscular capacity and dynamic shoulder stability in overhead athletes, which could provide information to determine a risk of injury.

Purpose
To investigate if the CKCUEST is an appropriate test to implement within team elite handball players to evaluate dynamic shoulder stability across sexes and in the screening of shoulder pain.

Study design
Cross-sectional study

Methods
Elite team handball players were recruited and performed the CKCUEST from which three different scores (raw, touch, and power) were calculated and compared among handball players playing with shoulder pain, previous pain, and no pain.

Results
A total of 106 handball players were included: 49 females (1.74±0.03 m, 70.4±6.7 kg, and 22±4.9 years) and 57 males (1.90±0.08 m, 91.6±11.4 kg, and 22±5.4 years). A significant difference was found between the female and male handball players when comparing all three CKCUEST scores (p<0.01). No significant differences were found in the CKCUEST scores among the three different groups (F≤1.23, p>0.30, η²≤0.03). Among the female participants, no significant differences were found between performing the CKCUEST and the modified test. A significant correlation was found between height and the power score for men (r=0.661, p≤0.001) and women (r=0.434, p=0.01).

Conclusion
A comparison of scores across sexes appears unsuitable, due to the possible positive influence of height on the final score. But within the female group, performances of the CKCUEST and the modified CKCUEST were comparable. Additionally, the CKCUEST was...
not able to differentiate among elite handball players who are playing with shoulder pain, previous shoulder pain, and no pain.

Level of evidence

INTRODUCTION

Team handball is an Olympic sport, and it is known for its complexity of high technical demands in both the lower and upper extremities, together with high speed and physical contact. Repeated throws are primarily performed with the hand above shoulder height with maximal and submaximal throwing velocity. The shoulder-specific loads vary with the total number of throws, playing position, and type of training, and shoulder pain is one of the most common injuries.\(^1\) Shoulder pain affects athletes’ performance, training, and daily life.\(^3\) In Norway, 44–75% of all senior handball players have experienced shoulder pain at some point, and 12–40% were still participating in training and matches, but with modifications.\(^4\) Several authors have identified deficits in glenohumeral range of motion, strength imbalances, increasing training load, and scapular dyskinesia as risk factors for developing shoulder pain in adolescents and senior elite team handball players.\(^7\)–\(^10\) With the high prevalence and persistence of shoulder pain in adolescents and senior elite handball players, there is a need for high-quality assessment tools to evaluate upper-body strength and stability. A clinical assessment tool should be easy to implement in the field and at a low cost, but most importantly, it should be a tool that could assist the coach, athlete, and medical team in discerning injury risk and return to play for athletes with and without a history of shoulder injury. Several sport-specific functional tests are presented in the literature to assess performance in throwing athletes. Even though the tests do not include throwing, they involve the entire kinetic chain in the test performance: the Posterior Shoulder Endurance Test (PSET),\(^11\) the Shoulder Endurance Test (SET),\(^12\) the Y-Balance Test for upper extremities,\(^13\) the seated medicine-ball throw,\(^14\) and the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST).\(^5\)\(^,\)\(^15\)–\(^18\)

The CKCUEST was originally described by Goldbeck and Davies\(^19\) to provide objective data on muscle capacity and neuromuscular control that could assist the clinician in determining the patient’s readiness to return to activities, resume competition, or continue further rehabilitation. The CKCUEST requires the proximal segments to stabilize the upper extremity, while the trunk moves freely, and the center of mass is transferred between arms, to single arm stabilization, alternately. Athletes’ ability to transfer forces and shift the center of mass over the base of support could perhaps provide information to determine if an athlete is at risk of injury.\(^20\) Furthermore, the test has been presented to be easy to understand and to implement, be cost-efficient, and take up minimal space in the clinic or in the training facility.\(^19\)\(^,\)\(^20\)

The original test protocol was developed for male athletes, who were placed in a push-up position with their toes on the ground and their hands 91.4 cm (36 inches) apart. Previous studies on the CKCUEST have investigated reliability and validity\(^18\)\(^,\)\(^19\)\(^,\)\(^21\)–\(^23\) in persons with and without shoulder impingement syndrome, and indicate that the CKCUEST scores differ between players with previous injury/ pain history compared with healthy players.\(^20\)\(^,\)\(^24\)–\(^26\) Tucci et al.\(^24\) determined that the CKCUEST was reliable for both healthy adults and individuals with shoulder impingement syndrome. One preliminary study investigated differences between healthy and previously injured/in-pain baseball pitchers from high school and college.\(^27\) Sex differences in height, weight, and arm length have also been discussed in several studies, and modified CKCUEST variations of arm position and knee position have been validated\(^15\)\(^,\)\(^28\)–\(^32\).

In previous studies, mostly baseball athletes have been investigated. To the best of the authors’ knowledge, no studies have investigated the CKCUEST performance in elite team handball players, including those playing with or without shoulder pain or a history of shoulder pain. Since many elite handball players with shoulder pain still compete on the highest national and international levels, the question therefore arises whether the level of perceived shoulder pain causes less dynamic shoulder instability within this group of athletes, and whether current and previous pain affects performance in the CKCUEST. Therefore, the purpose of this study was to investigate if the CKCUEST is an appropriate test to implement within team elite handball players to evaluate dynamic shoulder stability across sexes and in the screening of shoulder pain. The first aim was to investigate if performance on the CKCUEST and the modified CKCUEST varies among elite handball players playing with shoulder pain, previous pain, or no pain. The second aim was to investigate if the performance varies between male and female elite handball players and to evaluate if height may influence performance, as the distance between the lines is constant (91.4 cm) and thereby not compensating for height. The hypothesis was that male athletes would achieve a higher number of touches compared to female athletes, and that athletes playing with shoulder pain would have lower scores compared with the two other groups due to less dynamic shoulder stability.

MATERIALS AND METHODS

PARTICIPANTS

Elite team handball players were recruited from clubs in the top two divisions in Denmark and Norway, together with the top division in Romania and the Netherlands. The total group was divided into three groups: playing handball with shoulder pain, playing with previous shoulder pain, and healthy subjects and all completed a version of the CKCUEST. All players volunteered for the project after providing written and oral consent. Ethical approval was obtained.
from the Norwegian ethics committee REK Midt in September 2019 (ref. 7189).

All 106 players replied to a medical questionnaire regarding pain, pain history, injury history, training, and match exposure. The medical questionnaire was used to divide the players into three groups: 1) playing with shoulder pain, 2) playing with previous shoulder pain, and 3) healthy subjects. Participants included in the pain group played with shoulder pain that had been present for a minimum of four weeks and developed over time. The participants included with previous shoulder pain had to report no current pain and when they last registered shoulder pain (start and stop of previous shoulder pain). The participants in the healthy group never had experienced shoulder pain. Included players were required to take part in both offensive and defensive parts of the game during training and match. Players were excluded if they were recovering from musculoskeletal injuries, had been excluded from participation in the prior six weeks, or presented with pain/previous shoulder pain which was associated with a traumatic event or surgery. The presence of pain was established by the validated Oslo Sports Trauma Research Center questionnaire. An oral interview performed by a physical therapist was carried out to determine whether the pain registered in the group with pain and previous pain had a non-traumatic occurrence.

TEST PROCEDURE

First, the player was given an oral introduction. The subject started in a push-up position, with the hands placed outside each line (3.8 cm of tape) distanced 91.4 cm (36 inches) between the lines with the feet at shoulder width. During the CKCUEST, subjects reached with alternating hands across their body to touch the athletic tape by the opposing hand as many times as possible within 15 seconds (Figure 1). The test started when the tester said "go" and ended when the tester said "stop." To ensure correct timing, an app with a predefined time setting at 4 x 15/45 seconds was placed in front of the player. The test was performed four times with a 45-second pause in between: one submaximal test and three maximal tests. The first submaximal performance was used as a test run for the participant, with the purpose of introducing the test. The final three test performances were used in the analysis.

All elite team handball players were selected to participate in the CKCUEST, but 15 female players were not able to perform the original CKCUEST due to the wide distance between the hands compared with body anthropometrics, so they were allowed to perform the modified CKCUEST (Figure 1). The modified CKCUEST was completed with the subject starting in a push-up position on their knees and the hands placed outside the tapeline with a distance of 91.4 cm.

The CKCUEST raw score was calculated as an average of the touches performed during the final three maximal tests. The test was administered by the same experienced tester, who had 10 years of experience in physical therapy and physical testing in team handball.

DATA ANALYSIS

The average score of the final three maximal tests was calculated as recommended by Goldbeck and Davies. The CKCUEST has been provided with three different calculation scores to compensate for differences in body composition: 1) the raw touch score represents the number of touches the subject can perform within 15 seconds; 2) the touch score represents the number of touches performed divided by the height of the subject; and 3) the power score represents the number of touches multiplying 68% of the subject’s body weight in kilograms divided by 15 (power = 68% body mass [kg] x average number of touches / 15). The 68% corresponds to the combined body mass of the subject’s arms, head, and trunk.

STATISTICAL ANALYSIS

Statistical analyses were performed in SPSS version 27.0 (IBM Corp., Armonk, New York, USA). All data distributions were tested for normality with the Shapiro–Wilk test, histogram, and qq plots. Means and standard deviations (SDs) were calculated for all data, and p-values of ≤ 0.05 were considered statistically significant. A sample size calculation was based on previously published estimations containing people with and without pain in the upper limbs.
The target participants were 88 subjects, based on an alpha of 0.05 and a power of 0.80.

All descriptive statistics and distributions of status of shoulder pain are presented with mean and SD. Correlations between the subjects’ height and the three CKCUEST scores (raw, touch, and power score) were made using Pearson’s correlation test. The interpretation of the Pearson’s correlation coefficient was made as recommended by Portney. A coefficient >0.25 was considered trivial, 0.25–0.50 low to fair, 0.50–0.75 moderate to good, and >0.75 a strong relationship. A one-way ANOVA was used to identify any statistical differences between the female participants performing the CKCUEST and the modified CKCUEST.

A two-way ANOVA was performed to identify statistical differences in the CKCUEST scores between players with shoulder pain, those with previous pain, and healthy subjects and the whole group, and between men and women. An effect size calculation was used to determine the magnitude of the effect. Effect size was evaluated with $\eta^2$ (partial eta square), where 0.01-$\eta^2<0.06$ constitutes a small effect, 0.06-$\eta^2<0.14$ a moderate effect, and $\eta^2>0.14$ a large effect.

### RESULTS

A total of 106 elite team handball players, 49 females (174 ± 3 cm, 70.4 ± 6.7 kg, and 22.4 ± 9 years) and 57 males (190±7.5 cm, 91.6±11.4 kg, and 22 ± 5.4 years), participated in this cross-sectional study of the CKCUEST. All 106 included elite handball players were able to complete the tests: 23 playing with shoulder pain, 54 with previous pain, and 49 with no pain. A total of 91 players performed the CKCUEST, 34 females (175 ± 5 cm, 72 ± 6.8 kg, and 22.7±4 years) and 57 males, and a total of 15 female players (172 ± 6 cm, 66.8 ± 4.6 kg, and 20.3±6 years) performed the modified CKCUEST.

### PERFORMANCE AMONG PLAYERS WITH PAIN, PREVIOUS PAIN, AND NO PAIN

Across sexes, no significant differences between pain groups were found in any of the CKCUEST scores: raw score (F=0.651, p=0.52, $\eta^2=0.02$), touch score (F=1.23, p=0.30, $\eta^2=0.03$), and power score (F=0.71, p=0.50, $\eta^2=0.02$), all with small effect sizes. No significant differences were found within the female group: raw score (F=0.915, p=0.41, $\eta^2=0.06$), touch score (F=1.20, p=0.51, $\eta^2=0.07$), and power score (F=0.41, p=0.67, $\eta^2=0.05$). Also, no significant differences were found within the male group: raw score (F=0.855, p=0.44, $\eta^2=0.05$), touch score (F=1.47 p=0.24, $\eta^2=0.05$), and power score (F=2.18, p=0.12, $\eta^2=0.08$). (Table 1).

### PERFORMANCE BETWEEN MEN AND WOMEN

Significant differences and large effect sizes were found between the female and male team handball players when comparing all three CKCUEST scores (p<0.01): raw score (F=125, p<0.01, $\eta^2=0.59$), touch score (F=107, p<0.01, $\eta^2=0.71$), and power score (F=82.6, p <0.01, $\eta^2=0.48$) (Table 2).

### PERFORMANCE IN THE MODIFIED AND ORIGINAL CKCUEST

The female athletes performing the modified test had an average height of 1.72±0.06 m compared to 1.75±0.05 m for the females in the regular test, but no significant differences were found in any of the CKCUEST scores between the females performing the CKCUEST and the modified test in any of the scores: raw score (F=1.39, p=0.244, $\eta^2=0.03$), touch score (F=2.55, p=0.12, $\eta^2=0.05$), and power score (F=0.09, p=0.76, $\eta^2<0.01$), all with small effect sizes. Furthermore, no significant difference was found in the CKCUEST scores in the three groups: pain, previous pain, and healthy players performing the modified CKCUEST (Table 3).

### Table 1. Mean (SD) and minimum and maximum CKCUEST scores for all players with pain, previous pain and no pain.

<table>
<thead>
<tr>
<th>Score / Category</th>
<th>All</th>
<th>Men</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean±SD</td>
<td>Min–max</td>
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<tr>
<td><strong>Raw</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Pain</td>
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<td>8.7–26.4</td>
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<tr>
<td>Previous pain</td>
<td>31</td>
<td>19.9±5.4</td>
<td>7–26.7</td>
</tr>
<tr>
<td>No pain</td>
<td>39</td>
<td>20.1±4.5</td>
<td>7.8–26.3</td>
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<td><strong>Touch</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Pain</td>
<td>21</td>
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<td>5.2–13.5</td>
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<tr>
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<td>3.8–14.2</td>
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<tr>
<td>No pain</td>
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<td>11.0±2.3</td>
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<td><strong>Power</strong></td>
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<td></td>
<td></td>
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<tr>
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<td>Previous pain</td>
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<td>No pain</td>
<td>39</td>
<td>75.2±24.4</td>
<td>26.3–117.6</td>
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Table 2. Mean (SD) and minimum and maximum CKCUEST scores for all participants and per sex

<table>
<thead>
<tr>
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<th>Raw score</th>
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<th>Power score</th>
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<tr>
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<td>Female</td>
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<tr>
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<td>2.5</td>
<td>3.8</td>
<td>4.8</td>
</tr>
<tr>
<td>Maximum</td>
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<td>21</td>
<td>26.7</td>
</tr>
<tr>
<td>Minimum</td>
<td>16.0</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

* Indicates a significant difference between men and women on a p < 0.05 level

Table 3. Mean (SD) and minimum and maximum scores in the modified and original CKCUEST

<table>
<thead>
<tr>
<th></th>
<th>Raw score</th>
<th>Touch score</th>
<th>Power score</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Pain</td>
<td>Previous pain</td>
<td>No pain</td>
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<td>Mean</td>
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<td>17.4</td>
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<tr>
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<td>7.7</td>
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<td>22.7</td>
</tr>
<tr>
<td>Minimum</td>
<td>11</td>
<td>7</td>
<td>10.3</td>
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CORRELATION BETWEEN PERFORMANCE AND HEIGHT

Significant correlations were found in both the male and female groups between height and the power score. Males had a significant moderately positive correlation (r=0.661, p<0.001) compared to the female athletes, who presented a significant fair correlation (r=0.434, p=0.01). A fair, non-significant correlation (r=0.332, p=0.06) was found in the female group between the raw score and height. In the modified CKCUEST, a significant moderate correlation was found between height and power score (r=0.55, p=0.03), while no significant correlations were found with the raw (r=0.49, p=0.07) and touch scores (r=0.40, p=0.14) (Figure 2).

DISCUSSION

The purpose of this study was to investigate whether the CKCUEST and the modified CKCUEST are appropriate clinical assessment tools for dynamic shoulder stability in male and female elite handball players. Furthermore, the study sought to evaluate if variation is detectable in the performance of the CKCUEST between players performing with shoulder pain, previous pain, and no pain, and if performance varies across gender and height. The main findings were that significant differences were found in the raw and touch CKCUEST scores between male and female participants, but not among the players playing with shoulder pain, previous pain, and no pain. A significant correlation between height and the power score was found in both groups.

In the current study, the male athletes achieved a significantly higher score compared to the female elite athletes. A higher number of touches indicates the athlete found it easier to stabilize and move the center of mass from one arm to another, which demands high-power neuromuscular activity, motor control, and proprioception. The current findings are consistent with the study by Borms and Cools in which the male players had a higher number of touches compared to female players. However, Borms and Cools presented a higher number of touches than in the present study in both men (27.4±2.7) and women (20.8±2.7). Additionally, higher scores were found in college baseball in the studies by Taylor et al. at 25±4.5 and Roush et al. at 50.4±3.9, while Schilling and Elazzazi presented scores from college baseball, where the pitchers scored 19.1±4.5 and the other positions scored 18.8±3.5.

Prior studies have performed the CKCUEST with small differences in the test setting. Cogley et al. showed that a different hand placement during a push-up alters upper-body muscle activity and therefore changes the muscle work. Furthermore, Schilling and Elazzazi performed the test with a distance of 36 inches, where the middle of the hands was placed on top of the two pieces of tape, not outside the tape. Negrete et al. had the push-up position with the hands within the two pieces of tape, and Taylor et al. started with the arms in a push-up under the shoulders. The combination of small differences in test setting and different population groups may influence the variety in number of touches observed; therefore, making a comparison of the performance across sexes and sports can be difficult.

This study observed higher numbers of touches performed by the male athletes compared with the female elite handball players. The differences in performance may be explained by the anthropometric differences measured between the male and female subjects. Powell et al. found that the length of the arm has a significant positive effect...
on the CKCUEST score. Unfortunately, Powell et al. did not measure the length of the participants’ arms but found a fair to moderate significant correlation between height and sex within the elite team handball players. Taking an anthropometric perspective, a person with longer arms has a shorter distance of transfer in the body and an advantage in performing the CKCUEST. Furthermore, Callaway et al. argued that the distance of 91.44 cm has not been justified, and they therefore investigated the CKCUEST with modified test settings in healthy male subjects and compared them to the original CKCUEST. They recommended clinicians to use a width matching 50% of the individual’s height, which showed excellent repeated measures reliability and the smallest minimal detectable change. This recommendation was used in the present study with the modified CKCUEST. The female athletes were instructed to perform the CKCUEST but could choose to perform the modified test if they were unable to perform the original CKCUEST (Figure 1). In general, the shorter female athletes (1.72±0.06 m vs. 1.75±0.05 m) chose the modified CKCUEST, with similar results between the two groups, indicating that perhaps the CKCUEST needs to be modified for arm length or height, due to the unfavorably long hand-to-hand distance. Based on these findings, it cannot be recommended to use scores from the original CKCUEST to evaluate performance across sexes in team elite handball players, even though the touch and power scores try to compensate for differences in weight and height within and across genders. However, more studies are needed to confirm these findings.

The current study did not find any significant differences in performance within the three groups measured by the numbers of touches performed. Previous literature has presented the CKUEST as an option to evaluate the dynamic stability of the shoulder and upper body by moving the center of mass from side to side. It was expected by the authors that this dynamic shoulder and upper body stability would be affected by shoulder pain. The painful shoulder would cause more time spent on the injured side together with other compensating movement patterns, as shown by Barfield et al. They showed that high school and collegiate baseball pitchers who were previously injured had less pelvic rotation and dominant hip abduction during the touch of the non-dominant hand compared to the healthy group. This indicates kinematic changes that could affect the CKUEST scores between the groups. The fact that no differences were found between the groups can be explained by several possibilities. Firstly, it is not known if decreased dynamic stability is the cause of shoulder pain in the pain and previous-pain groups. Forty-four to 75% of senior players have experienced shoulder pain, and 12–40% are playing with modifications, but studies have not presented the distribution of diagnosed reasons for pain. This group of elite athletes presented with a high level of physical fitness but may have experienced challenges when performing a bilateral closed kinetic exercise when their specialized movement pattern is a unilateral open kinetic chain. Furthermore, the included athletes were all still active participants in handball. If the shoulder pain kept them from playing, a difference in score may have been observed, as Tucci et al. observed in players with shoulder impingement syndrome who scored only 10–12 touches.

The question of whether the CKCUEST can be used as a screening tool in elite handball players playing with pain, previous pain, or no pain can be answered in the negative. However, the CKCUEST might be used to identify the risk for in-season shoulder injury, as has been suggested by Pontillo et al. In a prospective study on American college football players, they found a trend in the athletes developing a shoulder injury during the season. The authors suggested that a score of fewer than 21 touches in male athletes would indicate a higher risk of developing a shoulder injury. However, they used a small cohort design including 26 male athletes; they did not report whether the injury stopped the American football athletes from participating completely; and the CKCUEST was included as a

![Figure 2. Correlation between height and the power score](image-url)
functional test but was only performed two times with a one-minute break, in contrast to the recommendations of Goldbeck and Davies.\(^9\) When comparing their recommendation to the findings of the current study, all included elite handball players performed more than 21 raw touches (Table 1). Therefore, the suggestion of 21 raw touches is perhaps a little conservative for the group of team elite handball athletes investigated in this study.

The CKCUEST did not show any statistically significant differences between the players playing with shoulder pain, previous pain, and no pain, which raises the question of the relevance of the test as part of a test battery or screening tool to detect shoulder pain among handball players who are still playing. The cause of shoulder pain among overhead athletes is often a combination of several risk factors. To prevent shoulder injuries in pre- and in-season athletes, the use of a test battery of strength, fatigue, and functional testing may be helpful in identifying who is at higher risk for sustaining a shoulder injury.\(^6,7,44\) But few non-professional handball clubs have the possibility to create such a medical setting; therefore, it is important to continue using easily implemented clinical tools that could help in screening risks for shoulder injuries.

LIMITATIONS

A growing number of performance assessments are available for clinicians to use to screen and evaluate throwing athletes. The CKCUEST has been presented with moderate to strong reliability.\(^18,45,46\) But the interpretation of the current results must still be viewed within the limitations of the study. Only a small sample performed the modified CKUEST test, and an uneven group size in the number of participants with previous or current shoulder pain compared to healthy subjects must be considered. Finally, this study has reported performance in the CKCUEST with a cross-sectional design, and it has not been assessed whether the CKCUEST can be a relevant test regarding use for injury prevention and return to performance decision-making. Future studies should include the CKCUEST in longitudinal study designs and investigate the ability to predict shoulder pain and the readiness to return to activities, resume competition, or continue further rehabilitation in elite team handball players.

CONCLUSION

The results of the current study provide novel data on CKCUEST performance in team elite handball players playing with shoulder pain, previous shoulder pain, and no shoulder pain. A significant difference between male and female athletes indicates that a comparison in performance across sexes is not suitable, due to the possible positive influence of height in the test setup. But within the female group, performances of the CKCUEST and the modified CKCUEST were comparable. Additionally, the CKCUEST was not able to differentiate among elite handball players who are still playing with shoulder pain, previous shoulder pain, and no pain.

ACKNOWLEDGEMENTS

Many have contributed to this project. The authors would particularly like to thank the medical staff in the clubs and Olympic Centers and all the elite handball players for supporting and participating in the project.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

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Original Research

Hip and Trunk Variables in University Students with and without Recurrent Low Back Pain

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Keywords: low back pain, hip, trunk, range of motion, strength

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Background
Low back pain (LBP) is a leading cause of disability. Recurrent low back pain (rLBP) is defined as two or more episodes of LBP in a 12-month period, each lasting more than 24 hours and separated by at least one pain-free month. Many studies have shown that hip and trunk variables have an influence on LBP. However, most of these are studies of participants with acute or chronic LBP rather than rLBP.

Purpose
To examine the difference between hip and trunk variables of university students with and without rLBP.

Study Design
Cross-Sectional

Methods
Participants with and without rLBP between 18 and 35 years of age not currently undergoing clinical orthopedic care were recruited for this cross-sectional study. Bilateral hip range of motion (ROM) and trunk ROM were measured with a goniometer or measuring tape (hip motions in all planes along with trunk flexion, extension, and lateral flexion). Strength of the hip extensors, abductors, and external rotators was measured using a handheld dynamometer, and a single-leg bridge endurance test was performed to assess differences and correlations between outcomes.

Results
Twenty-six subjects aged 18 to 35 years with rLBP (n=10) and without rLBP (n=16) participated. Statistically significant differences between the two groups were found for right and left hip flexion (p = 0.029 and 0.039, respectively), right hip adduction (p = 0.045), and right hip extension (p = 0.021). No significant differences were found between groups for strength, endurance, or other ROM measures.

Conclusion
The findings of this study show statistically significant although clinically non-meaningful differences in hip flexion, extension, and adduction ROM in the rLBP group compared to the control group. This lack of clinically meaningful difference may be relevant to testing procedures and treatment of patients or athletes with rLBP. This study also suggests that hip strength and endurance may not play a major role in the development or treatment of rLBP.

Level of Evidence: 3
INTRODUCTION

Low back pain (LBP) is the leading cause of disability globally.1 The annual prevalence of LBP is estimated to be around 38%,2 Its prevalence in university students appears higher at 43%.3 Similarly problematic is the recurrence of LBP in the university population.4 Recurrent LBP (rLBP) is most consistently defined as two or more episodes of LBP in a 12-month period, each lasting more than 24 hours and separated by at least one pain-free month.5 Between 25% and 69% of individuals in the general population who experience an acute bout of LBP are estimated to experience rLBP.6-8 However, up to 77% of university students report recurrence.9

Hip and trunk variables appear to have an influence on LBP. Many authors have demonstrated a link between reduced lumbar range of motion (ROM) and LBP.10 Authors have also suggested that decreased hip ROM, hip extensor strength, and hip endurance may be related to LBP.11 However, participants in most of the prior studies report acute or chronic LBP rather than rLBP. Individuals with acute or chronic LBP are more likely to report pain at the time of testing than those with rLBP; therefore, they may demonstrate different hip or trunk kinematics and strength secondary to pain.

Although previous episodes of LBP and select psychosocial variables appear to increase the risk of LBP, evidence shows it is difficult to predict who will have a recurrence of LBP.8,12,15 Occupational trunk flexion and rotation may contribute to a poor prognosis for individuals with rLBP.13 Limited sagittal and frontal plane trunk ROM may also be risk factors for rLBP.14 Moreover, hip ROM and strength as well as trunk endurance seem related to rLBP, albeit in a limited number of studies.14,15 These variables have been studied in adolescents and adults, but not in the university population.

Some data suggest that motor control changes are related to rLBP. While prospective studies of motor control variables and rLBP are limited, one literature review concluded motor control exercises were superior to general exercise, manual therapy, or minimal intervention regarding pain and disability in the rehabilitation of those with rLBP.16 However, multiple authors have demonstrated minimal or no difference between motor control exercises and a daily walking program in the treatment of LBP, suggesting motor control exercises beyond a walking program may be unnecessary.17,18

Some data exist regarding collegiate athletes and rLBP, although the incidence appears lower than the non-athletic university population around 2%.19 One study of 679 varsity collegiate athletes concluded that athletes who reported previous low back injury were at three times greater risk to experience another bout of LBP. Moreover, those with pain at the time of survey were six times more likely to sustain LBP than athletes without a history of LBP.20 The authors suggested that rLBP may be due to congenital factors or a result of insufficient recovery time after the first LBP episode.

Figure 1. Hip Flexion Range of Motion Measurement

Given the prevalence of rLBP and the need for further study of its risk factors, the purpose of this study was to examine the difference between hip and trunk variables of university students with and without rLBP. Participants with rLBP were expected to demonstrate less hip and trunk ROM, hip strength, and hip endurance than those without rLBP.

METHODS

Participants with and without rLBP were recruited as a sample of convenience for this cross-sectional design study from a university population following Institutional Review Board approval (#4896). Participants between 18 and 35 years of age completed a written informed consent form and health questionnaire prior to testing and were excluded if they reported any of the following: severe spinal deformities; chronic disease affecting the musculoskeletal system; orthopedic surgery within the last six months; current pregnancy; or current spine, hip, or knee pain. Participants were assigned to the rLBP group if they reported two or more episodes of LBP in the previous year, each lasting more than 24 hours and separated by at least one pain-free month. Otherwise, the participants were assigned to the control group.

Participants completed a two-minute stationary bicycle warm-up between 50 and 60 rotations per minute.21 During the warm-up, participants were educated on the testing procedures. After the warm-up, bilateral hip ROM and trunk ROM were measured with a standard goniometer on a standard plinth. Three trials of hip flexion (Figure 1), extension (Figure 2), abduction, adduction, external rotation, and internal rotation as well as trunk flexion, extension, and bilateral lateral flexion ROM were taken via goniometer and tape measure, respectively, and recorded in centimeters by a researcher blind to group assignment. These measurements have previously been found reliable.22

Next, strength of the hip extensors, abductors, and external rotators was measured using a handheld dynamometer (Lafayette Manual Muscle Tester, FEI, White Plains, NY). The peak force over three seconds was recorded. Participants completed three trials per leg, alternating legs, and allowing at least 30 seconds of rest between trials. Measurements were taken using a stabilization belt on a standard plinth by a researcher blind to group assignment. Hip extensor strength was measured with the participant in
prone, the knee flexed to 90 degrees, and the stabilization strap and dynamometer positioned over the posterior distal femur. Hip abductor strength was measured with the participant in sidelying with the hip to be tested nearest the ceiling in 0 degrees of abduction using a pillow. The stabilization strap and dynamometer were placed over the lateral distal femur. Lastly, hip external rotator strength was measured in sitting with the hip in 90 degrees of flexion and neutral rotation. The stabilization belt and dynamometer were placed over the medial ankle. This method of strength testing has demonstrated high reliability in a previous study.23

The last measurement was a timed single-leg bridge, taken at least 90 seconds following strength measurements to allow adequate rest. This measure has demonstrated high reliability (ICC = 0.87-0.99) with a low standard error of measurement (SEM = 8.9 seconds).24 Participants were positioned in hooklying with the knee to be measured flexed to 135 degrees and asked to hold a raised unilateral bridge until fatigue. One measurement on each leg recorded in seconds was taken by a researcher blind to group assignment with at least 90 seconds of rest between sides.

Data were analyzed using SPSS v28.0 (SPSS Inc, Chicaco, IL) via independent t-tests to determine significant group differences using an alpha level of 0.05. Descriptive statistics were calculated for all measures and demographic variables. The researcher performing data analysis was blind to group assignment.

RESULTS

Twenty-six participants’ data were analyzed (mean age = 23 ± 2 years; mean height = 1.77 ± 0.10 meters; mean weight = 80.46 ± 14.07 kilograms). Descriptive statistics and results of independent t-tests for ROM measures are provided in Table 1. Those for strength and endurance measures are provided in Table 2. Statistically significant differences between groups were found for right hip flexion ROM (p = 0.029; 95% CI -1.18 to 6.66), left hip flexion ROM (p = 0.059; 95% CI -12.29 to 5.41), right hip adduction ROM (p = 0.045; 95% CI -4.32 to 0.15), and right hip extension (p = 0.021; 95% CI -1.31 to 7.50). No statistically significant difference was found between groups for the strength, endurance, or other ROM measures.

Participants with rLBP demonstrated less right and left hip flexion than participants without rLBP (2.61 and 3.44 degrees, respectively). Participants with rLBP also demonstrated 2.09 degrees less right hip adduction than those without rLBP. However, participants with rLBP demonstrated 3.1 degrees more right hip extension than those without rLBP. Each of those ROM differences were significantly different. Participants with rLBP demonstrated 0.64-2.58 pounds less hip strength than those without rLBP for all measures except left hip extension, however none of these were statistically significantly different. Single-leg bridge endurance was 2.7 seconds more on the right and 9.06 seconds less on the left among participants with rLBP than those without rLBP (also not significantly different).

DISCUSSION

The primary purpose of this study was to compare hip and trunk variables in university students with and without rLBP. The main finding was that participants reporting rLBP demonstrated significantly less hip flexion bilaterally, less right hip adduction, and more right hip extension than those without rLBP. However, these differences were between one and three degrees with overlapping confidence intervals, so the differences should be interpreted with caution. Even if the confidence intervals were smaller, one to three degrees among a sample this size is arguably not clinically significant.

Moreover, strength and endurance differences were not seen between groups. This finding may help explain why studies such as one by Cairns et al. demonstrated no additional benefit at a 12-month follow-up of adding specific spinal stabilization exercises to conventional physical therapy for patients with rLBP.25 In a similar study, a general exercise program reduced disability in the short term to a greater extent than a stabilization-enhanced exercise approach in patients with rLBP.26 However, several authors have demonstrated a benefit to trunk or hip strengthening and endurance for addressing rLBP. For example, trunk muscle endurance14 and hip muscle strengthening15,27 have both appeared to decrease the incidence or intensity of rLBP. Unilateral bridging, also called a Gluteal Endurance Measure (GEM), was the choice measure of endurance because of its high reliability and specificity to gluteal fatigue.28 Future study may benefit from using an endurance measure that targets the erector spinae such as the Sorensen test to evaluate muscle endurance in those with rLBP.

In the current study, significantly less hip flexion ROM on either limb, less right hip adduction, and more right hip extension were seen in the participants with rLBP. Several prior authors have shown similar associations between hip motion and rLBP. For example, Jones et al. demonstrated that hip motion, including hip flexion, was a risk factor for rLBP or associated with its improvement.14,28 Limited sagittal plane hip motion and hip motion asymmetry also appears correlated with chronic LBP by several authors.27,29
Table 1. Descriptive statistics and results of independent t-tests for ROM measures (hip ROM recorded in degrees; lumbar ROM recorded in centimeters)

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD for rLBP group (n = 10)</th>
<th>Mean ± SD for control group (n = 16)</th>
<th>p-value [95% CI]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right hip flexion ROM</td>
<td>104.95 ± 14.73</td>
<td>107.56 ± 8.28</td>
<td>0.029*[-11.88, 6.66]</td>
</tr>
<tr>
<td>Left hip flexion ROM</td>
<td>103.52 ± 13.67</td>
<td>106.96 ± 8.29</td>
<td>0.039*[-12.29, 5.41]</td>
</tr>
<tr>
<td>Right hip extension ROM</td>
<td>16.22 ± 3.70</td>
<td>13.12 ± 6.06</td>
<td>0.021*[-3.11, 7.50]</td>
</tr>
<tr>
<td>Left hip extension ROM</td>
<td>16.53 ± 4.01</td>
<td>11.27 ± 4.43</td>
<td>0.421[1.69, 8.82]</td>
</tr>
<tr>
<td>Right hip adduction ROM</td>
<td>10.95 ± 2.05</td>
<td>13.04 ± 3.01</td>
<td>0.043*[-4.32, 0.15]</td>
</tr>
<tr>
<td>Left hip adduction ROM</td>
<td>10.88 ± 2.71</td>
<td>12.06 ± 2.76</td>
<td>0.582[-3.47, 1.09]</td>
</tr>
<tr>
<td>Right hip abduction ROM</td>
<td>25.19 ± 6.51</td>
<td>21.96 ± 6.19</td>
<td>0.792[2.02, 8.48]</td>
</tr>
<tr>
<td>Left hip abduction ROM</td>
<td>25.29 ± 6.63</td>
<td>20.67 ± 5.67</td>
<td>0.251[-0.41, 9.65]</td>
</tr>
<tr>
<td>Right hip internal rotation ROM</td>
<td>37.96 ± 4.31</td>
<td>31.74 ± 5.22</td>
<td>0.212[2.13, 10.28]</td>
</tr>
<tr>
<td>Left hip internal rotation ROM</td>
<td>37.06 ± 4.56</td>
<td>33.09 ± 7.06</td>
<td>0.102[-1.22, 9.16]</td>
</tr>
<tr>
<td>Right hip external rotation ROM</td>
<td>35.10 ± 4.95</td>
<td>34.13 ± 5.35</td>
<td>0.951[-3.36, 5.31]</td>
</tr>
<tr>
<td>Left hip external rotation ROM</td>
<td>36.56 ± 3.49</td>
<td>34.00 ± 5.93</td>
<td>0.115[-1.73, 6.85]</td>
</tr>
<tr>
<td>Lumbar flexion ROM</td>
<td>5.40 ± 1.07</td>
<td>5.70 ± 1.25</td>
<td>0.631[-1.28, 0.69]</td>
</tr>
<tr>
<td>Lumbar extension ROM</td>
<td>3.52 ± 1.31</td>
<td>3.13 ± 1.49</td>
<td>0.616[-0.79, 1.58]</td>
</tr>
<tr>
<td>Right lateral lumbar flexion ROM</td>
<td>25.25 ± 2.70</td>
<td>22.18 ± 3.06</td>
<td>0.519[0.64, 5.51]</td>
</tr>
<tr>
<td>Left lateral lumbar flexion ROM</td>
<td>24.99 ± 2.74</td>
<td>23.23 ± 3.33</td>
<td>0.166[-0.84, 4.35]</td>
</tr>
</tbody>
</table>

CI = confidence interval; cm = centimeters; rLBP = recurrent low back pain; ROM = range of motion; SD = standard deviation; * = statistically significant difference at the p < 0.05 level

Table 2. Descriptive statistics and results of independent t-tests for strength (recorded in pounds) and endurance (recorded in seconds) measures

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD for rLBP group (n = 10)</th>
<th>Mean ± SD for control group (n = 16)</th>
<th>p-value for group differences [95% CI]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right hip extensors</td>
<td>62.18 ± 18.93</td>
<td>62.82 ± 20.00</td>
<td>0.631[-16.96, 15.67]</td>
</tr>
<tr>
<td>Left hip extensors</td>
<td>61.42 ± 18.15</td>
<td>60.53 ± 21.08</td>
<td>0.614[-15.78, 17.55]</td>
</tr>
<tr>
<td>Right hip abductors</td>
<td>37.81 ± 8.26</td>
<td>39.93 ± 6.61</td>
<td>0.143[-8.17, 3.93]</td>
</tr>
<tr>
<td>Left hip abductors</td>
<td>35.99 ± 7.01</td>
<td>38.45 ± 7.32</td>
<td>0.896[-8.45, 3.54]</td>
</tr>
<tr>
<td>Right hip external rotators</td>
<td>29.69 ± 7.77</td>
<td>31.20 ± 8.00</td>
<td>0.646[-8.10, 5.07]</td>
</tr>
<tr>
<td>Left hip external rotators</td>
<td>27.63 ± 9.14</td>
<td>30.21 ± 9.02</td>
<td>0.677[-10.12, 4.97]</td>
</tr>
<tr>
<td>Right single-leg bridge endurance</td>
<td>56.70 ± 31.79</td>
<td>54.00 ± 35.22</td>
<td>0.995[-25.56, 30.96]</td>
</tr>
<tr>
<td>Left single-leg bridge endurance (seconds)</td>
<td>49.50 ± 30.52</td>
<td>58.56 ± 39.81</td>
<td>0.484[-39.51, 21.39]</td>
</tr>
</tbody>
</table>

CI = confidence interval; lbs = pounds; s = seconds; rLBP = recurrent low back pain; SD = standard deviation

Lumbar motion as measured in the current study was not statistically associated with rLBP, although lumbar ROM has been linked to rLBP in prior studies. In one such study, symptomatic participants had significantly reduced lateral flexion of the spine and total lumbar sagittal plane mobility measured using a tape measure and the modified Schöber procedure when compared to asymptomatic participants. In another study, lumbar sagittal mobility increased with improvements in rLBP. Limited lumbar lordosis and total lumbar sagittal ROM are associated with LBP in other
studies also; however, these were studies of general LBP rather than rLBP and used different ROM measurement methods, such as motion capture systems, spinal pantographs, and inclinometers.

The link between hip ROM, specifically hip flexion ROM, and LBP is intuitive and supported by multiple studies. However, this study did not find ROM differences between those with and without rLBP that exceed typical measurement error. More studies of rLBP and its relationship to hip variables are needed to draw firm conclusions.

Limitations of this study include a small sample size and a specific population of university students. Also, previous treatment received by those with rLBP and the intensity and duration of their LBP was unknown. Lastly, participants self-reported their rLBP, introducing potential reporting bias.

CONCLUSION

Recurrent low back pain is a significant problem among the general and university populations. This study of university students demonstrated a statistically significant difference in bilateral hip flexion, right hip adduction, and right hip extension ROM between those with and without rLBP. These differences, although statistically significant, are clinically non-meaningful differences of 1-3 degrees. Strength and endurance measures were not significantly different in those with or without rLBP, which may indicate that they are not related to the presentation of rLBP.

CONFLICT OF INTEREST

There are no potential conflicts of interests, including financial arrangements, organizational affiliations, or other relationships that may constitute a conflict of interest regarding the submitted work.

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Health-Related Quality of Life and Psychological Outcomes in Participants with Symptomatic and Non-Symptomatic Knees after ACL Reconstruction

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Keywords: osteoarthritis, fear-avoidance beliefs, physical activity, resilience

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Background

Individuals who sustain an ACL injury and undergo reconstruction (ACLR) are at risk for the development of osteoarthritis. Recent investigations have applied the Englund criteria to categorize people with a history of ACLR as someone with a symptomatic or asymptomatic knee.

Purpose/Hypothesis

The purpose of this study was to examine differences in health-related quality of life (HRQL) and psychological outcomes in people with a history of ACLR who were categorized as symptomatic or non-symptomatic by application of the Englund criteria. The authors’ hypothesized participants classified as symptomatic would have lower HRQL, increased fear-avoidance beliefs, and decreased resilience compared to participants classified as non-symptomatic.

Study design

Cross-sectional, survey

Methods

Participants at least one-year after ACLR were recruited for the study and completed the Tegner Activity Scale, the Brief Resilience Scale (BRS), the modified Disablement in the Physically Active Scale (mDPA), and the Fear-Avoidance Belief Questionnaire (FABQ) at one time-point. Descriptive statistics were summarized using median [interquartile range] and differences between groups were examined using separate Mann-Whitney U tests.

Results

Participants with symptomatic knees had a significantly higher BMI (24.8 [6.4]) than the non-symptomatic group (21.2 [4.5], p=0.013). Participants in the symptomatic group had worse HRQL on the physical subscale (12.5 [16.3] vs. 0.0 [2.5], p<0.001) and mental subscale (2.0 [1] vs. 0.0 [1], p=0.031), higher scores on the FABQ-Sport (14.5 [11] vs. 0.0 [6], p<0.001) and FABQ-Physical Activity (20 [24] vs. 1 [4], p<0.001) and less resilience (3.7[0.42] vs. 4.0 [0.83], p=0.028) compared to those participants in the non-symptomatic group.
group. There were no differences in current physical activity (p=0.285) or change in physical activity (p=0.124) levels between the two groups.

Conclusions
This series of differences may represent a cascade of events that can continue to negatively impact health outcomes across the lifespan for individuals with a history of ACLR. Future research should consider longitudinal investigations of these outcomes after injury and throughout the post-surgical and post-rehabilitation timeframe.

Level of Evidence
Level 3b

INTRODUCTION

Injury to the anterior cruciate ligament (ACL) and subsequent reconstruction (ACLR) can be associated with a multitude of negative outcomes including decreased physical activity,\(^1\) decreased health-related quality of life (HRQL)\(^4\) and earlier development of osteoarthritis\(^5\) for some patients. Systematic reviews with meta-analyses have revealed that ACLR is associated with the development of osteoarthritis\(^5,6\) and prevalence estimates are as high as 56% as soon as 10-years after reconstruction.\(^7\) Typically, once a patient undergoes ACLR and completes formal rehabilitation, they are no longer under the direct care of a physician until early osteoarthritis symptoms have developed. By the time a patient presents to their provider with clinical signs and radiographic evidence of arthritic changes, the damage to the joint is irreversible.\(^8\) Given the nature of the development and presentation of osteoarthritis, clinicians and researchers alike have aimed to identify assessments that can classify individuals as symptomatic or non-symptomatic early on in their disease progression.\(^9\) The ability to identify patients that are symptomatic before the visualization of radiographic changes is pertinent for the advancement of intervention strategies to delay osteoarthritis development.\(^9\)

The Englund classification system was originally developed to identify patients with a history of meniscectomy who had symptomatic knees associated with osteoarthritis development.\(^10\) Specifically, the Englund classification classifies patients with symptomatic knees if they have a score of $87.5$ on the Knee Osteoarthritis Outcome Score (KOOS) Quality of Life subscale, and two or more of the following scores on the remaining subscales: $86.1$ on the KOOS-Pain, $85.7$ on the KOOS-Symptoms, $86.8$ on the KOOS-Activities of Daily Living (ADL) and $85.0$ on the KOOS-Sports and Recreation (Sports) subscale.\(^10\) The Englund classification has also been applied to patients early after ACLR.\(^11,12\) Recent investigations have explored the relationship between symptomatic knees and clinical outcomes,\(^12\) and explored the utilization of these criteria in patients approximately 6-months post-ACLR.\(^11\) However, to the authors’ knowledge, there is limited evidence that has explored the relationship between osteoarthritis symptomology, health-related quality of life and psychological outcomes in people with a history of ACLR.

Deficits in HRQL and fear-avoidance beliefs in people with a history of ACLR have been identified compared to healthy controls.\(^13\) However, there is a lack of evidence to suggest these outcomes are different between people that are classified by the Englund criteria as symptomatic or non-symptomatic.\(^10\) Understanding this relationship is important as clinicians and researchers begin to focus on the development of holistic patient-centered treatment strategies to address pain, symptoms and osteoarthritis in people with a history of ACLR. In addition, physical activity is a part of the non-surgical treatment strategy for osteoarthritis.\(^14\) Therefore, it is important to examine psychological outcomes that may influence physical activity participation in this population such as fear-avoidance beliefs and resilience. Fear-avoidance beliefs have been associated with physical activity after ACLR.\(^4,15\) Resilience is a term often used to describe a person’s ability to adapt and overcome to their circumstances.\(^16\) Factors associated with resilience such as communication and social support, self-efficacy and goal setting have been previously examined in patients who successfully undergo ACLR.\(^17\) Previous literature has determined that patients with knee osteoarthritis with high resilience had a higher odds of having better self-reported overall health.\(^18\) Therefore, the purpose of this study was to examine differences in HRQL and psychological outcomes in symptomatic and non-symptomatic individuals with a history of ACLR, as classified by the Englund criteria.\(^10\) It was hypothesized that there would be significant differences in HRQL and psychological outcomes between these two groups. Specifically, we hypothesize that participants classified as symptomatic will have lower HRQL, increased fear-avoidance beliefs and decreased resilience compared to participants classified as non-symptomatic. These results will further support the need to develop treatment algorithms that can effectively address HRQL and psychological outcomes in people with a history of ACLR that have symptomatic knees.

METHODS
STUDY DESIGN

A cross-sectional survey-study was used to examine differences in patient-reported outcomes between participants with a history of ACLR with symptomatic knees and those without symptomatic knees. The dependent variables were scores on the Tegner Activity Scale, the Brief Resilience Scale (BRS), the modified Disenability in the Physically Active Scale (mDPA), and the Fear-Avoidance Belief Questionnaire (FABQ).
PARTICIPANTS

Participants with a history of ACLR were recruited via ResearchMatch. ResearchMatch is a national health volunteer registry that was created by several academic institutions and supported by the U.S. National Institutes of Health as part of the Clinical Translational Science Award (CTSA) Program. To be included, participants must have been between the ages of 18-40 years, had a history of a unilateral or bilateral ACLR within the prior 10 years and had been cleared to participate in physical activity by a physician. Participants were excluded if they had surgery to the lower extremity within the last year, reported any additional ligament repair at the time of ACLR surgery, had a lower extremity injury within the prior six weeks, were diagnosed with any condition that may affect their ability to participate in physical activity, or were unable to speak or read English. This study was approved by the University of Kentucky Institutional Review Board.

PROCEDURES

Participant recruitment occurred from July 2020 to December 2020. Interested participants received a link via email to participate that first included an electronic consent form. If the participant agreed to participate, they clicked "yes" on the electronic consent form, and proceeded to the anonymous survey. Next, the participants completed an inclusion criterion followed by a demographic questionnaire that recorded age, race, sex, ethnicity, physical activity participation, and lower extremity injury history information. Included in this questionnaire, participants recorded details of their ACLR(s) such as graft type, post-operative bracing, and post-operative rehabilitation participation and years since their most recent ACLR. Each participant then completed the patient-reported outcomes. The patient-reported outcomes were not administered in a randomized order. All data were collected utilizing Real Electronic Data Capture (REDCap).20,21

INSTRUMENTATION

The Tegner Activity Scale: The Tegner Activity Scale was utilized to determine participants’ activity level prior to their knee injury and after their knee injury. From these data, an activity change score was calculated by subtracting their previous activity level from their current activity level. A negative value indicates a decrease in activity level after their injury, a positive value indicates an increase in activity level after their injury. The Tegner is a reliable measure of self-reported physical activity in patients with a history of ACLR. Recent analyses revealed acceptable test-retest reliability and a minimal detectable change of one point in patients that had recently undergone ACLR.22

The Brief Resilience Scale: The 6-item Brief Resilience Scale (BRS) was used to measure self-reported resilience. Questions 1, 5 and 5 were assessed on a 5-point Likert Scale with 1 meaning "strongly disagree" and 5 meaning "strongly agree,"23,24 Questions 2, 4, and 6 were reversed scored and assessed on a 5-point Likert Scale with 1 meaning "strongly agree" and 5 meaning "strongly disagree."23,24 The final scores are interpreted as 1.00-2.99 low resilience, 3.00-4.30 normal resilience, and 4.30-5.00 high resilience.24 The BRS has acceptable test-retest reliability and internal consistency in healthy populations and populations with various health conditions.24

The Modified Disableness in the Physically Active Scale: The mDPA was used to measure general HRQL. The mDPA consists of two summary components that comprise the original DPA, the Physical summary component (PSC) and the Mental summary component (MSC).25 The 12-item mDPA-PSC and 4-item mDPA-MSC are scored on a 5-point Likert scale with 0 representing "no problem" and 4 representing a "severe problem." The scores for each subscale are summed, and a higher overall score indicates a higher level of disableness.25 The original DPA has acceptable test-retest reliability, internal consistency and validity for people with a history of injury, acute injury and individuals classified as healthy.26 The mDPA has excellent internal consistency.25

Fear Avoidance Beliefs Questionnaire: The FABQ modified for the knee and sports is a 15-item instrument that was used to measure fear-avoidance beliefs. The original FABQ consisted of two subscales, physical activity (PA) and work,27 but has since been modified for patients with knee injury by changing the word "back" to the word "knee,"28 and for sports where the word "work" was changed to "sport."29 The 5-item FABQ-PA subscale and 10-item FABQ-Sports subscale are scored on a 7-point Likert scale where 0 indicates "completely disagree" and 6 indicates "completely agree." Higher scores for each subscale indicate higher fear avoidance beliefs.27 The original FABQ has acceptable test-retest reliability and internal consistency for both subscales in patients with chronic low back pain.27

Knee Injury and Osteoarthritis Outcomes Score: The KOOS was used to measure self-reported knee function and classify the participants as symptomatic or non-symptomatic according to the Englund symptomatic knee classification.10 The 42-item KOOS evaluates five dimensions regarding knee function: pain (KOOS-Pain), current symptoms (KOOS-Symptoms), activities of daily living (KOOS-ADL), function in sports activities (KOOS-Sports), and quality of life (KOOS-QOL) relating to the knee.30 A 5-point Likert Scale is used to score the separate subscales.30 The highest possible score on each subscale is 100 with higher scores indicating higher function.30 In order to be classified as symptomatic, participants had to score ≤ 87.5 on the KOOS-QOL, and score below the following cut-offs on two or more of the remaining subscales: ≤ 86.1 on KOOS-Pain, ≤ 85.7 on KOOS-Symptoms, ≤ 86.8 on KOOS-ADL, and ≤ 85 on KOOS-Sports.10 All five subscales have demonstrated acceptable internal consistency and test retest reliability in athletes with a history of ACLR and many other patient populations with knee injuries and osteoarthritis.32

STATISTICAL ANALYSIS

Descriptive statistics (means and standard deviations) were calculated for participant demographics. If an instrument
was missing a response to an item, the person mean was calculated for that specific scale and inserted for the missing data point. The outcome data were not normally distributed and thus summarized using median and interquartile ranges (IQR). Due to the non-normal distribution of the data, independent-samples Mann-Whitney U tests were used to examine differences in the demographic variables and patient-reported outcomes between those participants categorized with symptomatic knees and those classified with asymptomatic knees. Alpha was set a-priori to <0.05. All statistical analyses were performed in IBM SPSS Statistics Processor version 28.0.0.0.

RESULTS

There were a total of 29 participants, 17 (5 females) were classified as participants with symptomatic knees and 12 (7 females) classified as non-symptomatic knees. A total of five participants classified in the symptomatic knee group had a history of two ACLRs, while none of the participants classified in the non-symptomatic knee group had a history of more than one ACLR. Summaries of the demographic variables can be found in Table 1. Participants with symptomatic knees had a significantly higher BMI than participants with non-symptomatic knees (p=0.021).

Summaries of the dependent variables for each group can be found in Table 2. Participants in the symptomatic group had worse HRQL as measured by the mDPA-PSC (<0.001) and mDPA-MSC (p=0.018), higher levels of fear-avoidance beliefs (FABQ-PA: p<0.001. FABQ-Sport: p=0.001), and lower levels of resilience compared to those participants in the non-symptomatic group (p=0.030, Table 2). There were no differences in current physical activity or change in physical activity levels between the two groups (Table 2).

DISCUSSION

The purpose of this study was to examine differences in HRQL and psychological outcomes in participants with a history of ACLR that were classified as symptomatic compared to those classified as non-symptomatic according to the Englund criteria. The hypothesis was confirmed as participants with symptomatic knees had lower HRQL, higher fear-avoidance beliefs and lower resilience compared to the non-symptomatic group. Furthermore, the authors identified differences in BMI between groups, with participants with symptomatic knees having a higher BMI than those with non-symptomatic knees. While these differences identified are not causal, and are limited in their application based on study design, these results are foundational to the development of effective intervention strategies to address osteoarthritis symptomology in people with a history of ACLR.

The results of this cross-sectional analysis present an interesting, potential cyclical cascade of outcomes that are of primary concern for the long-term health of patients with a history of ACLR as presented in Figure 1. The results of this study align with previous research demonstrating decreased HRQL after knee surgery and in individuals with symptomatic knees. While the authors did not attempt to quantify specific symptoms in this sample, previous studies have identified that knee pain, stiffness, and weakness in surrounding musculature are common in those with symptomatic knees. It is likely that changes in knee symptoms negatively impact other aspects of life as previous literature has identified links between HRQL, BMI, and physical activity participation. For example, individuals with symptomatic knees after ACLR often present with increased BMI which align with the results of the present study. Additionally, higher BMI has been associated with decreased HRQL in the general population, adolescent populations, and older adults (>65 years). However, based on the study design, it is unable to be determined whether those with symptomatic knees had higher BMI at time of injury or
surgery or whether these differences are associated with factors experienced between ACLR and participation in this study.

Individuals with symptomatic knees also reported increased fear avoidance beliefs compared to individuals with non-symptomatic knees. Fear avoidance refers to the avoidance of activities that could illicit pain, potentially cause reinjury, or any other negative stimuli. The Fear Avoidance Model suggests that increased perceptions of fear and increased incidence of avoidance will lead to disuse, dysfunction, and depression. Similarly, pain catastrophizing, kinesiophobia and fear of reinjury are common psychological factors that have been observed post-ACLR. Qualitative evidence demonstrates that fear of reinjury is a primary barrier for returning to activity after ACLR and many patients self-limit and/or avoid physical activities to avoid reinjury. We did not identify significant differences in physical activity measured by current Tegner scores between our two groups; however, we did see that the symptomatic participants scored one point lower on the Tegner activity scale than the group that had non-symptomatic knees and had a larger change from baseline. While we are not able to report differences in physical activity between the groups or a cause-and-effect relationship between ACLR, decreased HRQL, higher BMI and decreased activity, we do believe that these findings are of interest for future research investigations. Fear-avoidance beliefs have been associated previously with physical activity in people with a history of ACLR. Individuals with a history of ACLR participate in less MVPA compared to non-injured peers. This is problematic as physical activity has been found to be the most effective intervention for treating pain in patients with knee osteoarthritis and is known to be beneficial for weight loss, potentially decreasing a person’s BMI. Additionally, it has been demonstrated that individuals who participate in greater MVPA report higher HRQL even when they report increased knee symptomology. Lastly, it is also important to note that all 5 participants that reported having a history of 2 ACLR were included in the symptomatic group.

Finally, the symptomatic group demonstrated lower resilience scores compared to the non-symptomatic group. Resilience, as operationally defined by Liu et al., is the process by which an individual adjusts and responds to challenges. Resilience has been sparsely examined as a psychological factor associated with outcomes after ACLR; however, qualitative evidence has identified resilience as a key theme. Johnson et al. concluded that patients that were more resilient had better outcomes after ACLR, while Disantis et al. revealed that individuals that viewed recovery as an opportunity to ‘overcome adversity’ experienced personal growth as a result of their injury. It has been suggested that cognitive behavioral therapies and resilience training can improve coping strategies and decrease psychological distress in patients undergoing knee surgery. This, in turn, may have positive effects on other psychological factors (e.g., fear avoidance), physical activity adherence, and HRQOL (Figure 1).

**LIMITATIONS**

This study was not without limitations. All data associated with this investigation are self-reported and were captured via electronic survey. Participants may not have understood every question presented and were not able to ask clarifying questions based on this study design. Methods used for pa-

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**Table 2. Summary of dependent variables for included participants (median (interquartile range)).**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Symptomatic Participants (n=17)</th>
<th>Non-Symptomatic Participants (n=12)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brief Resilience Scale</td>
<td>3.7 (0.50)</td>
<td>4.0 (0.83)</td>
<td>0.030*</td>
</tr>
<tr>
<td>Modified Disablement in the Physically Active Scale-Physical Summary Component</td>
<td>13 (16.0)</td>
<td>0.0 (2.5)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Modified Disablement in the Physically Active Scale-Mental Summary Component</td>
<td>2.0 (4)</td>
<td>0.0 (1)</td>
<td>0.018*</td>
</tr>
<tr>
<td>Fear-Avoidance Beliefs Questionnaire- Physical Activity</td>
<td>22 (30)</td>
<td>1 (4)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Fear-Avoidance Beliefs Questionnaire- Sport</td>
<td>15 (10)</td>
<td>0.0 (6)</td>
<td>0.001*</td>
</tr>
</tbody>
</table>

* significantly different between groups, p<0.05

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**Figure 1. Proposed model depicting the cascade of events associated with increased symptoms in individuals with a history or ACL reconstruction.**

HRQL= health related quality of life, BMI= body mass index, PA= physical activity
tient classification were also limited to patient self-reports. No additional clinical criteria (i.e., radiographs) associated with the determination of a symptomatic knee were used, other than the completion of the KOOS survey. It is possible that the symptoms identified by completion of the KOOS could have been from origins other than osteoarthritis. Furthermore, the results of this study cannot be considered evidence of a cause and effect relationship. This was a cross-sectional study design that was only able to determine differences between the two groups of participants. These results are preliminary in nature, and are intended to support future investigations to determine the progression of osteoarthritis symptoms, quality of life, physical activity and fear-avoidance beliefs. Given the cross-sectional nature of this investigation, we are unable to determine if these outcomes preceded the ACL injury, reconstruction, and now symptomatic knee. The authors are also unable to determine if participants underwent any other lower extremity surgery after their ACLR but within the inclusionary time frame. Future investigations into the development of these outcomes should be longitudinal in nature to better understand the cascade of events. Lastly, these data were captured during COVID-19 in a small sample. It is possible that restrictions associated with the pandemic could have impacted participant responses on the surveys and responder bias may have influenced those who chose to complete the survey.

CONCLUSION

In conclusion, differences in BMI, HRQL, fear-avoidance beliefs and resilience were identified between participants with symptomatic knees and those with non-symptomatic knees. This series of relationships may be a cascade of events that can negatively impact health outcomes across the lifespan for this post-ACLR population. It is necessary for future longitudinal investigations to examine these outcomes after ACLR and as these individuals progress after rehabilitation and beyond clearance from formal rehabilitation. Should it be warranted, clinicians may consider patient education with a focus on the importance of physical activity for decreasing pain and other symptoms associated with symptomatic knees. Clinicians may consider exercise as a prescription for symptomatic joints after injury, but must include an overall assessment of the patient's psychological variables (e.g. fear-avoidance beliefs and resilience) and consider additional treatment strategies as warranted.

ACKNOWLEDGEMENTS

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CONFLICTS OF INTEREST

The authors report no conflicts of interest.

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Original Research

Initial versus Subsequent Injury and Illness and Temporal Trends Among Professional Hockey Players

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Keywords: Professional Hockey, Injury surveillance, Ice Hockey

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Background
Research is limited investigating injuries/illness incidence among National Hockey League (NHL) players. This study sought to establish injury/illness incidence, initial versus subsequent injury risk among NHL players, and determine temporal trends of injury and illness incidence.

Hypothesis
Variations in injury incidence by body region, and initial versus subsequent injury would be observed among positions.

Study Design
Retrospective cohort study

Methods
Publicly available data were utilized. NHL players 18 years or older between 2007-2008 to 2018-2019 were included. Injury and illness was stratified by position and body segment. Incidence rate (IR), and initial versus subsequent injury and illness risk ratios were calculated. Temporal trends were reported.

Results
Nine thousand, seven-hundred and thirty four injuries and illnesses were recorded. Centers had the highest overall IR at 15.14 per 1000 athlete game exposures (AGEs) (95%CI:15.12-15.15) and were 1.4 times more likely to sustain a subsequent injury compared to other positions. The groin/hip/thigh was the most commonly injured body region with an IR of 1.14 per 1000 AGEs (95%CI:1.06-1.21), followed by the head/neck (0.72 per 1000 AGEs, 95%CI:0.66-0.78). Combined injury and illness IR peaked in 2009-2010 season at 12.01 (95%CI: 11.22-12.79). The groin/hip/thigh demonstrated peak incidence during the 2007-2008 season (2.53, 95%CI:2.17-2.90); head/neck demonstrated a peak incidence in 2010-2011 season (Overall: 1.05, 95%CI:0.81-1.26). Injuries reported as 'lower body' increased over time.

Conclusions
Positional differences were observed; centers demonstrated the highest overall IR, and subsequent injury risk. Injury by body region was similar to previous literature. Head/
INTRODUCTION

The National Hockey League (NHL) is the professional league for ice hockey in North America. Ice hockey demonstrates a high risk of injury with overall incidence rates ranging from 5.93-15.6 per 1000 athlete exposures. This high injury rate is related to the level of physicality required for the sport. Players skate in excess of 32-48km per hour, 4 with contact occurring via body checking the most common mechanism of injury. These high rates of injury come at a cost to teams in the league. Fifty point nine percent of NHL players missed at least one game resulting in a total of $218 million dollars in lost salaries (based on individual player salary and number of days missed due to time loss injuries) per season between 2009-2010 to 2011-2012 seasons. Due to the injury and financial burden to players and teams, a comprehensive, transparent approach to injury surveillance is needed to attempt to mitigate injury risk. Further, the time trend analysis of injury patterns is an essential step in this process for both risk factor identification and evaluation of modulators, such as equipment changes or body checking.

A systematic approach in injury prevention research has been suggested by van Mechelen et al. to determine injury incidence and burden to inform future studies on preventative measures. Data among NHL players for injury surveillance are often reported by a singular body region, or do not encompass the whole league making comparisons by body region and position challenging. Additionally, given the risk of repeated high impact contact, players are at risk for subsequent injuries, further impacting injury burden. Players who sustain an injury are at risk of sustaining a second or third injury, particularly to the shoulder, groin, or specific to a diagnosis of concussion. One study analyzed league wide injury rates across multiple body regions in the NHL from 2006-2007 to 2011-2012 seasons. Authors of this study demonstrated an incidence rate of 15.6 per 1000 athlete exposures. Since then, rule changes on illegal checks and equipment updates have occurred. During the 2010-2011 NHL season, lateral or blind side hits meant to target the head, known as an ‘illegal check to the head’ resulted in a two minute minor or a match penalty; furthermore, visor wear was mandated for those entering the league in 2015. This warrants an updated epidemiological injury profile that reflects temporal trends to improve injury mitigation programs and assess efficacy of league rule changes on injury.

One way to identify injury incidence and temporal trends among NHL players is through publicly available data. Publicly available data improves transparency, and allows for collaboration among organizations to advance data robustness and distribution among stakeholders. This transparency and potential for collaboration is essential to promote open science initiatives. An open science approach allows researchers to assess, reproduce, and conduct studies for independent research with data that is easily accessible. Publicly available data have been utilized across professional leagues and demonstrated high reporting reliability. However most public data utilization in the NHL has been for cost analysis of injury and influence of schedule density on injury, not injury surveillance. Publicly available data are accessed via a computer iterative repeatable process which is an efficient method of data extraction. This process increases repeatability, and offers the potential for shared league wide injury risk identification and injury mitigation programs. This study sought to use publicly available data to determine injury and illness incidence by position and body region and determine initial versus subsequent injury risk. A secondary purpose of this study was to determine temporal trends of injury and illness incidence by position and body region.

METHODS

STUDY DESIGN

This was a retrospective cohort study. Participants were NHL players 18 years or older who competed in at least one season between 2007-2008 to 2018-2019. Players were categorized by position. Two online resources were used to create a combined data set for this study, including 1) https://www.prosportstransactions.com, and 2) http://www.nhl.com/stats/. These data have been previously utilized in Major League Baseball, the National Football League, and the National Basketball Association. The data can be accessed through the Open Science Framework data repository https://osf.io/rx4jb/. NHL stakeholders were included to aid in research question development and clinical interpretability including team physicians, athletic trainers, data analysts, and performance specialists. Strengthening the Reporting of Observational Studies in Epidemiology for Sport Injury and Illness Surveillance guideline was used.

INJURY AND ILLNESS CLASSIFICATION

Injuries and illnesses that occurred from the first game of the regular season to the last game of the post season were included in this study. Injury was defined as tissue damage or derangement of normal physical function occurring during any training session or competition that resulted in at least one day time loss. Illness was defined as a complaint or disorder reported by a player and his team, not related to injury, resulting in at least one day time loss.
The authors defined injury based on a specific joint or body segment as defined by the Orchard Sports Injury Classification System.30 Concussions were highlighted separately from head/neck injuries, and represented the only distinct diagnosis highlighted separate from body region (i.e. head/neck). Some data points are presented as a crude descriptor (i.e. "upper body") and were reported in this study as general classifications (upper body, lower body, or other), if injury to a joint or segment was not discernable. Initial injury was defined as the first injury documented; subsequent injuries were defined as either multiple or recurrent injuries, or an exacerbation of a previous injury.31

ATHLETE EXPOSURE

Athlete exposure was calculated based on game exposure (AGE) only, as determining practice exposure was not possible with this data set. For the 2015-2019 seasons, AGEs were calculated based on all 32 NHL teams and a 23 active man roster (8 defensemen, 8 wing players, 4 centers, 3 goalies) playing 82 regular season games between 2007-2008 to 2011-2012, and 2013-2014 to 2018-2019 seasons. The 2012-2013 season was representative of a player strike; this the AGEs were calculated based on 32 NHL teams and a 23 active man roster (8 defensemen, 8 wing players, 4 centers, 3 goalies) playing 48 regular season games. For all seasons, a postseason exposure adjustment was included to account for post season injuries based on the number of playoff games that occurred each season, with a reduction in the number of active players as teams were eliminated.1

DATA EXTRACTION, DATA REDUCTION AND EXTERNAL VALIDATION

For a detailed description of data repository used refer to Supplemental File 1. Data extraction, data reduction, and external validation used have been previously described,20, 21,27 External validation demonstrated high reliability for injury reporting (98%). Refer to Supplemental File 2 for detailed methods.

STATISTICAL ANALYSES

Injury and illness count data was converted to seasonal incidence proportion (IP) and incidence rate (IR). IR was calculated by total number of injuries or illness divided by total number of players per season.16 IR was calculated by sum of injuries and divided by the sum of player-games, multiplied by 1000 x Athlete-Game Exposures (AGEs). Initial and subsequent injury and illness risk ratios were calculated by specific position incidence for initial or subsequent injury, divided by all other position incidence for initial or subsequent injury for combined 13 seasons. Subsequent injury risk ratios were further stratified by number of subsequent injuries by position to explore burden. 95% confidence intervals (CIs) were reported for all IP and IR calculations. Temporal trends were reported. Sensitivity analyses were performed to calculate injury incidence for aggregated four season intervals to evaluate influence of seasonal outliers. All analyses were performed in R version 4.02 (R Core Team, 2020) using the rvest, tm, and xtm2 packages.

RESULTS

Over thirteen seasons, 10,549 athletes participated in the NHL and 9,734 injuries and illnesses were recorded. Centers had the highest combined injury and illness incidence rate (15.14 per 1000 AGEs 95% CI:15.12-15.15) (Table 1).

INITIAL AND SUBSEQUENT INJURIES BY POSITION

Centers presented with the highest incidence of multiple injuries reported for two (IP: 22.19% CI: 21.2-23.0) and three (IP: 9.0, 95% CI: 8.6-9.4) total injuries per season. (Table 2).

| Table 1. Overall Incidence Rate by Position |
| Position | IR    | 95% CI          |
| Defense  | 10.90 | 10.52-11.27     |
| Left Wing + Right Wing | 10.94 | 10.57-11.32     |
| Center   | 13.01 | 12.47-13.55     |
| Goalie   | 5.11  | 4.73-5.49       |

IR=Incidence Rate; CI= Confidence Interval; IR was calculated by sum of injuries and divided by the sum of player-games, multiplied by 1000 x Athlete-Game Exposures (AGEs) and adjusted for number of regular and post-season games each year.

| Table 2. Athletes with One or More Injuries |
| Position | IP    | 95% CI          |
| Defense  | 1 Injury | 53.09 | 51.45-54.73 |
| Left Wing + Right Wing | 1 Injury | 54.43 | 52.75-56.11 |
| Center   | 1 Injury | 76.55 | 73.20-79.89 |
| Goalie   | 1 Injury | 32.11 | 30.51-33.72 |

IP=Incidence Proportion; CI= Confidence Interval; IP was calculated by total number of injuries or illnesses divided by total number of players per season.
Table 3. Risk Ratios by Position

<table>
<thead>
<tr>
<th>Injury Type</th>
<th>n</th>
<th>RR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Defense</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial Injury</td>
<td>2103</td>
<td>0.97</td>
<td>0.94-1.01</td>
</tr>
<tr>
<td>Subsequent Injury</td>
<td>1267</td>
<td>1.14</td>
<td>1.08-1.22</td>
</tr>
<tr>
<td>Reinjury to same body location</td>
<td>443</td>
<td>1.07</td>
<td>0.96-1.20</td>
</tr>
<tr>
<td>Injury to new body location</td>
<td>824</td>
<td>1.05</td>
<td>0.97-1.13</td>
</tr>
<tr>
<td><strong>Left Wing + Right Wing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial Injury</td>
<td>2156</td>
<td>1.01</td>
<td>0.97-1.04</td>
</tr>
<tr>
<td>Subsequent Injury</td>
<td>1220</td>
<td>1.10</td>
<td>1.04-1.16</td>
</tr>
<tr>
<td>Reinjury to same body location</td>
<td>433</td>
<td>1.04</td>
<td>0.93-1.16</td>
</tr>
<tr>
<td>Injury to new body location</td>
<td>787</td>
<td>1.00</td>
<td>0.92-1.08</td>
</tr>
<tr>
<td><strong>Center</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial Injury</td>
<td>1516</td>
<td>1.66</td>
<td>1.60-1.71</td>
</tr>
<tr>
<td>Subsequent Injury</td>
<td>729</td>
<td>1.40</td>
<td>1.31-1.49</td>
</tr>
<tr>
<td>Reinjury to same body location</td>
<td>264</td>
<td>1.37</td>
<td>1.21-1.56</td>
</tr>
<tr>
<td>Injury to new body location</td>
<td>465</td>
<td>1.91</td>
<td>1.75-2.09</td>
</tr>
<tr>
<td><strong>Goalie</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial Injury</td>
<td>477</td>
<td>0.52</td>
<td>0.48-0.56</td>
</tr>
<tr>
<td>Subsequent Injury</td>
<td>237</td>
<td>0.48</td>
<td>0.43-0.54</td>
</tr>
<tr>
<td>Reinjury to same body location</td>
<td>106</td>
<td>0.59</td>
<td>0.49-0.72</td>
</tr>
<tr>
<td>Injury to new body location</td>
<td>131</td>
<td>0.34</td>
<td>0.29-0.40</td>
</tr>
</tbody>
</table>

RR: Risk Ratio; CI: confidence interval; Risk ratio calculated by specific position incidence/all other positions incidence (i.e. defense incidence/left wing-right wing, center, goal incidence)

Centers were 1.4 (95% CI: 1.3-1.6) times more likely to sustain a subsequent injury, with a higher likelihood of sustaining multiple injuries, or new body region (RR: 1.9, 95% CI:1.8-2.1) versus an injury exacerbation or recurrent injury (RR: 1.4, 95% CI: 1.2-1.6) (Table 3). Refer to Supplemental file 3-5 for further information on initial versus subsequent injury and illness IP.

INCIDENCE BY BODY REGION AND POSITION

The groin/hip/thigh was the most commonly injured body region with an IR of 1.14 per 1000 AGES (95% CI: 1.06-1.21), followed by the head/neck (0.72 per 1000 AGES, 95% CI: 0.66-0.79), and knee (0.60 per 1000 AGES, 95% CI: 0.55-0.66) (Table 4). By position, centers demonstrated the highest IR among the top three most injured body regions (groin/hip/thigh: 1.41 per 1000 AGES, 95% CI: 1.23-1.59; Head/Neck: 0.86 per 1000 AGES, 95% CI: 0.72-1.00; knee: 0.80 per 1000 AGES, 95% CI: 0.66-0.93) (Table 4).

TEMPORAL TRENDS

Combined injury and illness IR peaked in 2009-2010 season at 12.01 (95% CI: 11.22-12.79) (Supplemental File 6). Among the most commonly injured body regions, the groin/hip/thigh demonstrated peak incidence during the 2007-2008 season (Overall: 2.53, 95% CI: 2.17-2.90) (Supplemental File 7) along with the knee (Overall: 1.46, 95% CI: 1.19-1.74) (Supplemental File 8); head/neck demonstrated a peak incidence in 2010-2011 season (Overall: 1.03, 95% CI: 0.81-1.26) (Supplemental File 9). All three body regions demonstrated a variable, though declining incidence over the study time frame. Injuries reported as 'Lower Body' demonstrated an increase in incidence over time peaking in 2015-2016 (Defense: 2.68, 95% CI: 2.09-3.28; Goalie: 1.45, 95% CI: 0.80-2.11) or 2016-2017 seasons (LW+RW: 2.51, 95% CI: 1.75-2.86, Center: 2.57, 95% CI: 1.78-3.35) (Supplemental File 12). For further breakdown of temporal trends, please reference Supplemental Files 6-13.

SENSITIVITY ANALYSES

Centers reported the greatest mean consecutive four-season incidence proportion for the groin/hip/thigh (15.09) (Supplemental Files 14, 17), knee (7.40) (Supplemental Files 14, 18), concussion (5.66) (Supplemental Files 14, 19) and shoulder/arm/elbow (5.43) (Supplemental Files 14, 20). The mean difference was similar between season and four-season analyses across all body parts for overall, and most commonly injured body regions (Supplemental Files 14, 15). For most commonly injured body region by position, the Groin/Hip/Thigh mean difference comparing season
Table 4. Overall Incidence Rate by Body Region and Position

<table>
<thead>
<tr>
<th>Body Region</th>
<th>IR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankle</td>
<td>0.29</td>
<td>0.25-0.33</td>
</tr>
<tr>
<td>Overall</td>
<td>0.36</td>
<td>0.30-0.43</td>
</tr>
<tr>
<td>Defense</td>
<td>0.20</td>
<td>0.15-0.25</td>
</tr>
<tr>
<td>Center</td>
<td>0.27</td>
<td>0.19-0.35</td>
</tr>
<tr>
<td>Goalie</td>
<td>0.11</td>
<td>0.05-0.17</td>
</tr>
<tr>
<td>Concussion</td>
<td>0.47</td>
<td>0.42-0.52</td>
</tr>
<tr>
<td>Defense</td>
<td>0.32</td>
<td>0.26-0.39</td>
</tr>
<tr>
<td>Left Wing + Right Wing</td>
<td>0.50</td>
<td>0.42-0.58</td>
</tr>
<tr>
<td>Center</td>
<td>0.61</td>
<td>0.50-0.73</td>
</tr>
<tr>
<td>Goalie</td>
<td>0.15</td>
<td>0.09-0.22</td>
</tr>
<tr>
<td>Head/Neck</td>
<td>0.72</td>
<td>0.66-0.78</td>
</tr>
<tr>
<td>Overall</td>
<td>0.80</td>
<td>0.69-0.90</td>
</tr>
<tr>
<td>Defense</td>
<td>0.48</td>
<td>0.40-0.56</td>
</tr>
<tr>
<td>Left Wing + Right Wing</td>
<td>0.86</td>
<td>0.72-1.00</td>
</tr>
<tr>
<td>Center</td>
<td>0.35</td>
<td>0.25-0.44</td>
</tr>
<tr>
<td>Goalie</td>
<td>0.35</td>
<td>0.20-0.44</td>
</tr>
<tr>
<td>Foot/Toe</td>
<td>0.33</td>
<td>0.30-0.38</td>
</tr>
<tr>
<td>Overall</td>
<td>0.40</td>
<td>0.33-0.47</td>
</tr>
<tr>
<td>Defense</td>
<td>0.27</td>
<td>0.21-0.33</td>
</tr>
<tr>
<td>Left Wing + Right Wing</td>
<td>0.35</td>
<td>0.26-0.44</td>
</tr>
<tr>
<td>Center</td>
<td>0.10</td>
<td>0.04-0.15</td>
</tr>
<tr>
<td>Goalie</td>
<td>0.10</td>
<td>0.04-0.15</td>
</tr>
<tr>
<td>Forearm/Wrist/Hand</td>
<td>0.51</td>
<td>0.46-0.56</td>
</tr>
<tr>
<td>Overall</td>
<td>0.49</td>
<td>0.41-0.57</td>
</tr>
<tr>
<td>Defense</td>
<td>0.48</td>
<td>0.41-0.56</td>
</tr>
<tr>
<td>Left Wing + Right Wing</td>
<td>0.53</td>
<td>0.42-0.64</td>
</tr>
<tr>
<td>Center</td>
<td>0.19</td>
<td>0.12-0.26</td>
</tr>
<tr>
<td>Goalie</td>
<td>0.19</td>
<td>0.12-0.26</td>
</tr>
<tr>
<td>Groin/Hip/Thigh</td>
<td>1.14</td>
<td>1.06-1.21</td>
</tr>
<tr>
<td>Overall</td>
<td>0.72</td>
<td>0.62-0.82</td>
</tr>
<tr>
<td>Defense</td>
<td>1.23</td>
<td>1.10-1.36</td>
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<tr>
<td>Left Wing + Right Wing</td>
<td>1.41</td>
<td>1.23-1.59</td>
</tr>
<tr>
<td>Center</td>
<td>0.47</td>
<td>0.36-0.59</td>
</tr>
<tr>
<td>Goalie</td>
<td>0.47</td>
<td>0.36-0.59</td>
</tr>
<tr>
<td>Knee</td>
<td>0.60</td>
<td>0.55-0.66</td>
</tr>
<tr>
<td>Overall</td>
<td>0.54</td>
<td>0.45-0.62</td>
</tr>
<tr>
<td>Defense</td>
<td>0.47</td>
<td>0.39-0.54</td>
</tr>
<tr>
<td>Left Wing + Right Wing</td>
<td>0.80</td>
<td>0.66-0.93</td>
</tr>
<tr>
<td>Center</td>
<td>0.31</td>
<td>0.22-0.40</td>
</tr>
<tr>
<td>Goalie</td>
<td>0.31</td>
<td>0.22-0.40</td>
</tr>
<tr>
<td>Shoulder/Arm/Elbow</td>
<td>0.50</td>
<td>0.45-0.55</td>
</tr>
<tr>
<td>Overall</td>
<td>0.38</td>
<td>0.31-0.45</td>
</tr>
<tr>
<td>Defense</td>
<td>0.50</td>
<td>0.42-0.58</td>
</tr>
</tbody>
</table>

IR=Incidence Rate; CI= Confidence Interval; IR was calculated by sum of injuries and divided by the sum of player-games, multiplied by 1000 x Athlete-Game Exposures (AGEs) and adjusted for number of regular and post-season games each year and four-season analyses were: defense (Season: 5.48 vs 5 Season: 5.93), LW+RW (9.37 vs 10.17), centers (12.07 vs 13.09), and goalies (4.31 vs 4.69) (Supplemental Files 14, 15). Further information on sensitivity analyses can be found in Supplemental Files 14-22.

DISCUSSION

This study sought to establish injury incidence, initial versus subsequent injury incidence and determine temporal trends of injury incidence among NHL players. Centers had the highest combined injury and illness IR and the greatest incidence of subsequent injury. The groin/hip/thigh, knee, and head/neck were the most commonly injured body regions for all positions except LW+RW, which demonstrated the highest incidence for the groin/hip/thigh, head/neck, followed by equal injury incidence for the Shoulder/Arm/Elbow, and concussion. This suggests some position specific variability in injury may occur. Temporal trends for combined injury and illness incidence demonstrated the highest incidence during the 2009-2010 season. Head/neck injuries peaked in 2010-2011 season, prior to implementa-
tion of rule changes identifying illegal checks to the head. Groin/hip/thigh and knee injuries demonstrated declines over the study time frame, although ‘lower body’ injuries demonstrated an increase over time. Similar results were found in the sensitivity analyses using four-year increments for all temporal trends by body region and position suggesting four year or seasonal variance in injuries may still capture the overall trends in injury data.

INITIAL AND SUBSEQUENT INJURIES BY POSITION

Centers demonstrated the highest overall injury and illness IR and were 1.4 times more likely to sustain a subsequent injury within the same season. Research on injury by position is limited among NHL players and distribution can be conflicting depending on the league and level of play. A previous one-year prospective study among Swiss professional ice hockey players demonstrated near equal distribution of injuries by position for in-game injuries (i.e., right forwards: 23%, left forwards: 20%, centers: 17%, right defenders: 21%, left defenders: 15%). However this study did not include all teams in the league, and ice surface area is larger compared to the NHL (Swiss: 60 x 30 meters, NHL: 61.0 x 25.9 meters) potentially impacting injury incidence or severity. Similar to our findings, collegiate male ice hockey players have demonstrated that forwards account for 48.3-61.1% of injuries, but did not account for specific offensive positions. The increased incidence of initial and subsequent injury demonstrated among centers may be attributed to the demands of the position. Centers are expected to cover the largest zone of ice, may have increased defensive responsibilities compared to wing (LW+RW) players, and handle the puck more than other positions, all of which may influence contact with other players in open ice areas, or contribute to recurrent injuries. However, variability in coaching strategies for how centers are used are likely, and may not fully explain the higher injury incidence among centers.

INCIDENCE BY BODY REGION AND POSITION

The groin/hip/thigh, knee and head/neck were the most commonly injured body regions for centers, defense, and goalies. This finding is similar to previous studies among collegiate and professional players. Swiss professional players reported the most common injury to the hip/groin/thigh (25%), followed by head (17%)33, whereas a recent study among collegiate male players demonstrated that the head or face was the second most injured body region (15.2%) followed by the hip or groin (12.1%). Groin and hip injuries have previously been shown to be evenly distributed across all players, although intra-articular injuries are more common in goalies. Hip/groin/thigh injuries in hockey can be acute or chronic in nature and may present as intra-articular or extra-articular issues. Additionally, hip/groin/thigh injuries that present as chronic in nature may be related to overuse mechanisms, and may be underreported. Among knee injuries, medial collateral ligament tears followed by anterior cruciate ligament tears are the most common knee injuries resulting in time loss via contact. Head/neck injuries often include facial injuries (4.1 per 1000 player games), as well as cervical spine injuries. The NHL requires players to wear half shields on helmets, compared to collegiate ice hockey full face shield requirements. Previous literature has suggested a lower incidence of facial injuries when wearing a full face shield among collegiate players. The current data are similar to or lower than previous collegiate ice hockey reports comparing head/neck injuries (0.72 per 1000 AGEs versus 0.34-2.71 per 1000 Athlete Exposures). The current study did not differentiate among players who wore full versus half shield protection. Therefore, the impact of face shield type on head/neck injuries cannot be determined from our data and warrants further investigation. The high incidence demonstrated among hip/groin/thigh, knee, and head/neck injuries for a majority of players informs clinicians on need to consider injury mitigation programs for the lower extremity and cervical region, keeping in mind positional needs (i.e., goalie’s positional stance versus skaters).

One position subcategory, LW+RW, demonstrated differences among highest injured body regions after hip/groin/thigh. These players demonstrated the second highest injury incidence for the trunk/back/buttock, followed by equal injury incidence for the shoulder/arm/elbow, and concussion. Similar to our results, collegiate and Swiss professional players demonstrated the trunk or abdomen/thorax injuries accounted for 9-9.04% of all injuries and the fourth or fifth most commonly injured body region; however these studies did not report specific incidence by individual positions. The shoulder is the most commonly injured joint in the upper extremity, oftentimes presenting with acromioclavicular sprains, glenohumeral instability, as well as minor injuries such as contusions which likely reflects the majority of injuries among the shoulder/arm/elbow reported in the current study. In addition to centers, the finding that LW+RW players demonstrated a higher incidence of concussion compared to defense or goalies is consistent with previous NHL literature. Offensive players sustain hits from defensemen that are on average larger in stature. Furthermore, previous research has demonstrated that location of concussion event is more evenly distributed across all zones compared to defensemen and goalies. Forwards also incurred more concussions when ‘on the rush’ when the player is skating at a higher speed. These variations of position stature, location, and nature of play may explain the current study findings of higher incidence of concussion among offensive players.

TEMPORAL TRENDS

Head/neck IP peaked in 2010-2011 season, followed by a drop beginning in 2013-2014 seasons. From 2010-2011 season to 2013-2014 season, modifications were made to rules defining illegal checks to the head and subsequent penalties following research on concussion incidence and screening protocols. This rule change likely contributed to the decreased incidence in head and neck injuries noted in our results. Furthermore, the 2013-2014 season implemented a mandate requiring all players to wear a pro-
tective visor; players who wore a visor demonstrated more than a four-fold decreased risk of orbital or eye injuries.9
Visor wear increased from 32% during the 2002-2003 season9 to 97% during the 2018-2019 season,18 likely contributing to the decrease in injuries in the body region category of ‘head/neck’ injuries seen after the 2013-2014 season in our findings. However, these studies were not based on individual visor wear and the impact of injury should be interpreted with caution. Specific to concussion, incidence decreased over time after the highest peak noted during the 2011-2012 season likely in part to improved concussion recognition and stricter protocols.17,39 However, a spike in suspensions for illegal checks were demonstrated in 2013-2014 and 2018-2019 seasons which may in part contribute to the slight increase in overall or position specific (centers and RW+LW players) incidence, compared to the 2014-2015 to 2017-2018 seasons.25 Notably, the slight increase in overall or position specific incidence of concussion during the 2013-2014 may have been impacted by the NHL player strike, resulting in a condensed season, and should be considered. Impact of regulation on body checks and association with lower head/neck and concussion rates have been established among youth ice hockey players.59 These results suggest that rule implementation preventing body checks to the head and neck may also have a positive impact on lowering the incidence of head/neck and concussion injuries when rules are adequately followed and enforced in the NHL.

Among the most injured body region, the groin/hip/thigh and knee injuries demonstrated declines over the study time frame, although ambiguous labels including ‘Lower Body’ injuries demonstrated an increase over time. Therefore, the current study may reflect an underrepresentation of injury incidence across multiple body regions including the lower extremity. The NHL is required to disclose to the public a player’s injury status39; however, teams are not required to disclose the specific nature of the player’s injury, such as pathology.39 Many teams have opted to use the terms ‘lower body’ injury which may explain the increase in incidence of injury labeled ‘lower body’ over time compared to hip/groin/thigh.39,40 This decreased transparency in injury reporting is in contrast to other leagues such as the National Basketball Association, who are required to disclose the specific nature of the player’s injury.39 Furthermore, decreased transparency of publicly available injury data and hesitancy to disclose epidemiological data to researchers5 is likely reflected in the substantially less injury surveillance research among NHL players compared to other professional leagues.41 Decreased transparency in data reporting and access impacts volume and quality of studies that can improve player injury outcomes and appropriate resource allocation.3,41

Concussion was the specific diagnosis that the current study was able to report beyond the Orchard Injury Classification System body region labels. This increased transparency of reporting specific to this diagnosis likely aided in informing rule changes, injury recognition, and implementation of stricter protocols which likely contributed to the decreased incidence rate over time.17,40 This application of transparency may be applicable to other diagnoses of upper and lower body injuries for improved quality of injury surveillance data across the NHL to ensure appropriate injury mitigation programs and effective resource allocation implementation.

LIMITATIONS

Only NHL players were assessed, decreasing generalizability of the results to other professional ice hockey leagues, amateur ice hockey players, or female ice hockey players. Further, the public data set does not allow for missing data to be quantified, which may impact the precision of these results. However, external data validation was performed with other publicly available data to increase the interpretability of these results. Due to ambiguous terms such as ‘lower body’ the injury incidence by specific body region may be underreported or misclassified.40 Furthermore, these ambiguous terms may impact the ability to differentiate by body region for subsequent injuries (i.e., initial injury reported as ‘knee injury’ if reinjured could be reported as a ‘lower body injury’). This data was not reported by a clinician or other medical practitioner, which may also influence misclassification. Additionally, an estimated athlete-game exposures (AGEs) value was used to calculate IR based on typical games played each season. Although this approach has been previously performed to estimate player-game exposures,1,20,21 athletes by position may have different exposure to sport, and residual confounding is possible, impacting the clinical interpretability of these findings. In future studies examining effects of policy or intervention effects, AGEs may be suitable to use as a denominator, though exposure that captures both practice and game exposures may be more applicable to discern individual treatment effects. Furthermore, research varies in how athlete exposure is measured (i.e. 1000 athlete exposures versus 10000 athlete game), impacting comparability of the results. Finally, some injuries were reported to the nearest anatomical body part or nonspecific labels such as ‘lower body’ with specific injury classification (e.g., knee injury versus lateral meniscal tear of the right knee) not possible, decreasing the clinical interpretability of these findings.

CONCLUSION

Centers demonstrated the highest overall combined injury and illness incidence, were more likely to report multiple injuries, and more likely to report a subsequent injury compared to other positions. The groin/hip/thigh, knee, and head/neck were the most commonly injured body regions for centers, defense, and goalies similar to previous literature; however, LW+RW players demonstrated higher incidence for groin/hip/thigh, trunk/back/buttock, shoulder/arm/elbow, and concussion. Head/neck injuries peaked in the 2010-2011 season but demonstrated a substantial decrease in the following seasons. These findings inform clinicians on specific injury incidence that may reflect positional variability, which may inform injury mitigation programs that address these position specific variations. Further, the cur-
rent findings provide initial insight into injury trends that occur during periods of rule changes for illegal checking and visor wear for those who entered the league after 2013. Future literature is needed to investigate effects of rule or equipment changes to further confirm their effectiveness. Clinicians should be aware that although injury incidence decreased for groin/hip/thigh and knee, 'lower body' injuries demonstrated an increase over time, indicating that these injuries are likely underreported, citing a need for greater transparency of reporting injury.

CONFLICTS OF INTEREST
The authors report no conflicts of interest

FUNDING
None to disclose.

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REFERENCES


SUPPLEMENTARY MATERIALS

Supplemental File 1

Supplemental File 2

Supplemental File 3
Case Series

Combining Static and Dynamic Myofascial Dry Cupping Therapy to Improve Local and Regional Symptoms in Individuals with Low Back Pain: A Case Series

Brent Harper1, Alana Dudek, Julianne Williamson, Alex Siyufy2, Jo Armour Smith1

1 Physical Therapy, Chapman University, 2 Physical Therapy, South College

Keywords: low back pain, fascia, myofascial pain syndromes, cupping therapy, negative pressure

Introduction

Chronic low back pain is a common musculoskeletal healthcare presentation with an expense of over $100 billion annually. The clinical effect of myofascial cupping on pain and function is not clear, especially when different cupping techniques are combined. The purpose of this case series was to explore changes in pain and function following local static and distal dynamic myofascial dry cupping treatments in patients with chronic low back pain.

Case Descriptions

Three adults from the general population received three ten-minute treatment sessions, 48 hours between each session, of static dry cupping to the low back followed by dynamic myofascial cupping of the quadriceps and hamstring musculature. Outcome measures were taken at two different time points within one-week per participant. Subjective measures included the numeric pain rating scale and the Oswestry Disability Index, objective measures included passive straight leg raise measurements, and pressure pain threshold.

Results and Discussion

Local static combined with distal dynamic myofascial cupping reduced pain, pain sensitivity and perceived disability, and improved hamstring muscle extensibility in all three participants. These encouraging results support the initiation of a larger controlled trial aimed at investigating the efficacy of combined dry cupping interventions to treat musculoskeletal dysfunction and pain.

Level of Evidence

4 (case series)

INTRODUCTION

Chronic low back pain (LBP) is one of the most common reasons for healthcare visits, costing Americans over $100 billion annually.1-4 A systematic review by Meucci et al.5 reported the prevalence of chronic LBP in adults aged 18 years and older ranges from 3.9% to 20.3%. Multiple interventions are used to address impairments in range of motion, symptoms of pain, and perceptions of disability in individuals with LBP. These interventions include therapeutic exercise, manual therapy, patient education about lifestyle changes, pharmacological management, and modalities...
such as cryotherapy, heat, ultrasound, and electrical stimulation. Several interventions for LBP are acutely effective. The long-term effects of existing approaches are inconsistent, with over half of individuals with LBP experiencing a relapse of symptoms leading to costly surgeries or dependence on pain medication for symptom management. Therefore, more effective interventions are needed.

Recently, researchers have highlighted the potential benefit of therapies targeting the myofascial tissue in individuals with low back pain. One alternative intervention for acute and chronic back pain symptoms that targets the myofascial tissues is therapeutic dry cupping. Originating from traditional Chinese medicine, static dry cupping (SDC) is a passive technique where the cup is placed and left stationary on the body and is used to induce negative pressure in the underlying tissues. In Chinese medicine it is thought that SDC promotes the free flow of blood and the vital life force, qi, dispelling chronic pain and swelling. In Western medicine, many mechanisms of action have also been proposed for SDC, yet no clear explanation for observed clinical gains has been identified. Decreased pain following cupping may be a result of inhibitory pain modulation resulting in altered pain sensitivity, increased blood circulation, reduced inflammation, or immunomodulation. Locally, the negative pressure induced by SDC may separate layers of skin and fascia and affect fluid dynamics by stimulating the processes of proteoglycan, hyaluronic acid, and glycosaminoglycan production. This results in a more hydrophilic environment and altered biomechanical tissue properties such as tissue extensibility. Static dry cupping may also result in peripheral and central nervous system changes, including restoration of sensory processing. One potential example is the release of nerve growth factor (NGF) in the brain, which may improve proprioceptive feedback and motor patterning.

Static cupping appears to have a therapeutic effect and is utilized for various musculoskeletal conditions, primarily to decrease pain. In a systematic review, Kim et al. reported the findings of two randomized control trials suggesting that cupping reduced pain in patients with LBP compared with usual care methods and analgesia. The results of a systematic review by Chao et al. suggest that cupping might have a short-term benefit in reducing pain for acute and chronic pain conditions. A recent systematic review by Mohamed et al. suggested low to moderate support for dry cupping to decrease LBP.

To date, few studies have investigated dynamic myofascial cupping. For the purposes of this manuscript, dynamic myofascial cupping (DMC) is defined as cups being placed and left stationary on the body while the participant actively performs a movement. Most of the cupping literature involves static cup placement and little is known about what benefits, if any, are obtained by DMC. In persistent musculoskeletal disorders such as LBP, passive interventions that only address the area of symptoms may be inadequate. Chronic LBP disrupts sensory processing resulting in cortical reorganization and impaired touch perception, and is associated with neuroplastic changes at multiple levels, resulting in central sensitization. Back pain is also commonly associated with reduction extensibility of muscle groups distal to the region of pain such as the hamstrings. Reduced hamstring extensibility in individuals with LBP may be due to altered local myofascial tissue characteristics as well as altered motor responses to sensory input during hamstring elongation. Reduced hamstring extensibility has been associated with adverse spinal alignment and motion in some individuals without LBP. Although conclusive data for a relationship between hamstring length and LBP are lacking, restriction in hamstring extensibility is often addressed clinically in individuals with LBP, particularly those with occupational or athletic activities that require large ranges of motion at the hip. Interventions involving active movements, such as dynamic cupping, may be required to reorganize or reset regional movement patterns and impairments such as reduced hamstring extensibility.

It is not known how combining SDC with DMC during active movement influences pain, perceived disability, and hamstring extensibility in those with LBP. The purpose of this case series was to explore changes in pain and function following local static and distal dynamic myofascial dry cupping treatments in patients with chronic low back pain.

**CASE DESCRIPTIONS**

The case series was conducted according to the guidelines of the Declaration of Helsinki, and was approved by a university Institutional Review Board. Informed consent was obtained from all individuals included in this case series. Participants were recruited from the general population via recruitment flyers posted within the general areas of a local hospital facility.

Criteria for inclusion were that participants were between the ages of 18-55 years. Participants were recruited if they had experienced constant LBP of at least 3/10 on the numeric pain rating scale (NPRS) for at least two weeks, or if they had experiences of recurring, but not necessarily constant, LBP of at least 3/10 for more than two months. Participants had to be cleared to participate in physical activity as determined by the Physical Activity Readiness Questionnaire (PAR-Q). The Physical Activity Readiness Questionnaire is used when a physician consult is not warranted and is commonly used as a safety screen for participation in research. Exclusion criteria included any current local or systemic infections, vascular disease including varicose veins, current use of NSAIDS or other analgesics, active cancer, history of lumbar surgery, lumbar fracture, rheumatic disease, currently receiving treatment with corticosteroid, epidural steroid injection, or opioids, moderate to severe osteoporosis, and any previous medical intervention (e.g., physical therapy and chiropractic treatment) for the current episode of LBP. Each participant was screened for potential articular or joint limitations to knee and hip movement and range prior to the PSLR. There were no identified articular limitations noted for any of the
three participants. Any potential limitations in the PSLR were due to tissue extensibility disorder, which often limits muscle length. This case series was prepared following the CARE Guidelines for case reports.41 Two female participants and one male participant with LBP were included in this case series. Participant demographics are presented in Table 1.

**Table 1. Patient Demographics**

<table>
<thead>
<tr>
<th>Baseline Characteristics</th>
<th>Participant 1</th>
<th>Participant 2</th>
<th>Participant 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>Female</td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>Age (years)</td>
<td>40</td>
<td>24</td>
<td>26</td>
</tr>
<tr>
<td>Past Week NPRS</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>ODI (%)</td>
<td>12</td>
<td>20</td>
<td>30</td>
</tr>
</tbody>
</table>

NPRS = Numeric Pain Scale. ODI = Oswestry Disability Index.

**Figure 1. Intervention and study timeline.**

NPRS = Numeric Pain Rating Scale; ODI = Oswestry Disability Index; PPT = pain pressure threshold; PSLR = passive straight leg raise.

OUTCOME MEASURES

Participants attended three intervention visits, followed by one final data collection visit during which no intervention took place. Intervention visits were spaced 48 hours apart with the final data collection (e.g., post testing) visit occurring 72 hours after the third, and final, intervention (Figure 1). The outcomes were assessed at baseline and at the final post testing visit (Figure 1). The participants were instructed to avoid the use of any non-steroidal anti-inflammatory drugs, painkillers, or new activities throughout the duration of the study. The cupping interventions used in this case series included both SDC and DMC, where cups are placed stationary on a body region during an active movement exercise. A hypoallergenic oil-based lubricant (coconut oil) was used during both cupping interventions to maintain the adhesion of the cup to the participant’s skin. The researcher administering the interventions was the same individual each time with cup placement and amount of pressure determined by a single supervising licensed physical therapist with experience in cupping.

Subjective patient-based outcome measures included the Oswestry Disability Index (ODI), a perception of functional disability questionnaire for those with LBP, and the Numeric Pain Rating Scale (NPRS), used to assess current pain severity. The ODI is a valid and reliable outcome measure for spine-related functional disability.52,53 The NPRS appears to be the most accurate of the rating scales for pain severity.54 The NPRS was recorded before and after each of the three intervention sessions, and during the non-interventional post testing visit (Figure 1).

Changes in central nervous system function in response to cupping were assessed using pressure pain threshold. Pressure pain threshold (PPT) is a reliable method of measuring pain sensitivity45,46 in patients with myofascial and low back pain.47-50 Pressure pain threshold localized to the painful area was measured at four locations on the participant’s low back. Participants identified the most painful area to palpation within each quadrant of the low back (right and left, upper lumbar and lower lumbar region, Figure 2).50 In order to determine if cupping influenced pain sensitivity at an area remote to the location of the intervention and the symptoms, generalized PPT was measured at a standard location on the tibialis anterior muscle belly51 on the bilateral lower extremities. A pressure pain algometer (Force Dial™ FDK/FDN Series Push Pull Force Gage, Wagner Instruments) was used to induce steadily increasing force at each location and the participant was asked to verbally identify as soon as the sensation of pressure turned to pain.52,53 Three measurements were taken at each location and the PPT was averaged. For the low back sites, the average PPT across the four sites was then calculated. In order to ensure the same painful area was re-tested, the identified areas were marked during baseline testing with a dot using a black ink permanent marker. Participants were
instructed not to scrub off the marks, and marks were re-marked to prevent fading at each subsequent interventional visit to ensure the same location was re-tested.

Changes in tissue extensibility in the hamstrings were measured by the same investigator each time using the supine lower extremity passive straight leg raise range of motion test (PSLR ROM). The PSLR ROM was quantified on the bilateral lower extremities using a bubble inclinometer (Fabrication Enterprises, White Plains, NY). Inclinometers are a reliable and valid tool for ROM measurements with an ICC of ≥0.81.54-57

INTERVENTION

Static dry cupping was administered with the participant in the prone position on a treatment table with pillows placed beneath their abdomen and lower extremities for patient comfort and to reduce spinal extension. The researcher applied the lubricant and four cups bilaterally on the patient’s low back, one at each of the four sites that they had previously identified as the most painful area in each quadrant of the low back (Figure 2). Standardized cup pressure was applied with a pump to create 1.5 cm of tissue displacement, with all cups having a 2.0-inch diameter (Acu-Point manufacturer, Marknew Products, Buena Park, CA). Once the four cups were applied, the participants were instructed to remain still in the prone position for 10 minutes, after which the cups and lubricant were removed (Figure 2).

Dynamic myofascial cupping was then applied to each lower extremity. Participants were placed in the sitting position, and cups were placed on the quadriceps muscle, antagonist to hamstring, during the active knee extension movement, where the hip is fixed in 90° flexed position, in an attempt to place emphasis on proximal hamstring extensibility. Four cups were positioned in a standardized rectangular pattern over the right and left quadriceps on the anterior mid-thigh by the same researcher at each intervention. The standardized cup placement pattern ensured the cups were placed on the quadriceps muscle and were individualized to the size of each participant. In general, the distal cups were three-to-four inches from the joint line and three-to-four inches apart while the proximal cups were seven-to-eight inches from the joint line and three-to-four inches apart. The participant performed ten repetitions of seated knee extension through the full available knee ROM on one lower extremity followed by ten repetitions on the other. The participant completed two sets of ten repetitions on each leg (Figure 3). After removal of the cups and lubricant, participants lay supine with the knees extended and feet placed on a bolster. The same researcher applied lubricant and four cups bilaterally in a standardized rectangular pattern over the hamstrings on the posterior mid-thigh. The participant performed two sets of ten repetitions of a supine active straight leg raise with each leg with 10-15 seconds of rest between sets (Figure 3). The standardized cup placement pattern ensured the cups were placed on the hamstring muscle and individualized to the size of each participant. In general, the distal cups were three-to-four inches from the joint line and three-to-four inches apart while the proximal cups were seven-to-eight inches from the joint line and three-to-four inches apart.

Figure 2. Four quadrants of the low back used for placement of static dry cups and for pressure pain threshold assessment.

Participants selected the most symptomatic site within each quadrant. A) A = left upper quadrant; B = right upper quadrant; C = left lower quadrant; D = right lower quadrant. B) static cup placement.
Figure 3. Dynamic cupping intervention.
A) Seated knee extension movement.  B) Active straight leg movement

Table 2. Pain intensity, disability and passive straight leg raise range of motion pre- and post-intervention

<table>
<thead>
<tr>
<th>Variable</th>
<th>Left PSLR</th>
<th>Right PSLR</th>
<th>NRPS</th>
<th>ODI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Participant 1</td>
<td>80</td>
<td>107</td>
<td>95</td>
<td>105</td>
</tr>
<tr>
<td>Participant 2</td>
<td>60</td>
<td>70</td>
<td>65</td>
<td>72</td>
</tr>
<tr>
<td>Participant 3</td>
<td>60</td>
<td>75</td>
<td>55</td>
<td>66</td>
</tr>
</tbody>
</table>

PSLR = passive straight leg raise, in degrees; NRPS = Numeric Pain Rating Scale, 11-point scale from 0-10; ODI = Oswestry Disability Index, % disability.

Table 3. Pain pressure threshold averaged across the four low back sites and at the tibialis anterior pre- and post-intervention

<table>
<thead>
<tr>
<th>Participant</th>
<th>Mean Areas A-D</th>
<th>Pain Pressure Threshold (psi)</th>
<th>TA R</th>
<th>TA L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Participant 1</td>
<td>60.6</td>
<td>69.9</td>
<td>49.00</td>
<td>51.33</td>
</tr>
<tr>
<td>Participant 2</td>
<td>34.1</td>
<td>40.5</td>
<td>38.33</td>
<td>44.67</td>
</tr>
<tr>
<td>Participant 3</td>
<td>41.8</td>
<td>59.3</td>
<td>73.00</td>
<td>59.00</td>
</tr>
</tbody>
</table>

TA = tibialis anterior. R = right. L = left

RESULTS

Participant demographics can be reviewed under Case Descriptions, Table 1. Outcomes were measured by the same researcher for all participants and all visits. Baseline and follow-up scores for ODI, PSLR, and NRPS are presented in Table 2. PPT measures at baseline and follow-up are described in Table 3.

All participants had improved scores post-intervention on the NPRS and ODI. After three treatment sessions, ODI scores improved by an average of 9.33% across the three participants (Figure 4A). At the post-intervention visit, all three participants reported complete pain resolution with 0/10 pain on the NPRS. All participants had increased PPT averaged across the four low back sites (Figure 4C) but not at the tibialis anterior sites (average of both limbs shown in Figure 4D). PSLR ROM on the left improved by an average...
Results in the current study indicate improvement in symptoms as measured by two subjective outcome measures of NPRS, which resulted in an average 1.5 points decrease between the pre- and post-intervention assessment. Additionally, the results showed a decrease in ODI of 17.3 degrees and an average of 9.3 degrees on the right (average of both limbs shown in Figure 4B).

**DISCUSSION**

This is the first case series reporting the effects of combining static dry cupping and dynamic cupping to different body regions using multiple subjective and objective assessment metrics. The intervention was safe and was tolerated well without any adverse effects. The intervention resulted in lower perceived disability, decreased pain and pain sensitivity and improved hamstring extensibility. The multiple clinical effects observed in this study may be due to the ability of cupping to decrease pain and inflammation, promote cutaneous blood flow and change biomechanical tissue properties, improve local anaerobic metabolism, and influence the immune system by modulating cellular mechanisms.15,16,20

Previous literature has suggested that a reduction of one point or 15.0% in NPRS scores indicates a minimal clinically important difference (MCID) in relation to chronic musculoskeletal pain58 while others state that a two point change is necessary for the changes to be meaningful.59 Results of a previous study identified meaningful NPRS change in sub-acute LBP to range between 3.5 and 4.7 points while those with chronic pain ranges from 2.5 to 4.5 points.60 In this study, all participants had reductions greater than these MCID values, averaging 6 points with a range of 5-7 points, indicating that cupping reduced pain severity. All three participants also demonstrated decreases in perceived disability, quantified by the ODI. These findings are similar to results found in previous literature that demonstrated improvements in ODI scores following treatment of the lower back.14,61 Copay et al.62 reported a minimum detectable change (MDC) of 10 percentage points for the ODI in lumbar spine surgery patients. One out of the three participants had a change in ODI score greater than 10 points, which suggests that this participant had meaningful improvements in perceived disability. However, the ODI might have a floor effect,63 preventing a meaningful difference to be identified in this group of participants.

Pressure pain threshold increased, or improved, in all participants, with an average increase in 11.0 psi (Table 3, Figure 4C). There is no consensus regarding clinically meaningful changes in PPT. However, it has been suggested than when the PPT changes are accompanied by a 2.5 point NPRS change in those with LBP, the PPT changes are considered meaningful.60 In this case series, the average pain decrease was 6 points, indicating the PPT changes after cupping may have been meaningful changes. These changes may be due to manipulation of the skin, subcutaneous fat, muscle, and fascial layers using cupping therapy thereby stimulating inhibition of nociceptive dorsal horn neurons in the spinal cord and brain.14,18 The decrease in perceived pain levels on the NPRS and pain sensitivity at the PPT locations may be related to inhibition of nociceptive receptors following cupping.

The improved hamstring extensibility post-intervention may be explained by restoration of normal fascial gliding. Impaired fascial gliding can lead to modifications in the composition of surrounding loose connective tissue and induced muscular stiffness, leading to dysfunctional move-
ment patterns and reduced mobility. Cupping is theorized to restore normal fascial gliding by creating negative pressure, which increases lubrication, prevents collagen cross-binding, and restores hyaluronic acid viscosity. In addition, mechanical stress on the fascia increases the temperature of the tissue and reduces the viscosity of hyaluronic acid polymers to restore normal fascial gliding. In the hamstring musculature, the intent was to also influence the mechanoreceptors for stretch (muscle spindles) and tension (Golgi tendon organs) to increase the hamstring's ability to lengthen and to decrease coactivation during lengthening, thus influencing central neural control and increasing spatial range prior to contraction during movements which lengthen the muscle. Both of the dynamic myofascial cupping interventions used active contraction of the anterior lower extremity musculature to leverage reciprocal inhibition relaxation (RIR), where the contracting muscle is the antagonist to the muscle being treated. Performing the active exercises with the hamstring at different lengths appeared to improve hamstring extensibility, which may have been the result of improvements throughout the entire muscle length. Active knee extension with the hip in generally fixed flexed position intended to target the distal hamstring whereas hip active straight leg raise with motion with the knee in a generally fixed extended position intended to focus the intervention to the proximal hamstring.

The results of this case series must be interpreted with caution due to limitations in study design. A first limitation is the lack of standardization of the low back locations where the cups were placed on the subjects. This reduces the ability to compare findings between the subjects, but the subject-specific approach was consistent with clinical practice. A second potential limitation is the incorporation of multiple treatment methods. This study assessed two forms of cupping applied to sites in the painful area and sites non-local to the symptoms. We did not assess which method was more effective to reduce pain and functional disability. The chosen treatment approach was based on the concept of regional interdependence, which considers all regions of the body to be mechanically influenced by one another. This concept may explain how treatment of the anterior and posterior surfaces of the lower extremities may have affected lower back pain symptoms. A third limitation is the small sample size and strict exclusion criteria, which may limit the generalizability to other back pain populations, and the absence of a control group for comparison of treatment outcomes. Although hamstring extensibility, or length, was used as a metric of improvement and the protocol for cup placement was intentional for improving the length of the hamstring muscle, it was not an inclusion criterion and should be interpreted based on individual clinical presentations and within the context of positive changes within all four metrics. Since cups were placed on the low back as well as the hamstring, any improved hamstring length cannot be directly attributed to placement of the cups on either the hamstring or the low back. However, the combination of cup placements appeared to make positive changes in both the subjective and objective measures.

CONCLUSION

The results of this case series indicate positive outcomes of combining static and dynamic cupping on pain and muscle extensibility in three participants with LBP. These results should be interpreted with caution until future research involving randomized trials with rigorous methods and a control group are conducted to investigate the efficacy of combinations of static and dynamic cupping to treat musculoskeletal dysfunction and pain.

COMPEting INTERests

Authors state no conflict of interest.

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Introduction
Effective rehabilitation strategies for upper extremity injuries in softball pitchers are scarce in current literature, especially among youth athletes. Additionally, there continues to be ambiguity regarding the interpretation and clinical practicality when treating an overhead athlete with scapular dyskinesis. The purpose of this case report is to highlight the examination and treatment of a youth softball pitcher referred to physical therapy with the diagnosis of scapular dyskinesis.

Case Description
This case report presents data and outcomes for a 14-year-old female who experienced chronic right shoulder discomfort related to performing the windmill softball pitch (WSP). The subject was clinically diagnosed with scapular dyskinesis by her referring physician and demonstrated abnormal scapular movement when elevating and lowering her upper extremity. Internal and external rotator isokinetic strength testing and the Athletic Shoulder Test (ASH) were used as primary objective measures. Both were performed six days after the initial evaluation and again six weeks later. Initial testing demonstrated decreased peak torque and total work. Initial treatment involved periscapular and shoulder strengthening with progression to overhead loading. Later rehabilitation strategies focused on neuromuscular control, functional training, and sport-specific activities.

Outcomes
The subject initially demonstrated improved peak torque and total work of the shoulder with isokinetic strength testing but continued to have symptoms with pitching, even though the Scapular Dyskinesis Test had become negative. After changing the focus to neuromuscular and functional training the subject had fewer symptoms and became comfortable with self-management.

Discussion
This case matches previous research that endorses scapular dyskinesis being a normal finding in overhead athletes with and without shoulder pain. Neuromuscular control and functional training after a period of scapular strengthening were beneficial in improving symptoms in this athlete.

Level of Evidence
5

INTRODUCTION
There is a paucity of literature on the biomechanics of the windmill softball pitch (WSP) and their impact on the upper extremity in comparison to overhead baseball pitching (OBP). It is believed that because during the WSP the ball is released below the shoulder, it is considerably safer than the OBP. However, the WSP has been shown to have injury...
rates comparable to baseball, particularly when considering overuse shoulder injuries.  

Significant acceleration occurs during the delivery of the WSP, which puts large amounts of stress on the upper extremity. A study by Barrentine et al. comparing kinematics and kinetics for the WSP and the OBP of collegiate pitchers showed similar joint speeds and loads at both the shoulder and elbow but occurring at different phases of the pitch delivery. The only critical difference was during the WSP, forces to resist distraction at the shoulder and elbow were the greatest during acceleration, whereas during the OBP, forces were greatest during deceleration. However, biomechanical evidence indicates relatively similar distraction forces at the shoulder for both the WSP and OBP.

There are even fewer studies on youth softball pitchers, with a recent prospective study finding that 23% of youth fastpitch softball players had shoulder injuries sustained while pitching during a single season. With the popularity of softball rising and WSP injuries frequently resulting in a significant decrease in quality of life, there is a need for more research on WSP.

Scapular dyskinesis has been associated with most shoulder pathologies. However, the clinical relevance of scapular dyskinesis has recently been challenged, as nearly half of asymptomatic people have scapular dyskinesis and there are few prospective studies to establish causality. Additionally, there have been inconsistent definitions of what is actually considered scapular dyskinesis. When compared to controls, some authors describe decreased scapular upward rotation as scapular dyskinesis while others have defined it as a loss of scapular downward rotation. In light of these conflicting views on classifications, there is also evidence supporting scapular dyskinesis as being a normal finding in both symptomatic and asymptomatic overhead athletes or even that it may be a beneficial adaptation to increase velocity through force coupling and/or length-tension relationships for force generating muscles with overhead hitting or throwing.

The purpose of this case report is to highlight the examination and treatment of a youth softball pitcher referred to physical therapy with the diagnosis of scapular dyskinesis. Key components of the examination, including WSP physiology, will be presented and discussed; along with the relevance of scapular dyskinesis in this case.

CASE DESCRIPTION

The subject was a right hand dominant 14-year-old female with right shoulder pain that began six months prior to her evaluation. She participated as a pitcher in softball, a thrower in track and field, a middle hitter in volleyball, and as a basketball athlete. The subject does not recall a distinct mechanism of injury but noticed her pain after pitching one day. At rest her pain is 0/10, however, she reports aches with symptoms at 4/10 after pitching, with symptoms lasting for the rest of the day and returning to baseline in the following day. She is unable to point to a specific point of pain but feels it in her shoulder when pitching, typically when the shoulder is in the 12 o’clock position. Currently, her symptoms are alleviated with rest and exacerbated with activity, reporting “feeling tired” with activity. The subject had radiographs taken by her orthopedist without any significant findings. She was referred to physical therapy with a clinical diagnosis of “scapular dyskinesis”.

EXAMINATION

At the initial examination no atrophy was noted and there was no tenderness to palpation in the glenohumeral or periscapular region, and no obvious scapular malposition was noted in a resting posture. Active range of motion was normal bilaterally with passive internal rotation being limited on the right, with a glenohumeral internal rotation deficit (GIRD) presentation. Right shoulder passive internal rotation was 45 degrees with 154 degrees of a total arc of motion, while the left shoulder passive internal rotation was 75 degrees with 185 degrees of a total arc of motion. The subject had slight hypermobility (grade four glenohumeral mobility) in the posterior and inferior directions of the right glenohumeral joint, which was assessed through a standard joint play assessment.

Manual muscle testing was performed at the initial evaluation, as well as isokinetic testing of the external rotators (ER’s) and internal rotators (IR’s) and the Athletic Shoulder Test (ASH) testing occurring at the next visit six days later. Table 1 presents manual muscle testing outcomes, performed in standard positioning. Table 2 presents isokinetic testing data at 90 and 270 degrees per second and shows decreases in strength of the right IR’s and ER’s at 270 deg/sec. ASH testing indicated equal and good strength without any significant deficits. The subject reported pain with strength testing.

Upon visual assessment of scapulohumeral rhythm via the Scapular Dyskinesis Test, the subject demonstrated reduced upward rotation of the scapula with increased anterior tilt on the right during active flexion and abduction. Pitching was pain-free at lower intensities, with symptoms present at about 50% throwing intensity. Special testing was negative for the scapular assist test and the Biceps Load II test. The hospital-specific outcome measure used was Focus on Therapeutic Outcomes (FOTO) and the subject scored 64/100, which indicates moderate dysfunction in the subject’s physical functional status. FOTO was used because it captures the breadth of health concerns associated with a subject’s perception of their functional status. The report also helps determine the subject’s individual preferences, needs, and values to help ensure that these values guide clinical treatment decisions.

A throwing assessment was performed three weeks after the subject’s initial evaluation. An iPhone with slow-motion camera mode was used to assess the subject’s pitching mechanics. There are multiple biomechanical risk factors documented in the literature that put softball pitchers at increased risk for upper extremity injury: greater shoulder horizontal abduction at foot contact, less trunk lateral flexion towards the throwing side, increased stride length, increased trunk rotation away from the throwing side, and increased center of mass posteriorly. None of the following were demonstrated during the throwing assessment.
Table 1. Manual muscle testing at evaluation

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Right</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder flexion</td>
<td>4/5</td>
<td>4+/5</td>
</tr>
<tr>
<td>Shoulder abduction</td>
<td>4/5</td>
<td>4+/5</td>
</tr>
<tr>
<td>Shoulder ER at 0 degrees</td>
<td>4/5</td>
<td>4/5</td>
</tr>
<tr>
<td>Shoulder IR at 0 degrees</td>
<td>4-/5</td>
<td>4-/5</td>
</tr>
<tr>
<td>Serratus Anterior</td>
<td>4-/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Middle Trapezius</td>
<td>4/5</td>
<td>4/5</td>
</tr>
<tr>
<td>Lower Trapezius</td>
<td>4/5</td>
<td>4/5</td>
</tr>
<tr>
<td>Latissimus Dorsi</td>
<td>4/5</td>
<td>4+/5</td>
</tr>
<tr>
<td>Rhomboids</td>
<td>4/5</td>
<td>4/5</td>
</tr>
<tr>
<td>Biceps</td>
<td>5/5</td>
<td>5/5</td>
</tr>
</tbody>
</table>

Abbreviations: ER, external rotation; IR, internal rotation

Table 2. Isokinetic testing at the first follow-up visit

<table>
<thead>
<tr>
<th>Peak Torque</th>
<th>Right (ft-lbs)</th>
<th>Left (ft-lbs)</th>
<th>Deficit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER at 90 degrees of abduction (90 degrees per second)</td>
<td>20.7</td>
<td>19.4</td>
<td>None</td>
</tr>
<tr>
<td>IR at 90 degrees of abduction (90 degrees per second)</td>
<td>28.2</td>
<td>29.7</td>
<td>None</td>
</tr>
<tr>
<td>ER at 90 degrees of abduction (270 degrees per second)</td>
<td>7.4</td>
<td>10.8</td>
<td>31.5%</td>
</tr>
<tr>
<td>IR at 90 degrees of abduction (270 degrees per second)</td>
<td>14.3</td>
<td>17.1</td>
<td>16.4%</td>
</tr>
<tr>
<td>Total Work</td>
<td>Right (ft-lbs)</td>
<td>Left (ft-lbs)</td>
<td>Deficit</td>
</tr>
<tr>
<td>ER at 90 degrees of abduction (90 degrees per second)</td>
<td>77.3</td>
<td>59.1</td>
<td>None</td>
</tr>
<tr>
<td>IR at 90 degrees of abduction (90 degrees per second)</td>
<td>143.4</td>
<td>111.1</td>
<td>None</td>
</tr>
<tr>
<td>ER at 90 degrees of abduction (270 degrees per second)</td>
<td>3.7</td>
<td>6.4</td>
<td>42%</td>
</tr>
<tr>
<td>IR at 90 degrees of abduction (270 degrees per second)</td>
<td>46.5</td>
<td>118.9</td>
<td>60.9%</td>
</tr>
</tbody>
</table>

Abbreviations: ft-lbs, foot-pounds; ER, external rotation; IR, internal rotation

Figures 1 and 2 show images of the subject’s pitching mechanics during initial foot contact from posterior and lateral views, respectively.

CLINICAL IMPRESSION #1

This case is particularly unique because of the discrepancy in the literature and the novelty of upper extremity injuries in youth softball. Differential diagnoses following the initial evaluation included scapular dyskinesis, labral pathology, multidirectional instability, rotator cuff pathology, cervical pathology, and thoracic outlet syndrome. The initial working diagnosis was multidirectional instability and scapular dyskinesis based on initial findings. Since there were deficits in the subject’s peak torque of the internal and external rotators along with scapular dyskinesis, the first objective was to improve the subject’s impairments of the muscle groups associated with her altered scapular movements including the middle trapezius, lower trapezius, serratus anterior and address rotator cuff strength deficits.

OUTCOMES

Following seven weeks of physical therapy the subject reported feeling better noting reduced pain with pitching. Her isokinetic measures were significantly improved, see Table 4 for details. The subject also tested as “normal” for the Scapular Dyskinesis Test. However, she was still having discomfort with pitching, therefore she had magnetic resonance arthrogram (MRA). The report from the MRA was negative for any pathologies including normal findings for the rotator cuff, labrum, and articular cartilage. Following the MRA results, the subject was nearing the end of the calendar year, in which her insurance benefits followed, and a conversation ensued with her mother regarding continuing a self-management home exercise program with a conservative progression back into pitching.

CLINICAL IMPRESSION #2

This case report has demonstrated the complexity of both the examination and treatment of a youth softball pitcher with a shoulder injury related to WSP. The initial impres-
progress regarding pain with pitching, the plan was to focus primarily on neuromuscular control and softball pitching specific functional training to improve the subject’s glenohumeral and scapular control during activity rather than focus on isolated strengthening. The subject was contacted roughly five months later for consent for publication of this case report and reported no pain with pitching following continued adherence to her home exercise program and progressive return to pitching with the return to pitching program.

**DISCUSSION**

Despite there being a lot of research related to overhead injuries in baseball pitchers, there continues to be a significant deficit in research studying overhead injuries in softball players. The scapula has long been demonstrated to be important in the performance of overhead athletes, as it serves as the link that transfers energy from the trunk and lower extremities to the glenohumeral joint and elbow. Scapular dyskinesis has been classified in multiple ways without consensus on a gold standard definition.11

In this case report, the authors attempted to isolate the scapular stabilizers to address scapular dyskinesis and address the subject’s shoulder pain because of the importance of the scapula when transferring kinetic energy. Although the subject had significant improvements in her peak torque with overhead internal and external rotation along with improvements in total work of the shoulder, she continued to be symptomatic during her full-intensity softball pitch. Following improvement in the subject’s shoulder peak torque, increased focus was placed on neuromuscular training in more functional overhead patterns including the use of proprioceptive neuromuscular facilitation (PNF). Because maximal scapular muscular activation occurs during functional movement patterns rather than isolated scapular strengthening,3 strengthening in sport-specific movement patterns should be considered during exercise selection.

But what about other considerations in the kinetic chain? An additional variable that could have been considered in this case report was lower extremity strength. During phase three of the WSP, also known as the acceleration phase, high gluteus maximus activity creates the energy needed to move the shoulder from the 3 o’clock position to the 12 o’clock position.15 Without sufficient gluteal strength, it is hypothesized that an athlete will instead rely on the shoulder complex to create more energy to maintain pitch velocity. When studying single-leg squat mechanics, youth and high school softball pitchers demonstrated increased trunk rotation and trunk flexion at peak depth. Those that demonstrated these altered mechanics during a single leg squat also demonstrated increased knee valgus and trunk flexion during initial contact when pitching, which may also be associated with greater risk for upper extremity injury.16

An additional parameter that could account for increased risk for upper extremity injury in softball pitchers is high pitch counts. Currently, the Amateur Softball Association, which is the national governing body for softball in

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**Figure 1. Initial contact during the WSP, from a posterior view**

**Figure 2. Initial contact during the WSP, from a lateral view**

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1. [Link to reference]
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4. [Link to reference]
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10. [Link to reference]
11. [Link to reference]
12. [Link to reference]
13. [Link to reference]
14. [Link to reference]
15. [Link to reference]
16. [Link to reference]
Table 3. Treatment Interventions and rationale

<table>
<thead>
<tr>
<th>Weeks 1-2</th>
<th>Interventions</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rotator cuff isometrics (starting with short lever arms and progressing to longer lever arms); pec minor stretching; prone I, Y, and T; Grade I and II posterior GH joint mobilizations; side-lying ER strengthening</td>
<td>Decrease pain, increase load capacity, improve neuromuscular control, address posterior capsule, improve muscular endurance</td>
</tr>
<tr>
<td>Weeks 3-4</td>
<td>Planks with scapular protection; overhead medicine ball rolls with perturbations; 90/90 ER/IR with TheraBand resistance; progression to holds with perturbations</td>
<td>Increase lever arms, increase overhead load capacity, increase functional neuromuscular control</td>
</tr>
<tr>
<td>Weeks 5-6</td>
<td>Shoulder-controlled articular rotations; body blade variations; overhead KB carries; CKC plank ½ bosu walkovers; landmine pressing; introduction to pitching variations including T’s and K’s</td>
<td>Increase strength, continue the progression of overhead loading</td>
</tr>
<tr>
<td>Weeks 7-8</td>
<td>PNF diagonal patterns with resistance and alternating intensities; a continuation of body blade progression' overhead KB press walking with perturbations; full pitching progression</td>
<td>Neuromuscular control and sport-specific functional training</td>
</tr>
</tbody>
</table>

Abbreviations: GH, glenohumeral; ER, external rotation; IR, internal rotation; IR, internal rotation; KB, kettlebell; CKC, closed kinetic chain; PNF, Proprioceptive Neuromuscular Facilitation

Table 4. Isokinetic testing at seven weeks

<table>
<thead>
<tr>
<th>Peak Torque</th>
<th>Right (ft-lbs)</th>
<th>Left (ft-lbs)</th>
<th>Deficit</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER at 90 degrees of abduction (90 degrees per second)</td>
<td>22.2</td>
<td>21.2</td>
<td>None</td>
<td>7.2%</td>
</tr>
<tr>
<td>IR at 90 degrees of abduction (90 degrees per second)</td>
<td>32.0</td>
<td>32.3</td>
<td>None</td>
<td>13.5%</td>
</tr>
<tr>
<td>ER at 90 degrees of abduction (270 degrees per second)</td>
<td>10.6</td>
<td>6.7</td>
<td>None</td>
<td>43.2%</td>
</tr>
<tr>
<td>IR at 90 degrees of abduction (270 degrees per second)</td>
<td>17.7</td>
<td>22.2</td>
<td>20.3%</td>
<td>23.8%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Work</th>
<th>Right (ft-lbs)</th>
<th>Left (ft-lbs)</th>
<th>Deficit</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER at 90 degrees of abduction (90 degrees per second)</td>
<td>70.2</td>
<td>70.0</td>
<td>None</td>
<td>-9.2% (decreased)</td>
</tr>
<tr>
<td>IR at 90 degrees of abduction (90 degrees per second)</td>
<td>145.6</td>
<td>142.7</td>
<td>None</td>
<td>1.5%</td>
</tr>
<tr>
<td>ER at 90 degrees of abduction (270 degrees per second)</td>
<td>15.3</td>
<td>7.8</td>
<td>None</td>
<td>34.3%</td>
</tr>
<tr>
<td>IR at 90 degrees of abduction (270 degrees per second)</td>
<td>136.7</td>
<td>95.5</td>
<td>None</td>
<td>193.7%</td>
</tr>
</tbody>
</table>

Abbreviations: ft-lbs, foot-pounds; ER, external rotation; IR, internal rotation

the United States, has no rules that limit the number of innings or pitches at any level of play.\textsuperscript{17} Within professional softball, injuries for pitchers increase by 5% for every additional 100 pitches thrown in a season.\textsuperscript{18} The athlete in this case report may have increased her risk for shoulder pathology because of high pitch counts and/or her participation in overhead sports year-round, however, pitch count was not assessed herein.

Other considerations for this case report would be using a validated outcome measure such as the Shoulder Pain and Disability Index (SPADI) or Quick Disabilities of the Arm, Shoulder and Hand (QuickDASH) which could have been utilized to more accurately track the athlete's subjective progress over time. Additional performance testing such as the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) could also have been used to more objectively track the athlete's upper extremity stability. A focus on endurance testing could also have been beneficial in guiding treatment.\textsuperscript{19}

**CONCLUSION**

The results of this case report demonstrate successful interventions that allowed an adolescent pitcher to return to sport. Further research is recommended to address any potential relationships between lower extremity strength and scapular dyskinesis in overhead athletes. It is also recommended that further research explore the differences between neuromuscular training strategies in overhead athletes with and without scapular dyskinesis, especially within a youth population. Lastly, pitch counts may assist in protecting some youth athletes from similar injuries.

**CONFLICTS OF INTEREST**

The authors report no conflicts of interest.
Clinical Diagnosis of Scapular Dyskinesis in a Youth Softball Pitcher: A Case Report
REFERENCES


Digital Health Corner by Genie Health

Can AI/Machine Learning Make Physical Therapy Valuable in the Healthcare Marketplace?

Reuben Gobezie, MD

Keywords: Artificial Intelligence, machine learning, FMS, functional movement

https://doi.org/10.26603/001c.92509

International Journal of Sports Physical Therapy

I have written, in past Editorials for IJSPT, regarding the fact that a significant body of literature has demonstrated that a ‘physical therapy first’ approach to the majority of musculoskeletal (MSK) problems in our patient populations is the most effective way to reduce the total MSK spend by employers and payors. The latest data continues to show that MSK costs are amongst the highest alongside pharmaceuticals and cancer treatments for all payors and that the spend on MSK treatment of our populations is continuing to climb. The most powerful way to increase the recognition by the payors, who fund healthcare providers, about the importance of physical therapy services [e.g. pay for the provision of therapy] is for our community to produce more data around cost reductions for a ‘therapy first’ approach. However, in order to achieve higher quality data on the value proposition of this ‘therapy first’ approach, we, as a community, need to have greater standardization in our diagnostic assessments and corrective exercise prescriptions for our patients. But how do we achieve this goal?

First, no algorithm for screening human movement is “perfect”. Functional Movement Systems (FMS) is the gold-standard in our industry for screening and assessing human movement. There are over 600 publications from investigators whose research is derived from FMS’ methodologies. Many of us have been certified and have taken continuing education courses on the FMS System. However, the challenge to adopting FMS assessments and prescriptive corrective exercises within our clinical practices is that it is difficult to master. It is my assertion that technology is needed to deploy functional movement screens ‘at scale’ so that our greater community of providers can standardize our evaluation of MSK disorders and treatments and enable us to generate the type of data that payors are seeking. This ‘movement’ towards standardizing data that validates the importance of therapy in controlling MSK spend is critical to the well-being of the physical and occupational therapy profession.

Genie Health is working closely with FMS to build the technology into our platform that will enable therapists, trainers and chiropractors to deploy FMS assessments virtually or in-person through client/patient smart devices. Our platform will ingest the data and derive prescriptive corrective exercises based on the results of the individual’s assessments. This achievement is a significant step in the MSK space towards the “holy grail” of predictive care, the ability to assess a person and ‘diagnose’ their MSK disorder and predict the outcome of treatment success for specific rehab programs. Genie Health is committed to strengthening the position of therapy providers, trainers and chiropractors in the MSK healthcare marketplace. Stay tuned....

Reuben Gobezie, MD

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Abstract
Lateral ankle sprains, predominantly involving the anterior talofibular ligament (ATFL) and calcaneofibular ligament (CFL), constitute a significant portion of sports-related injuries, with a notable rate of recurrence and progression to chronic instability. Precise diagnosis and effective treatment of the ATFL and CFL injuries are crucial in preventing long-term complications. Musculoskeletal (MSK) diagnostic ultrasound has emerged as a pivotal tool in the rehabilitation sector, particularly in assessing lateral ankle ligament injuries. This article will highlight its benefits over traditional diagnostic methods and the emerging role of MSK diagnostic ultrasound as a superior tool for accurate, cost-effective, and comprehensive assessment of these injuries. We discuss the technology’s ability to provide objective, real-time imagery, facilitating accurate diagnosis, treatment planning, and injury monitoring emphasizing the need for a standardized approach to ultrasound evaluation to improve diagnostic accuracy and patient outcomes.

Keywords: MSK Diagnostic Ultrasound, Lateral Ankle Ligament injury, Non-Invasive Assessment, Injury Evaluation, Treatment Planning.

Introduction
Ankle sprains are a prevalent issue in sports medicine, accounting for approximately 25% of all sports injuries with 85% affecting the lateral side. These sprains affect 1 in 10,000 people per day. Ankle sprains represent the second most common cause of emergency room access, second only to low back pain. The ATFL and CFL are the most frequently injured ligaments during an ankle sprain and constitute a significant portion of sports-related traumas. About 33% of individuals experience reinjury within 3 years, and 25% develop chronic ankle instability. Some reports suggest an even greater re-injury rate of 70% at the ankle. Accurate diagnosis and early treatment are crucial in preventing long-term complications. While physical examination and radiography are traditional diagnostic tools, these methods have limitations in identifying soft tissue injuries and small avulsion fractures. Magnetic resonance imaging (MRI) and computerized tomography (CT) scans, despite their accuracy, are less frequently used due to high costs and time constraints. These limitations necessitate more effective alternatives. With the advent of MSK diagnostic ultrasound, a window has opened to diagnose and manage lateral ankle ligament injuries more accurately and efficiently and its diagnostic value has been previously described. Oae and colleagues have previously reported that lateral ankle injuries can be identified with MSK ultrasound with greater than 90% accuracy.

Advantages of MSK Diagnostic Ultrasound
1. Point of Care Utility: MSK ultrasound can be used in various settings, enhancing the clinician’s ability to make timely and informed decisions.
2. Accuracy and Precision: Ultrasound allows for a detailed view of the ATFL and CFL which allows for precise identification of injuries at the tender point and adjacent areas. This in turn provides clarity in diagnosing the extent of ligament integrity, tears or sprains.
3. Cost-Effectiveness and Accessibility: Compared to MRI and CT, ultrasound is a more affordable and readily available option.
4. Real Time Dynamic Imaging: Real-time imaging enables dynamic assessment, crucial for understanding the functional impairment and precise localization of injuries. One advantage of the use of MSK ultrasound imaging is that the clinician can perform a real-time stress ultrasound, meaning a gentle varus stress force can be applied to the ankle while imaging and quickly compare that to the normal contralateral side. Rossi et al. have shown that when performing ankle and foot sonography, the healthy contralateral side can safely be used as a reference during real-time MSK ultrasound evaluation of multiple structures.
5. Non-Invasive and Safe: Free from radiation, making it suitable for repeated use and in different patient populations.

Clinical Approach and Standardization
To ensure comprehensive and accurate diagnosis, a systematic approach to ultrasound scanning of the lateral ankle is necessary. Clinicians should:
1. **Expand Examination Scope:** To avoid misdiagnosis, MSK ultrasound scanning should not be limited to the ATFL and CFL but should include a broader examination of the lateral ankle. A wider area should be routinely examined to avoid missing associated injuries.

2. **Combine with Physical Examination:** Ultrasound should be used in conjunction with medical history and physical examination for a comprehensive evaluation. The thorough physical examination should guide the ultrasound imaging, focusing on tender points and specific ligament structures.

3. **Advocate for Training and Standardization:** There is a pressing need for standardized protocols for lateral ankle ultrasound scanning to ensure uniformity and accuracy in diagnosis. Standardized training for clinicians in the use of MSK ultrasound will help to promote uniformity and reliability in diagnoses.

### Anterior Talofibular Ligament

The probe is placed in the transverse plane at the lateral ankle (Figure 1A and 1B). The lateral malleolus is clinically palpable, and the probe is placed at the most distal aspect of the lateral malleolus in the longitudinal axis of the foot. In this position, the ATFL ligament can be seen. Deep in relation to the ligament, a small amount of joint fluid may be seen in the normal ankle. On anatomic slices, the ligament is seen as a bandlike structure extending from the distal fibula to the talus. The ligament is identified as a fibrillar hyperechoic structure that may show anisotropy artifact if the probe is not in the optimal plane of view.

### Calcaneofibular Ligament

The probe is placed in an oblique coronal plane at the posterolateral ankle (Figure 1C). Oblique positioning is mandatory for exact localization of the ligament. The CFL is then seen extending from the fibula to the calcaneus. The peroneal tendons are in close proximity to the ligament and may help in precisely localizing the ligament. On MRI, the ligament is seen originating on the fibula and extending to the calcaneus with a course deep in relation to the peroneal tendons. The ligament may be seen as a hyperechoic fibrillar structure, again with the possibility of anisotropy artifact.

### Implications for Rehabilitation: Incorporating MSK

#### Diagnostic ultrasound in rehabilitation:

1. **Enhances Treatment Planning:** Provides a detailed assessment that informs more tailored and effective treatment strategies.

2. **Improves Patient Outcomes:** Accurate diagnosis leads to better-targeted interventions, reducing the likelihood of chronic instability and recurrent injuries.

3. **Facilitates Monitoring:** Enables ongoing evaluation of the healing process, allowing adjustments in treatment as needed.

### Conclusion

MSK diagnostic ultrasound significantly enhances the diagnosis and management of lateral ankle sprains, particularly involving the ATFL and CFL. Its accuracy, cost-effectiveness, and dynamic imaging capabilities make it a superior tool in the rehabilitation provider's arsenal. Despite its advantages, the adoption of ultrasound in evaluating lateral ankle sprains is not without challenges, primarily due to the lack of standardization in scanning protocols and interpretation. There's a need for systematic ultrasound examination of the lateral ankle to avoid misdiagnosis and overlooked injuries. By offering a comprehensive guide on the use of MSK diagnostic ultrasound, this article aims to equip rehabilitation providers with the knowledge and rationale to incorporate this technology into their practice, thereby improving the standard of care for patients with lateral ankle ligament injuries. As technology advances and accessibility increases, its integration into clinical practice is crucial for improving patient care and outcomes in musculoskeletal injuries.

### REFERENCES


**LATERAL ANKLE LIGAMENTS: ANTERIOR TALOFIBULAR LIGAMENT (ATFL) AND CALCANEOFIBULAR LIGAMENT (CFL):**

*Figures 1A and 1B: ATFL Patient Position and Transducer Placement.*
The patient can be supine on the exam table with the hip and knee flexed, and the ankle is in plantar flexion and inversion. The position allows for a static stress test to be applied to the ATFL. An alternative position would be for the patient lying supine with the hip and knee relaxed and the foot resting off the edge of the table. This second position provides allowance for dynamic inversion stress maneuvers to test the integrity of the ATFL ligament. The transducer is placed obliquely longitudinal/LAX on the anterior margin of the rounded, bony prominence of the lateral malleolus while the remainder of the transducer is placed on the talus.

*Figure 1C: CFL Patient Position and Transducer Placement*
The patient can be supine or prone on the exam table, and the foot may or may not be resting on a bolster to enhance the required dynamic dorsiflexion for optimal visualization of the CFL. Having the foot in a fixed dorsiflexion position will help place tension on the lateral tendons. The transducer will need plenty of gel (floated) and is placed on the inferior aspect of the lateral malleolus. The angle is considered an obliquely longitudinal/LAX orientation on the anterior-inferior margin of the fibular/lateral malleolus while the remainder of the transducer is placed on the calcaneus angled slightly posterior.
Figures 2A and 2B Oblique Longitudinal/LAX Axis View: Careful transducer placement spans the joint between the proximal fibula and the distal talus. The fibers of the normal ATFL will extend between the bony landmarks in a linear, uniform appearance. The ligament interdigitates with the deeper, anterior joint capsule and may appear to dip into the joint space.

Figures 3A and 3B Oblique Longitudinal/LAX Axis View: Dorsiflexion of the foot tensions the CFL and makes the fibers more visible as they reach from the fibula to the calcaneus. The peroneal/fibular tendons are superficial to the CFL. A careful downward rotation of the probe from a SAX image of peroneal tendons is needed for a LAX of the CFL. A normal, intact CFL shows a curved course with an echogenic fibrillar structure located between the calcaneus and peroneal tendons. If the ankle is kept in a relaxed and static position, the CFL will look slightly concave. With ankle dorsiflexion and inversion, the CFL is being stretched and will straighten resulting in a lifting up of the peroneal tendons a small amount called a “trampoline sign.” Lifting of the tendons and stretching of the ligament is a sign of ligament continuity.

COMPLETE TEAR OF ATFL:

Figure 4A: LAX ultrasonography of the ATFL shows hypoechogenic discontinuity of the ligament, compatible with a complete tear (blue arrows). An inversion stress image provides more diagnostic confidence regarding the complete tear. LM, lateral malleolus; Ta, talus
PARTIAL TEAR OF ATFL:

The ATFL exhibits heterogeneous hypoechogenicity with some calcifications. This finding reveals a chronic partial tear (blue arrow). ATFL, anterior talofibular ligament; LM, lateral malleolus; Ta, talus.

COMPLETE TEAR OF CFL:

Figure 6A: Complete tears might show anechoic defects (blue arrows) of the CFL along with a hypoechoic and wavy appearance (yellow arrows) of the torn ligament.

PARTIAL TEAR OF CFL:

Figure 7A: The CFL will be hypoechoic and thickened or swollen in case of a partial tear and sprain (blue arrows). Partial tears might show anechoic defects and undulated or irregular ligament fibers.