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- Opening ceremony
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- Symposium: The adolescent athlete
- Break
- Symposium: Tendinopathy – understanding the underlying pathology
- Lunch and activity break
- Symposium: Muscle injury prevention and rehabilitation update
- Patient voices via live session or video interview/clip
- Patient voices coffee break
- Parallel 50-minute applied sessions repeated twice
  - Overuse Injuries in adolescents
  - Lower limb tendinopathy
  - Muscle injury diagnosis and rehabilitation
  - ACL injuries in the young athlete – best care in the interest of the athletes
  - The hyperflexible young athlete
- Poster/Infographic competition
- Gala dinner and party

DAY 2 PROGRAMME
- Symposium: The brain in sports related injury/pain: Local structural damage or central changes
- Networking break
- Parallel 50-minute applied sessions repeated twice
  - Athletes with multifactorial painful conditions
  - Get control over shoulder instability and pain in athletes
  - Handling concussions in the real world
  - Diagnosing and treating hip pain female athletes
  - Rehabilitation of athletes in contact and collision sports
- Lunch and physical activity break
- Symposium: Physical activity: What the sports physical therapist needs to know
- Physical activity break
- Symposium: Motivation for exercise as medicine
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**ABSTRACTS FROM THE FOURTH WORLD CONGRESS OF SPORTS PHYSICAL THERAPY**

**AUGUST 26-27, 2022, NYBORG DENMARK**

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BACKGROUND
One of the missions of the International Federation of Sports Physical Therapy (IFSPT) is to encourage high standards of sports physical therapy research, education and practice. The IFSPT founded the World Congress of Sports Physical Therapy (WCSPPT) in 2015. International congresses are mainly organized to discuss a specific theme, exchange opinions, update knowledge and increase worldwide networking. Professionals and students collaborate and the new generation increases the awareness about the hot topics and gaps of the profession, bridging the gap between science and clinical practice.

Sports Physical Therapy is relatively new, since it was recognized as a Physical Therapy specialty only in the 1970s.\(^1\) During the profession’s growth, international congresses have been the best place to raise ideas and indicate future directions to guide clinical practice and research. The initiative from the IFSPT to organize a congress every two years started with the desire to increase the exchange of knowledge, develop consensus statements in sports physical therapy, and enhance networking among member organizations. To achieve this, the IFSPT works in collaboration with a member organization, always trying to be as inclusive as possible; Sports Physical Therapy for all is our guiding spirit.\(^1\)

FIRST EDITIONS OF THE WORLD CONGRESS OF SPORTS PHYSICAL THERAPY
The Swiss Sports Physiotherapy Association (SSPA), in cooperation with IFSPT and *BJSM*, organized the First World Congress of Sports Physical Therapy in Bern, Switzerland in 2015. The organization of the Congress was demanding, but thanks to the SSPA committee’s hard work and dedication, and IFSPT’s cooperation, this event turned out to be very successful. Almost 800 participants (from 45 countries) gathered in Bern for a two-day conference on “Return to Play” in sport, with a stellar line up of renowned clinicians and researchers. Attendees enjoyed networking and learning with the IFSPT community. Clare Ardern, Karim Khan and Mario Bizzini also coordinated a consensus meeting with the invited speakers, which resulted in a *BJSM* publication, the "Return to Sport Consensus Statement," which is still considered one of the most important papers on this topic today.\(^2\) It was a brilliant way to start this initiative and prepare for the next editions.

EDITORIAL

HOW IS THE IFSPT BRIDGING THE GAP BETWEEN SCIENCE AND CLINICAL PRACTICE?

Lars Damsbo,\(^{a,b}\) Luciana De Michelis Mendonça\(^d\)

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*a. Chairman of the Danish Society of Sports Physical Therapy*

*b. Chairman of the organizing committee of the 4th World Congress of Sports Physical Therapy*

*c. Physical Therapy Department, School of Physical Education, Physical Therapy and Occupational Therapy, Universidade Federal de Minas Gerais, Brazil*

*d. President of the International Federation of Sports Physical Therapy*
The Second World Congress in Sports Physical Therapy was held at the Titanic facility, Belfast, Northern Ireland, in 2017, hosted by Physios in Sport. The conference welcomed over 600 delegates from 40 different countries to explore the theme of "Optimal Loading in Sport." The main purpose was to bring together basic science, clinical research and practical application in a way that would challenge and equip delegates. The programme focused on tissue specific strategies for how sport PTs prescribe load, as lessons from the field of expert practitioners working in high level football and sport. The mix of science and application was a particular highlight - much of the feedback received from delegates following the conference emphasized how great it was to hear what people do in “real life” rather than solely covering research evidence.

ACPSEM president and five-time, multiple medals winning Olympian, Dame Kathryn Grainger, shared her experience as an athlete and the role physiotherapy played in her career. Her insightful and entertaining talk reminded attendees of the value of listening to athletes and how sport PTs can enhance their support. On reflection, a key standout was how the IFSPT members were able to connect so effectively as a global community, and the value of attending in-person conferences to share experiences, make new friends and build stronger relationships.

In 2019, Vancouver, Canada, received around 550 participants, from 26 countries and 6 continents, for the Third WCSPT. It was the first time that the WCSPT was hosted on the North American continent. The theme was “From High Performance to Clinical Practice.” Kay Crossley presented the opening keynote; she was chosen as someone who has transcended the divide between research and clinical practice and embodied the theme of the conference. The congress opened with Chief Bill Williams from the Squamish Nation welcoming all of the attendees to this land. Over 65 scientific posters were presented and the first WCSPT 5k fun run was promoted; it was won by internationally renowned author/journalist, Alex Hutchinson. Themes that emerged from the conference were mentorship, collaboration, bridging research/practice gaps, sex and gender in sport, individualized care, and leadership in sport physiotherapy.

**What to expect for the 4th WCSPT?**

The Fourth WCSPT will be held this year in Nyborg, Denmark. The Danish Society of Sports Physical Therapy (DSSF) has a great history and experience organizing Sportskongres, together with the Danish Association of Sports Medicine, and the Scientific committee consists of internationally proven researchers. Both IFSPT and DSSF are intentional when it comes to gender equality among speakers. This year's speakers are divided equally between women and men.

As in Belfast, several athletes will be sharing their experiences with physiotherapy and its role in their career.

DSSF and IFSPT acknowledge the importance of bridging the gap between science and clinical practice. The theme at WCSPT 2022 is “Translating science into practice.” Both organizations want to make room for discussion and reflection on how to apply new knowledge into a clinical setting. Five parallel sessions of applied science will run twice during the congress, all focusing on translation and implementation of some of the topics/presentations given in the main auditorium.

At WCSPT 2022, abstracts submission are to be followed by an accompanying infographic. The infographics focus on clinical take-home messages in a visually appealing format. The best-rated infographics will be printed in postcard format for delegates to bring back home for their clinic wall.

DSSF and IFSPT expect active networking during the congress since a two-hour lunch and activity break has been scheduled each day, where participants are invited to take part in different activities. DSSF has partnered with local organisations to allow participants to engage in physical and social activities such as mountain biking, yoga, paddle-tennis, tennis, running and other kinds of outdoor fitness, or simply enjoy leisurely outings and conversations by the waterfront directly at the Great Belt, where the venue of WCSPT 2022 is located. Both DSSF and IFSPT hope this facilitates a dynamic combination of physical activity, knowledge-sharing, reflection and networking with peers.

See you in Denmark!
Acknowledgments:
We are thankful to Mario Bizzini, Phil Glasgow and Chris Napier who provided information of the first three editions of the WCSPT, respectively.

References
IFSPT International Perspective

“The only certainties in life are … wait, I pay no taxes, and I’m not dead, yet.” A letter from Qatar.

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WE ALL CRAVE THE COMFORT OF CERTAINTY, YET PHYSIO IS MOSTLY GREY

On day one, mostly your patients want to know:

“What’s wrong with me?”
“What’s going to happen?” and
“What can I/you do about it?”

I’m reminded though that “for every complex problem there’s always an answer that’s clear, simple … and wrong”. So how do we look ourselves in the mirror when we can’t, typically, give our patients certain answers to those questions on every occasion?

The nihilist will throw their hands up and tell you to give the game away; the fabulist will tell you that there’s this new treatment approach that works 100% of the time for everything and everyone. I’ve been both at varying times in the 30-something years I’ve been working in sports physio, but these days I find myself more comfortable in the grey, and I’d like to explain how and why.

Complicated is sending a rocket to the moon, complex is raising a child. One is difficult but predictable; one is difficult and unpredictable. Caring for your patients is like raising children in that your protocol is helpful, but it should only be considered a guide. Crucially, the guide must have a mechanism to let you know if you’re on the right track so you can self-correct when you take a wrong turn (which you will).

MAKE A COLLABORATIVE PLAN WITH YOUR PATIENT

The plan you agree on needs to include ways to figure out the direction to head in, if it’s working, and what you’re going to do when it’s not. Develop this with your patient on day one. Don’t start until you have both agreed to the plan. This might well mean changing your plan when it turns out that with the two of you aren’t aligned on aspects of it, or if you’ve misunderstood their goals or preferences. The rehab journey might take a while, and there can be periods of little apparent progress and probably some regression - so you and your patient must be on the same page if you expect to ride through these bumps.

SHARED DECISION MAKING DOESN’T MEAN DOING WHATEVER THE PATIENT ASKS FOR

When healthcare was paternalistic we could simply tell the patient what they were going to get, and that was it. Mercifully patients are now empowered and treatment choices should be presented and weighed according to their preferences, most of the time. This doesn’t make you a waiter who will bring whatever type of coffee the customer asks for. The internet will provide them a laundry list of treatment options, but your science degree should equip you to translate the evidence into a tailored recommendation for the individual in front of you.

YOUR PATIENT IS LOOKING TO YOU FOR SOME GUIDANCE AND DISTILLATION OF THE EVIDENCE THAT CAN BE BLENDED WITH THEIR PREFERENCES

An epidemiology journal might technically have a point about confidence intervals, but your inner Bayesian should be able to provide a recommendation to the athlete in front of you after 8,000 athletes have gone through studies using (or not) the Nordic hamstring exercise as an injury prevention approach.¹ Other cases will be less clear, but you can still couch your recommendations in a manner that’s helpful:

“It seems that this sort of exercise will help your pain if you can do it for about 12 weeks, but honestly, they haven’t done a ton of studies on this yet. We are pretty sure though that no harm will come from trying this approach and we will track your progress to check it is helping”

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The only certainties in life are ... wait, I pay no taxes, and I’m not dead, yet.” A letter from Qatar.

IN PRACTICE HOW CAN I DO THIS SINCE ALL MY PATIENTS ARE SO DIFFERENT?

I like the relative simplicity of acute musculoskeletal injury. The main challenges here are figuring out the tissue that’s damaged and the extent, and then figuring out how to help the patient get back to their desired level of loading through that tissue in a way that works for them (unless there is no initial trauma or tissue damage but that is another story). More difficult is when you’re dealing with persistent pain where there’s no longer a clear relation between tissue damage and your patient’s pain/disability. Both broad categories, however, benefit from having a testable plan.

TEACH BACK AND THE FOLLY OF “DO YOU UNDERSTAND?”

Keep bringing yourself back to those questions patients want answered “what’s wrong with me, what can I do about it, what’s going to happen?” Don’t fall for the trap of simply asking your patient “do you understand?” Like you, your patients don’t want to seem dumb, so they will always tell you they understand. A better strategy is to put the onus back on yourself:

“It’s important that I’ve explained this to you properly, and I often get that wrong. To see if I’ve done my job, can you tell me what you’re going to tell someone at home: what is wrong with you, what you’re going to do about it, and what’s going to happen?”

<table>
<thead>
<tr>
<th>Acute hamstring strain</th>
<th>Non-specific low back pain</th>
<th>Patient questions being answered</th>
</tr>
</thead>
<tbody>
<tr>
<td>What I think is going on here is that you’ve damaged this muscle in the back of your leg when you were running. This happens quite a lot to people like you who have to run fast.</td>
<td>What I think is going on here is that you’re still feeling pain in your back that started out as a sprain or injury quite a while ago, but now this pain has taken on a life of its own. Your pain system was initially being helpful by protecting you from further damage, but now those protective responses have become unhelpful, sort of like a car alarm that’s going off for no reason. The most common protective response is muscle guarding, which actually puts more pressure on your back.</td>
<td>What’s wrong with me?</td>
</tr>
<tr>
<td>Your body is doing a pretty good job of healing things, but we can help it along by giving it the right amount and kind of exercise, at the right time. To figure out if I’m doing this right, each day I see you I’m going to do a few tests that give us an idea of how well that muscle is doing, and then we can figure out what kind of exercise, and how hard we should be going.</td>
<td>Your body has done a good job of healing, so now we need to turn down this unhelpful protection. This protection can be influenced by thinking your back is still damaged (but we have tested this and it seems ok). It is also influenced by other things going on like how you’re sleeping, your mood, how confident you’re feeling and how much activity you can enjoy. What we need to do to stop that protection alarm going off is gradually show your back that it can do stuff currently it’s worried about by changing how you go about it.</td>
<td>What’s going to happen?</td>
</tr>
<tr>
<td>If I’m right, then we should be seeing improvements in how hard you can push, how much pain there is when you’re doing things and when I poke on the muscle, and how fast you can run. If I’ve got this wrong, these things won’t be improving, and they might even go backwards.</td>
<td>If I’m right, then we should be seeing improvements in how much you can do and how much pain there is. This is a low-risk approach. If I’ve got this wrong, these things won’t be improving, and we will modify what we do. We will get you doing more things that you find tough, but in a different way - with less protection. You will also do more of things that you feel good about doing. Sometimes things change really quickly once the system is happy with protecting less, other times it takes a lot a work from both of us. At the end of this you should be in control of your back and your pain.</td>
<td>What can I/you do about it?</td>
</tr>
</tbody>
</table>

Table 1. Examples of patient examination and care plan summaries for an acute and a long-standing condition.
don’t need to be as formal as this but gathering your own normative data for the patients you see is a great exercise in reflection and helps you iterate your processes.

We’re lucky here at Aspetar in Qatar as we’ve got a centralized system of medical care for our athletes, professional and recreational, so it’s relatively easy for us to pull together bigger numbers of patients for analyses. Your average sports physio working in a club, looking after a single team, will likely only get a couple of any specific injury in any given year, yet patterns only start to emerge once you’ve seen dozens, or likely closer to hundreds of a specific thing. We’re happy to share our experiences and our outcomes where a lot of the clinical gold is in the normative data. Here’s where the connectivity the internet and social media has given us can be leveraged. Your 3 patients with this one condition can be shared with 10, 50, maybe 100 other clinicians around the world, and together you now have a lifetime of information that can inform your practice, and more importantly, your patients. How, and even if, we as a profession choose to do this remains an open question.

I have dodged death and taxes for a while now here at Aspetar, but I am increasingly comfortable that the only thing I am certain of is uncertainty, and that’s a nice place to be.

ACKNOWLEDGEMENTS

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REFERENCES


"The only certainties in life are ... wait, I pay no taxes, and I'm not dead, yet." A letter from Qatar.
Background
Many tests are used to examine the knee when anterior cruciate ligament (ACL) injury is suspected. However, evidence of diagnostic accuracy in the Lachman, anterior drawer, pivot shift, and lever sign tests is limited.

Purpose
The purpose of this study was to perform a systematic review and meta-analysis of original research studies that assessed the diagnostic accuracy of four physical examination tests for ACL injury acutely after an injury.

Study design
Systematic review and meta-analysis.

Methods
A literature search was conducted in the PubMed, MEDLINE, CINAHL, Web of Science, and Ichushi databases. Original articles with prospective cohort and cross-sectional studies in English and Japanese were included. The searched words were "anterior cruciate ligament", "injury", "rupture", "tear", "lachman test", "pivot shift test", "anterior drawer test", "lever sign test". The methodological quality of the diagnostic studies was evaluated using QUADAS-2. Summary sensitivity, specificity, likelihood ratio (LR)+, and LR− with 95% confidence intervals were calculated.

Results
Eight studies were included in this review. The methodological quality of the included studies was mostly favorable. For the domain of flow and timing in the QUADAS-2, three studies did not assess the timing between the reference and index tests. The pooled sensitivities were 0.79, 0.78, 0.55, and 0.82 in the Lachman, anterior drawer, pivot shift, and lever sign tests, respectively, and the pooled specificities were 0.91, 0.91, 0.96, and 0.88, respectively. The lever sign test had the lowest LR− (0.21) and the pivot shift test had the highest LR+ (11.60). The area under the curve for the four physical examinations was > 0.70.

Conclusion
The lever sign and pivot shift tests are useful for diagnosing ACL injuries in an acute setting.
Level of Evidence
Level 2

INTRODUCTION

Anterior cruciate ligament (ACL) injury is one of the most common injuries in the knee joint occurring amongst adolescents and young adults during sports that involve sudden stops or changes in direction, jumping, and landing. Diagnosis of ACL injury in the initial medical consultation is difficult because of the common acute signs and symptoms of an ACL injury, such as immediate pain, swelling, and hemarthrosis. According to two previous studies in the U.K., correct ACL injury diagnosis was made in 28.2% and 14.4% of cases in the acute phase, respectively, which suggests that diagnostic accuracy is lower and difficult in the acute phase, as the median time to diagnosis was six weeks after ACL injury. Poor diagnostic accuracy within the first six weeks after injury is often related to an unnecessary delay in the diagnosis and subsequent treatment, and increases the risk of secondary injury to the knee joint. Accurate diagnosis in the acute stage is needed to reduce these secondary risks and appropriately manage ACL injuries.

Diagnostic imaging modalities and physical examinations are used to diagnose ACL injuries. Magnetic resonance imaging (MRI) is the gold standard owing to its high diagnostic accuracy. A previous systematic review indicated that the positive likelihood ratio (LR+) and negative likelihood ratio (LR−) were 14.4 (95% confidence interval [CI] = 9.2–22.5) and 0.1 (95% CI = 0.1–0.3), respectively, indicating that MRI is a useful independent tool for diagnosing ACL injury.

Conversely, physical examinations performed by athletic trainers, physical therapists, and medical doctors are inexpensive and can be performed without the use of highly specialized machines. Four tests are commonly used to diagnose or determine ACL injury: the Lachman test, the anterior drawer test, the pivot shift test, and the lever sign test. The diagnostic accuracy of these tests has been examined in systematic reviews and meta-analyses. The Lachman test had the lowest LR− of 0.17 (95% CI = 0.11–0.25), and the pivot shift test had the highest LR+ of 16.00. Additionally, the latest systematic review, conducted in 2019 regarding the lever sign test, suggested that it may be used in addition to other tests to rule out the presence of an ACL injury.

Based on these findings of systematic reviews, physical examination is useful in clinical practice for diagnosing ACL injury. However, previous meta-analyses have not analyzed acute and chronic conditions individually, and no systematic review has examined whether these physical examination tests are useful in acute settings for diagnosing ACL injuries. There is a possibility that the diagnostic accuracy for ACL injury differs between acute and chronic conditions because of the effects of signs and symptoms in acute conditions, such as pain, swelling, and hemarthrosis. Additionally, there has been no systematic review examining the diagnostic accuracy of these four physical examinations, including the lever sign test, in the same analysis, and the evidence for the efficacy of these tests for the diagnosis of acute ACL injury is limited. Clarifying the diagnostic accuracy of physical examination tests can help healthcare providers with the decision-making process in clinical practice.

Thus, this study aimed to perform a systematic review and meta-analysis of original research studies that involved the diagnostic accuracy of four physical examination tests for ACL injuries in acutely after an injury in adolescents and young adults.

MATERIALS AND METHODS

This study was conducted according to the Preferred Reporting Items for Systematic Review and Meta-analysis of Diagnostic Test Accuracy (PRISMA-DTA). The study protocol of this systematic review was registered in the University Hospital Medical Information Network (UMIN), the biggest registration system in Japan. The study approval number was UMIN000044766.

PHYSICAL EXAMINATION TESTS

This systematic review included studies evaluating the accuracy of four physical examination tests (Lachman, anterior drawer, pivot shift, and lever sign tests) in diagnosing ACL injuries. All tests are performed in the supine position. The Lachman test is performed with the knee flexed at 15°. The examiner stabilizes the distal femur with one hand and grasps the proximal tibia with the other hand. Then, the examiner applies an anterior tibial force to the proximal tibia. The anterior drawer test is performed with the knee flexed at 90°. The examiner sits on the patient’s foot and grasps behind the proximal tibia with the thumbs palpating the tibial plateau and index fingers palpating the tendons of the hamstring muscle group medially and laterally. The anterior tibial force is then applied by the examiner. In these two tests, a positive test for a torn ACL is indicated by greater anterior tibial displacement on the affected side when compared to the unaffected side. In the pivot shift test, the examiner stands on the side of the patient’s knee under examination. The examiner wraps one arm around the patient’s leg, pinning it firmly and flexing the knee to 90° while using the palm of the other hand to rotate the tibia medially, effectively subluxing the lateral tibial plateau. The examiner slowly extends the knee while maintaining the rotation of the tibia. As the patient’s knee reaches full extension, the tibial plateau relocates. A positive test traditionally is indicated by an audible or palpable click. In the lever sign test, the patient lies in the supine position with both legs fully extended. One fist of the examiner is placed under the proximal third of the calf of one leg. Then, with the other hand, a downward force is applied over distal third of the patient’s quadriceps of same leg. A positive test is indicated by a heel rise (Figure 1).
ELIGIBILITY CRITERIA

Studies were included in this review if they met the following inclusion criteria: (1) original articles in English or Japanese; (2) single-gate studies, such as prospective cohort and cross-sectional studies including acute settings; (3) reported findings that enabled the calculation of the number of true-positive (TP), true-negative (TN), false-positive (FP), and false-negative (FN) values for the test accuracy of index tests (the present study included articles that reported sensitivity, specificity, and prevalence to manually calculate TP, TN, FP, and FN if the study did not show specific numbers); (4) reported data on adolescents and young adults; (5) reported findings of partial or complete ACL injury; and (6) evaluated MRI and/or arthroscopy as the reference standard. Based on previous studies,1,7 the acute phase was defined as six weeks in this study. No limits regarding the date of publication were established, although the following types of studies were excluded: (1) participants who had undergone surgery in knee joints affected by ACL injury, (2) participants with other associated diseases such as osteoarthritis and meniscus injury, (3) diagnosis determined using questionnaires, (4) diagnosis determined using devices, and (5) participants who were diagnosed with laxity.

SEARCH STRATEGY

The languages used in the search were English and Japanese. The electronic search was conducted using the following databases: PubMed, Medical Literature Analysis and Table 1. Search strategy

<table>
<thead>
<tr>
<th>#</th>
<th>Query</th>
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<tr>
<td>#1</td>
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<tr>
<td>#2</td>
<td>Injury</td>
</tr>
<tr>
<td>#3</td>
<td>Rupture</td>
</tr>
<tr>
<td>#4</td>
<td>Tear</td>
</tr>
<tr>
<td>#5</td>
<td>#2 OR #3 OR #4</td>
</tr>
<tr>
<td>#6</td>
<td>&quot;Lachman test&quot;</td>
</tr>
<tr>
<td>#7</td>
<td>&quot;Pivot shift test&quot;</td>
</tr>
<tr>
<td>#8</td>
<td>&quot;Anterior drawer test&quot;</td>
</tr>
<tr>
<td>#9</td>
<td>&quot;Lever sign test&quot;</td>
</tr>
<tr>
<td>#10</td>
<td>#6 OR #7 OR #8 OR #9</td>
</tr>
<tr>
<td>#11</td>
<td>#1 AND #5 AND #10</td>
</tr>
</tbody>
</table>

The same approach was used for all searches and was adopted as necessary, according to the specifics of each database.

SELECTION OF THE STUDIES

First, duplicate studies were removed after searching databases. One evaluator (ST) read the titles and abstracts of the identified articles and excluded irrelevant studies. The full texts of the selected studies were evaluated, and the suit-
ability for inclusion was determined by two independent evaluators (ST and YI). Disagreements between evaluators were resolved by consensus. In cases in which no consensus was reached, a third evaluator (RT) was consulted to determine eligibility.

**RISK OF BIAS**

The methodological quality of the diagnostic studies was evaluated using the Quality Assessment of Diagnostic Accuracy Studies (QUADAS)-2 tool. This tool comprises four domains: patient selection, index test, reference standard, and flow and timing. Each domain of the QUADAS-2 was assessed in terms of the risk of bias and classified accordingly as low, high, or unclear by two independent evaluators, ST and RT. Applicability concerns of the three domains of the QUADAS-2, such as patient selection, index test, and reference standard, were assessed by ST and RT.

**STATISTICAL ANALYSIS**

To analyze the data, free software Meta-Disc version 1.4 was used. The statistical methodology was based on a previous study described by Devillé et al. Summary sensitivity, specificity, LR+, and LR− with 95% CI were calculated using random-effects models with the Der-Simonian and Laird method or fixed-effects models with the Mantel-Haenszel method, depending on the level of heterogeneity of the study. Data are presented as forest plots and summary receiver operating characteristic (SROC) curve plots. The percentage of variability was crossed using the chi-squared test (p < 0.10) and I² statistics. A random-effects model was used if the heterogeneity test showed statistical significance (I² > 50%, p < 0.01). Otherwise, a fixed effects model was used. In addition, the area under the curve (AUC) was calculated using 95% CI. A mean AUC-ROC value of > 0.70, was defined as an effective risk predictor.

**RESULTS**

A systematic electronic search of PubMed, MEDLINE, CINAHL, Web of Science, and Ichushi resulted in 3,836 studies. After duplicates were removed, 1,536 studies were included. The titles and abstracts of these studies were screened, and 86 full-text articles were evaluated for eligibility. Of the 86 articles, 40 were not applicable according to the study design, 14 did not describe test accuracy, 10 were review articles, eight articles did not use physical examination tests, and six articles did not include the acute phase. This, eight studies were included in this review. A summary of the literature search is shown in Figure 2. The characteristics of the included studies are summarized in Table 2.

A total of 620 participants were evaluated in the included studies. Six of the articles involved assessment using an index test by medical doctors, and two of the articles reported assessment using index test by physical therapists. The Lachman test was used in eight studies, the anterior drawer test in six studies, the pivot shift test in five studies, and the lever sign test in four studies. For the reference test, seven studies used MRI, one study used arthroscopy, and two studies used both MRI and arthroscopy. Index tests, which included the four physical examination tests of interest in this review, were performed while awake in four studies, under anesthesia in one study, and patient status was unclear in four studies (Table 2). In included studies, a test was considered positive if it met the following criteria: (1) > 1+ in the International Knee Documentation Committee parameters; (2) perceivable anterior subluxation of the tibia; (3) no positive endpoint to the subluxation of the knee in 10°–20° of flexion; and (4) the foot did not raise passively in the lever sign test.

The risk of bias assessment of the included studies is described under the headings of the QUADAS-2 assessment tool (Figure 3). For the patient selection domain, only one study had an unclear risk of bias because there was no information regarding consecutive sampling. For the index test domain, one study had a high risk of bias. This study did not state whether the index test was interpreted without the knowledge of the results of the reference test, and it was unclear how this study judged a positive result. For the domain of flow and timing, three studies had a high risk of bias because these studies did not assess the timing between reference and index tests. All applicability concerns in the three domains were judged to have a low risk of bias.

The sensitivity and specificity with 95% CI and forest plots for the four physical examinations for all included studies are shown in Figure 4. Pooled sensitivities for the Lachman, anterior drawer, pivot shift, and lever sign tests were 0.79 (95% CI = 0.74–0.83), 0.78 (95% CI = 0.73–0.83), 0.55 (95% CI = 0.49–0.60), and 0.82 (95% CI = 0.76–0.87), respectively. Pooled specificities were 0.91 (95% CI = 0.87–0.94), 0.91 (95% CI = 0.86–0.95), 0.96 (95% CI = 0.91–0.98), and 0.88 (95% CI = 0.82–0.95), respectively. Forest plots for LR+ and LR− are shown in Figure 5. The lever
Table 2. Summary of characteristics of the included studies

<table>
<thead>
<tr>
<th>Source (year)</th>
<th>No. of subjects</th>
<th>Male</th>
<th>Female</th>
<th>Age years mean (range)</th>
<th>Assessor</th>
<th>Anesthesia</th>
<th>Reference test</th>
<th>Index test</th>
<th>TP</th>
<th>TN</th>
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<td>58</td>
<td>44</td>
<td>23 (15-66)</td>
<td>Medical doctor</td>
<td>29 patients under anesthesia</td>
<td>MRI</td>
<td>Lachman test</td>
<td>40</td>
<td>56</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15 patients while awake</td>
<td></td>
<td>Anterior drawer test</td>
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<td>55</td>
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<td></td>
<td></td>
<td>MRI</td>
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<td>Pivot-shift test</td>
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<td></td>
<td></td>
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<td></td>
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<td>MRI</td>
<td></td>
<td>Lever sign test</td>
<td>28</td>
<td>52</td>
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<tr>
<td>Lee, 1988</td>
<td>79</td>
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<td>NA</td>
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<td>NA</td>
<td>MRI</td>
<td>Lachman test</td>
<td>67</td>
<td>30</td>
</tr>
</tbody>
</table>

TP, true positive; TN, true negative; MRI, magnetic resonance imaging.
sign test had the lowest LR− (0.21) and the pivot shift test had the highest LR+ (11.60). The SROC curves for the four physical examinations are shown in Figure 6. The AUC of the four physical examinations were > 0.70.

**DISCUSSION**

This systematic review included eight studies. The risk of bias of the included studies was evaluated using the QUADAS-2 tool. For the domains of patient selection, the index test, and the reference standard, the risk of bias was low. For the domain of flow and timing, three studies were evaluated as having a high risk of bias because they did not assess the timing between the reference and index tests. The present study included two new studies that were not included in previous systematic reviews. Thus, this study provides additional evidence and emphasize the method healthcare providers should select for ACL injury diagnosis in an acute setting in adolescents and young adults.

The AUC values of the Lachman, anterior drawer, pivot shift, and lever sign tests were large enough (0.9270, 0.9193, 0.8910, and 0.9038, respectively) for the physical examination tests to be considered effective in diagnosing ACL injuries. Furthermore, the pooled sensitivity was highest in the lever sign test, and the pooled specificity was highest in the pivot shift test. The lever sign test had the lowest LR− (0.21) and the pivot shift test had the highest LR+ (11.60). In general, LR+ above 10 and LR− below 0.1 are considered to provide strong evidence to rule in or rule out diagnoses, respectively, under most circumstances. Based on the results, the lever sign test is useful to rule out among the tests, and the pivot shift test is useful to confirm an ACL injury in an acute setting.

Previous systematic reviews have assessed the diagnostic accuracy of physical examination tests for ACL injuries. In a previous systematic review in 2016, it was elucidated that the pivot shift test was the most specific, showing a pooled specificity of 97.5% (95% CI = 0.95–0.99), and had the highest LR+ of 16.00 (95% CI = 7.34–34.87). Reiman et al. conducted a systematic review of diagnostic accuracy regarding the lever sign test and found that LR+ and LR− were 9.2 (95% CI = 0.70–46.1) and 0.58 (95% CI = 0.18–1.28), respectively. This study supports these findings, and the pivot shift and lever sign tests are proficient tools for the diagnosis of ACL injuries in acute settings. Although LR+ and LR− are sufficient to diagnose ACL injuries, it is difficult to make a complete diagnosis using a single physical examination test. Therefore, a combination of these four physical examination tests with high diagnostic accuracy may help reduce the number of incorrect diagnoses in clinical practice.

Among the four physical examinations, the lever sign test was introduced as a new physical examination test in the 2010s. This test is relatively easy to perform and requires less examiner strength than the other three commonly used tests. The lever sign test uses the common force of gravity instead of relying on the sensation of the examiner, thus increasing test accuracy. The results of the current study revealed that the diagnostic accuracy of the lever sign test is favorable. Furthermore, Lichtenberg et al. examined the reliability of four physical examinations and indicated that the kappa values for the lever sign test were the highest among the physical examinations. This is a notable point for considering the use of the lever sign test in clinical practice.

This systematic review and meta-analysis have some limitations. First, this study searched for both English and Japanese articles in various databases; however, EMBASE, a database frequently used in other systematic reviews, could not be used. Furthermore, this systematic review focused only on diagnosis in acute conditions and excluded chronic conditions; thus, only eight studies were included. There may be a difference in the included studies and results between other systematic reviews and those in the present study. Additionally, this study did not include subjects with meniscal injury and laxity. These factors may limit the generalizability of the results. Second, this systematic review did not consider the relationship between anesthesia and test result, and included patients with complete or partial...
Lachman test

Anterior drawer test

Pivot shift test

Lever sign test

Figure 4. Forest plots of sensitivity and specificity
Lachman test

Anterior drawer test

Pivot shift test

Lever sign test

Figure 5. Forest plots of positive/negative likelihood ratio
ACL injuries. In particular, anesthesia might be related to test accuracy due to complete relaxation of the patient. Therefore, clinicians should be cautious about its clinical applications. Additionally, two types of reference standards, MRI and arthroscopy, were used, which may have led to mixing bias.

CONCLUSION

The AUC of the Lachman, anterior drawer, pivot shift, and lever sign tests suggests high accuracy for use of each in the diagnosis of ACL injury. The lever sign test had the lowest LR− and the pivot shift test had the highest LR+. Thus, the lever sign test is recommended to rule out among the tests, and the pivot shift test is recommended to confirm an ACL injury in an acute setting.

COI STATEMENT

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International Journal of Sports Physical Therapy
REFERENCES


*International Journal of Sports Physical Therapy*
Introduction

Collegiate athletes who suffer a concussion may possess prolonged impairments even after clearance for return-to-participation, which may place them at an increased risk of lower extremity injury.

Objective

To conduct a systematic review and meta-analysis of studies examining risk of lower extremity musculoskeletal injury following a concussion in collegiate athletes.

Methods

A literature search was performed using the following databases: PubMed, CINAHL, SPORTDiscus. The following search terms were used to identify relevant articles, ["concussion" OR "brain injury" OR "mild traumatic brain injury" OR "mTBI"] AND ["lower extremity injury" OR "musculoskeletal injury"]. Articles were included if they were published between January 2000 and July 2021 and examined collegiate athletes’ risk of sustaining a lower extremity musculoskeletal injury following a concussion. Methodological quality of included studies was performed with a modified Downs and Black Checklist. The primary outcome of interest was the risk of sustaining a lower extremity musculoskeletal injury following a concussion. A random effects meta-analysis was conducted in which a summative relative risk (RR) for sustaining a lower extremity injury in athletes with and without a history of concussion was calculated.

Results

Seven studies met the eligibility criteria to be included in the systematic review. There were 348 athletes in the concussion group and 482 control athletes in the included studies. Most of the studies were of good or excellent quality. Five of the seven studies were able to be included in the meta-analysis. College athletes who suffered a concussion possessed a 58% greater risk of sustaining a lower extremity musculoskeletal injury than those who did not have a history of a concussion (RR = 1.58[1.30, 1.93]).

Conclusions

Lower extremity injury risk is potentially increased in college athletes following a concussion compared to those without a history of a concussion. Further research is needed to investigate the mechanism behind this increased risk. Clinical assessments throughout the concussion return-to-play protocol may need to be improved in order to detect lingering impairments caused by concussions.

Level of Evidence

1
INTRODUCTION

Sport-related concussion has been defined as a traumatically induced alteration of mental status that may or may not involve loss of consciousness and usually results in impaired mental status, balance, and delayed reaction time. Conussions constitute between 3.65 percent and 13.1 percent of all sport-related injuries that occur while participating in collegiate athletics. There is also a percentage of concussions that go unreported and undiagnosed each year. Since a number of concussions go unreported, the true annual incidence is likely 40% higher because college athletes knowingly hide symptoms of their concussion and choose not to report it.

Many different assessment tools and techniques are used to assess and diagnose a concussion and determine readiness for return-to-play (RTP). Traditional evaluation methods, such as static balance tests, may have limited clinical utility for detecting certain physiological deficits concussion patients experience after RTP. While static and responsive balance control must be restored, many individuals recovering from a concussion display an initial improvement in postural sway during balance assessment, but then regress after RTP. Furthermore, college football players who sustained a concussion during a season exhibited decreased knee stiffness with increased hip stiffness when competing in athletic competition compared to those who did not experience a concussion. Higher levels of overall leg stiffness lead to increased loading rates, thus increasing the risk for bony injuries such as stress fractures, while too small an amount of stiffness may lead to excessive joint motion, thus increasing the risk for soft tissue injury. These findings raise concerns that athletes who are still experiencing deficits and impairments after being cleared to return to play from a concussion may be at increased risk of lower extremity injury.

Previous authors have investigated the effects of concussion on lower extremity musculoskeletal injury risk. McPherson et al. conducted a systematic review and meta-analysis of studies that have examined the risk of musculoskeletal injury following a concussion in recreational, high school, college, and professional athletes. This research identified that athletes with a concussion had approximately two times greater odds of sustaining a musculoskeletal injury as compared to controls. Reneker et al. also conducted a systematic review and meta-analysis of studies that have examined the risk of injury following a concussion in athletes. In both military and athletic populations, the risk of any type of injury following a concussion was approximately 2.5 times higher in individuals with a history of concussion than those without a history of a concussion.

While these systematic reviews offer valuable insights regarding connections between concussion and subsequent lower extremity injury, they are partially limited by their inclusion of broad spectrums of athletic populations and musculoskeletal injuries. It is difficult to group service members and college athletes into one cohort because individuals in the military setting may experience concussions or injuries from high-explosive blast forces, which is not an environment college athletes are exposed to. Prolonged military operations and exposure to improvised explosive devices (IEDs) blasts have led to significant increases in the incidence and prevalence of concussion in service members. Concussions were a predominant injury of the military operations in Iraq and Afghanistan, and the majority were blast related. A focus on a narrower patient population, such as collegiate athletes, would allow for a potentially more targeted application of findings clinically. Additionally, because neuromuscular control, sensory processing, and sensory information impairments persist after concussion, risk of subsequent lower extremity injury risk is of particular concern. Researchers have indicated that neuromuscular impairments occur following a concussion, including impairments in both gait and dynamic postural control. Thus, the risk of lower extremity injuries following concussion should be specifically examined. A preliminary literature search indicates that since the previous systematic reviews were published, new original research has been published that would support an updated systematic review with a narrower scope. Therefore, the objective of this study was to conduct an updated systematic review examining the risk of lower extremity musculoskeletal injury following a concussion in collegiate athletes.

METHODS

SEARCH STRATEGY

Guidelines established within the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement were followed throughout the review. A literature search was performed using the following databases: PubMed, CINAHL, SPORTDiscus. The following search terms were used to identify relevant articles, "concussion" OR "brain injury" OR "mild traumatic brain injury" OR "mTBI" AND "lower extremity injury" OR "musculoskeletal injury".

SELECTION CRITERIA

The following inclusion criteria was applied:

1. Prospective studies examining lower extremity injuries in populations with a previous concussion;
2. Study population consisting of college athletes;
3. Studies that calculated odds, risk, and/or ratio of sustaining a lower extremity injury after a concussion;
4. Studies published between January 2000 and July 2021;
5. Studies published in English;

The following exclusion criteria was applied:

1. Review articles.

A hand search of articles was performed to find additional eligible studies. References lists of included studies were reviewed.

ARTICLE SELECTION

To determine which articles were to be included in the systematic review, two authors reviewed the article titles and eliminated those that had no relevance to concussion or...
lower extremity injury. The reviewers then screened the remaining abstracts and eliminated articles that were irrelevant to the systematic review’s topic. Remaining studies’ full text were read and assessed by both investigators, and those that met the inclusion criteria were included in the systematic review. In the case reviewers did not agree, a consensus was reached through discussion. If a consensus was not made, a third reviewer provided the tiebreaker.

QUALITY ASSESSMENT

Included studies were assessed for methodological quality using the Downs and Black Checklist.25 The Downs and Black Checklist was modified prior to quality assessment to eliminate items that were irrelevant to studies within the selection criteria. Items pertaining to study bias and internal and confounding bias, such as items 8 and 16, were removed. Additionally, items referring to follow-up, patient compliance, randomization, and blinding, including items 9, 14, 15, 19, 23, and 26, were removed. The maximum score of the modified Downs and Black Checklist was 19. All studies were assessed independently by two reviewers. In the case reviewers did not agree on initial rankings, a consensus was reached through discussion. If a consensus was not made, a third reviewer provided the tiebreaker.

DATA EXTRACTION

Sample sizes, participant demographics, participant inclusion and exclusion criteria, quantities of concussion and lower extremity injury cases, length of injury tracking period, and primary results were extracted from each study. Data were extracted regarding the risk of sustaining a lower extremity musculoskeletal injury following a concussion.

META-ANALYSIS

Review Manager software (RevMan, v 5.3; The Nordic Cochrane Center, The Cochrane Collaboration, 2014) was used to perform the meta-analysis. A random-effects meta-analysis produced a pooled relative risk (RR) calculation and 95% confidence interval (CI) that represented the overall results for the studies that provided data that allowed for calculation of relative risk. The relative risk was calculated by using the following formula:

\[
\text{Relative Risk} = \frac{[(\text{number of individuals with a history of concussion who suffered a lower extremity injury}/\text{total number of individuals with a history of concussion})/\text{(number of individuals who suffered a lower extremity injury without a history of a concussion}/\text{total number of individuals without a history of concussion})].}
\]

A relative risk value greater than one indicates that the odds of an athlete suffering a lower extremity musculoskeletal injury with a history of concussion is greater compared to those athletes with no history of concussion.26 A relative risk value less than one indicates that the odds of an athlete suffering a lower extremity musculoskeletal injury with a history of concussion is lower compared to those athletes with no history of concussion.26 The 95 percent CIs were used to determine the statistical significance of the difference in risk; if the CI crosses one, then it is not considered statistically significant. Heterogeneity of studies included in the meta-analysis was examined using the Q statistic. If the Q statistic was found to be significant, study variables that could potentially introduce heterogeneity were further analyzed. No further analysis was conducted if the Q statistic was not found to be significant. The study variable that was analyzed was the injury tracking timeline. The injury tracking timelines took place within the first 90 days of RTP and after one year of RTP.

RESULTS

A total of 2,873 studies were identified in the initial database search. The hand search process did not yield any additional results. Duplicates were removed and 2,644 articles were identified for assessment of the title. Following removal of articles with titles that had no relevance or concussion or lower extremity injury, 27 articles remained. Once abstracts and full texts were reviewed by the two authors, seven articles met the inclusion criteria for the systematic review. With the application of inclusion and exclusion criteria, seven eligible studies were included in the systematic review. Results of the literature search are shown in Figure 1. Study characteristics are reported in Table 1.

QUALITY ASSESSMENT

The scores of quality assessment of the included articles ranged from 11 to 18, with five27–31 of the studies scoring 15, 17, or 18. Scores between 16 and 19 were considered excellent quality, scores between 12 and 15 were considered good quality, scores between nine and 11 were considered fair quality, and scores less than nine were considered poor quality. These scores indicate that most of the studies were of good or excellent quality. Some of the reasons for the high-quality scores include clearly describing the study objective, outcome measures, and results, providing the actual probability values, choosing individuals who were representative of the desired population, and matching individuals to controls of the same population. Even though healthy, non-concussed controls were matched for potential confounding factors (i.e., sex, sports, position) in five studies,27–31 two27,28 reported that exposure levels may have not been the same between the concussed athlete group and the matched controls. Sample sizes of the concussed athlete group ranged between studies, ranging from 1227 to 36432 athletes.

DEMOGRAPHIC DATA

Participants in two28,30 studies were of one sex. Of the remaining five studies, four27–29,33 provided a sex breakdown of the two groups. Of those studies, there were 265 male and 83 female athletes in the concussion groups while there were 349 male and 153 female athletes in the control groups.27–29,33 Sport and participation levels for each study are included in Table 1. Six27–32 studies provided the sports in which the athletes from the concussion group participated. Not all sports were analyzed amongst the studies; the sports frequently investigated were football, men’s and
women’s soccer, men’s and women’s basketball, and swimming. Other sports investigated include hockey, wrestling, volleyball, baseball, softball, tennis, cheerleading, golf, field hockey, and rowing. Control athletes, when implemented, were matched by sport and sex. Some studies matched athletes by exposure and position as well.27,28,31,32 Lynall et al.32 further matched concussed athletes to control athletes by age, height, and weight. As for the lower extremity injury time tracking period following concussion, three studies27–29 tracked concussion patients for 90 days after their concussion, one32 reviewed the injury history of the concussed individuals until the end of their intercollegiate athletic career, and another study31 looked at the time before and after 90 days, 180 days, and 365 days of the concussion. Overall, there was a wide variety of inclusion and exclusion criteria for classifying musculoskeletal injuries. The variability of classification of lower extremity injuries amongst the studies may contribute to the different relative risk and results of each. Herman et al.29 found that the odds of sustaining a lower extremity musculoskeletal injury were 3.39 times higher in concussed college athletes, which was the largest odds ratio of all the studies investigated. Two studies30,31 found that individuals with a history of a concussion displayed higher lower extremity injury rates than the control group after 365 days following RTP from a concussion. It was shown that individuals with a history of a concussion were at increased risk of lower extremity musculoskeletal injury27,28,33; and the odds of sustaining a lower extremity injury during the first 90 days of RTP were 2.48 times higher in individuals with a history of concussion compared to those with a history of concussion.27 Furthermore, the odds of experiencing a lower extremity injury were 3.00 times higher in individuals with a history of multiple concussions compared to individuals with a history of a single concussion or no concussion history at all.32

INDIVIDUAL STUDY RESULTS

META-ANALYSIS

Meta-analysis of relative risk was performed using five27–30,32 of the seven studies. In the studies that provided sufficient information to perform calculations, the
Table 1. Study Characteristics

<table>
<thead>
<tr>
<th>Authors</th>
<th>Concussed Athletes</th>
<th>Control Athletes</th>
<th>Quality (Downs and Black)</th>
<th>Inclusion Criteria</th>
<th>Exclusion Criteria</th>
<th>Inclusion Criteria for MSK Injury</th>
<th>Exclusion Criteria for MSK Injury</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brooks et al., 2016</td>
<td>75 (58 male, 17 female)</td>
<td>182 (136 male, 46 female)</td>
<td>17/19</td>
<td>1) All athletes who sustained a concussion during athletic play were diagnosed with a concussion by a team physician 2) athletes who participated in games and practices for a minimum of 72 days (80%) of the 90-day period after RTP 3) athletes with complete medical records regarding diagnosis and RTP date</td>
<td>1) If athletes sustained a second concussion within the 90-day period after RTP 2) If a non-MSK injury, an UE injury, or illness was sustained that limited their sport participation for greater than 18 days (20%) of the 90-day period; 19 cases of concussion excluded</td>
<td>As non-contact acute fractures, muscle strain/tears, or ligament sprains or ruptures of the hip, groin, thigh, knee, shin, ankle, or foot</td>
<td>Contusion, stress fracture, abrasion, overuse injury, and other non-MSK injury</td>
<td>Incidence rate of MSK injury during 90-day period after RTP was higher in concussed athletes (17%) compared with matched controls (9%). Odds of sustaining a LE MSK injury were 2.48 times higher in concussed athletes than in controls</td>
</tr>
<tr>
<td>Fino et al., 2019</td>
<td>110 (76 male, 34 female)</td>
<td>110 (76 male, 34 female)</td>
<td>18/19</td>
<td>Concussion initially suspected by an athletic trainer and later diagnosed by a team physician</td>
<td>Previous concussion within 2 years, subsequent concussion within 365 days, incomplete medical record, or discontinued participation on athletic team; 46 cases excluded</td>
<td>Any acute injury (sprain, strain, contusion, or unspecified acute pain of the LE that required medical attention and were documented in the athlete’s electronic medical record; Included LE injuries in the 365 days preceding concussion and 365 days after concussion</td>
<td>None</td>
<td>Concussed group had a 67% greater relative risk of LE injury compared with controls after adjusting for presence of a previous LE injury</td>
</tr>
<tr>
<td>Harada et al., 2019</td>
<td>48 multiple concussion cases, 48 single concussion cases (all male)</td>
<td>48 male</td>
<td>16/19</td>
<td>MC were defined as any athlete sustaining 2 or more concussion in collegiate career</td>
<td>If athletes had incomplete roster or injury information</td>
<td>Not specified</td>
<td>Not specified</td>
<td>Athletes with MC were found to have a significantly greater odds of LE injury and shorter time to LE injury than matched SC and NC controls</td>
</tr>
<tr>
<td>Herman et al., 2017</td>
<td>73 (52 male, 21 female)</td>
<td>148 (106 male, 42 female)</td>
<td>15/19</td>
<td>Athletes with an in-season concussion as diagnosed by the university primary care sports medicine-certified physician</td>
<td>1) If they had a history of concussion within the prior 6 months, 2) the concussion occurred outside the competitive season, 3) player had time</td>
<td>Time loss injury (athlete being withheld from competition for at least 1 day); defined as a strain, sprain, dislocation, or rupture</td>
<td>Overuse injuries, fractures, or contusions</td>
<td>Concussed athletes had a 3.39 times greater risk of muscle strains or tears or ligament sprains/ruptures in...</td>
</tr>
<tr>
<td>Authors</td>
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<tr>
<td>Lynall et al., 2015</td>
<td>44</td>
<td>58</td>
<td>17/19</td>
<td>Concussion diagnosed by the university’s sports medicine staff</td>
<td>If concussion resulted in any positive imaging findings, if participant was admitted to the hospital, if participants sustained a previous concussion while at the university, if no appropriate matched control could be identified, or if there were incomplete notes in the athlete's medical record</td>
<td>Any injury recorded by a certified AT or team physician in the athlete's medical record</td>
<td>Not stated</td>
<td>College athletes are almost twice as likely to suffer an acute LE MSK injury after concussion</td>
</tr>
<tr>
<td>Krill et al., 2018</td>
<td>12</td>
<td>25</td>
<td>15/19</td>
<td>Not stated</td>
<td>Not stated</td>
<td>1) Occurred as a result of participation in an organized intercollegiate practice or contest, 2) required medical attention by a team certified athletic trainer or physician, and 3) resulted in restriction of the student-athlete's participation or performance for &gt; or equal to 1 calendar day beyond the day of injury; included contusion, strain, sprain, stinger or brachial plexopathy, dislocation, or rupture</td>
<td>Not stated</td>
<td>Not a clear increase in LE injury after an athlete sustains a concussion. However, there was an overall increase in the post-concussion group’s LE injury rate for the time period beyond 12 months after a concussion was sustained compared with the control group</td>
</tr>
<tr>
<td>Murray et al.,</td>
<td>42 (31 male, 11)</td>
<td>42 (31 male, 11)</td>
<td>13/19</td>
<td>Athletes with complete and available medical</td>
<td>If athlete possessed any self-reported vestibular,</td>
<td>Soft tissue injury or a fracture to the hip, groin, thigh, knee, lower</td>
<td>Chronic injury.</td>
<td>The association between</td>
</tr>
</tbody>
</table>

*The Effect of Concussion History on Lower Extremity Injury Risk in College Athletes: A Systematic Review and Meta-Analysis*
<table>
<thead>
<tr>
<th>Authors</th>
<th>Concussed Athletes</th>
<th>Control Athletes</th>
<th>Quality (Downs and Black)</th>
<th>Inclusion Criteria</th>
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<th>Exclusion Criteria for MSK Injury</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>female)</td>
<td>female)</td>
<td></td>
<td>records with a history of a medically diagnosed concussion</td>
<td>metabolic, or neurologic condition (excluding concussion), chronic injury that may have caused an individual to miss at least 3 months of sport play, preexisting condition, or a severe LE injury that permanently affected the ability to perform upright static stance</td>
<td>leg, ankle, or foot area</td>
<td>contusion, abrasion, and laceration</td>
<td>concussion history and injury incidence was significant and resulted in a relative risk of 1.88 for a lower extremity injury in individuals with a history of a concussion</td>
</tr>
</tbody>
</table>

MSK = musculoskeletal
RTP = return-to-play
UE = upper extremity
LE = lower extremity
NC = no concussion
SC = single concussion
MC = multiple concussions
AT = athletic trainer
risk of athletes sustaining a lower extremity musculoskeletal injury after a concussion was compared with athletes sustaining a lower extremity injury who did not have a history of a concussion. Studies were not included in the meta-analysis portion if the data was insufficient for calculating relative risk. Overall, athletes who sustained a concussion had greater risk of lower extremity musculoskeletal injury compared to athletes without a history of a concussion (RR = 1.58 [1.30, 1.93]) (Figure 2). Positive tests of heterogeneity were detected within comparisons of injury tracking timelines amongst the studies (Q = 11.46, p = 0.02). Subgroup analysis of injury tracking timelines revealed that the risk of lower extremity injury is particularly elevated within the first 90 days of RTP following a concussion (RR = 2.20 [1.58, 3.05]), but it is not significantly elevated one year after RTP (RR = 1.26 [0.98, 1.61]).

DISCUSSION

This systematic review and meta-analysis revealed that individuals are at greater risk of sustaining a lower extremity musculoskeletal injury following a concussion compared to individuals without a history of concussion. College athletes who suffered a concussion possessed a 58% greater risk of sustaining a lower extremity musculoskeletal injury than those who did not have a history of a concussion. The overall duration of this increased risk is unknown, but this risk may last up to one year from injury. The detection of heterogeneity reveals that the small sample of studies varied in their findings. The sub-analysis revealed that college athletes with a history of concussion appear to be at increased risk of lower extremity injury within the first 90 days of RTP, but not at the one-year mark. Injury risk does not appear to remain elevated in spite of evidence that motor impairments persist. The neuromuscular control deficits that individuals experience following a concussion may not be as severe, or even present, at the one-year mark compared to during the first 90 days. The ability of the neuromuscular control system to respond to disturbances may improve over time, but further research would need to be conducted to verify this hypothesis and determine an average timeline for recovery of these deficits.

These findings suggest that it is important to evaluate these individuals at different time points following RTP. It is not common to re-evaluate individuals who have been cleared to return to sport following a concussion. The findings suggest that re-evaluation may be beneficial and could possibly reduce future injury risk. Even though athletes are no longer experiencing concussion-like symptoms, they may still be experiencing motor abnormalities following return to play. However, these abnormalities may not be detected if the individuals are not re-evaluated.

This systematic review expands on the review performed by McPherson et al. by including three additional studies published since the publication of their research. One of these studies was included in the current meta-analysis. With the addition of the one study, the meta-analysis revealed similar results to the one performed by McPherson et al. Thus, this systematic review further emphasizes that collegiate athletes who have suffered a concussion are at increased risk of lower extremity injury compared to those without a history of concussion.

This meta-analysis strictly examined intercollegiate athletics; whereas the meta-analysis performed by McPherson et al. examined professional, recreational, and intercollegiate athletes. The included recreational athletes spanned from 18 to 29 years of age, which may serve as a confounding factor for the increased injury risk. Older individuals...
generally possess decreased musculoskeletal strength compared to younger individuals, which may serve as a risk factor for future injury.\textsuperscript{56} On the other hand, an increase in the number of years of experience in a specific sport may reduce an individual’s injury risk because they are an “expert” with better movement patterns and biomechanics.\textsuperscript{57} The meta-analysis performed in the current study included articles with a specific population, one of strictly college athletes. Since male college athletes were more frequently represented in the included articles, the findings are most applicable to this population. It is difficult to make a determination about the effects of concussion on lower extremity injury risk for males and females of different age groups.

The mechanism behind the increased risk of experiencing a lower extremity musculoskeletal injury is not yet fully understood, but several potential explanations exist. One explanation, which was not assessed in this study, is that a previous history of lower extremity musculoskeletal injury may place these individuals at increased risk of suffering a future injury. It has been shown that previous injury serves as a risk factor for future musculoskeletal injury.\textsuperscript{38,39} Strength imbalances between muscles have been suggested as risk factors for lower extremity injuries, and may be a consequence of a previous injury.\textsuperscript{38} Muscle imbalances may affect the efficiency of movements that involve quick accelerations and decelerations, which are common actions in athletics.\textsuperscript{38}

Concussions can involve multiple and varied regions of the brain, including those associated with orienting and executive components of visuospatial attention.\textsuperscript{40} The regions of the brain that are responsible for these attentional networks include the parietal, frontal, and temporal regions, the cingulate cortices, and the midbrain.\textsuperscript{41} When one suffers a concussion, these regions may become damaged or impaired, which compromises the ability to process stimuli in terms of disengagement, movement, and re-engagement.\textsuperscript{52} Even after classic concussion symptoms resolve, there is a possibility that neural and neuromuscular impairments are still present. There is ongoing research in this area that has revealed that individuals continue to experience neuromuscular, neurocognitive, sensory processing, and balance deficits related to concussion well after RTP.

Research has indicated that degradation of neuromuscular control, sensory processing, and sensory information can lead to increased injury risk.\textsuperscript{31,32} With regions of the brain associated with the executive components of visuospatial attention being most susceptible to damage following a concussion, individuals may possess deficits in processing important information while ignoring extraneous stimuli.\textsuperscript{35,40} Reduced speed of response to peripheral visual stimuli after concussion may negatively affect anticipatory muscle activation that relies on peripheral visual awareness.\textsuperscript{43,44} If individuals utilize improper or delayed muscle contractions, they may perform movements that place them in vulnerable positions, which could potentially increase their risk of musculoskeletal injury.

Which specific deficits and how they interact within the individual to increase injury risk has not yet been determined. It has been shown that neuromuscular impairments are risk factors for future injury\textsuperscript{45,46}; and with individuals still experiencing such deficits after return to activity, they may be influential risk factors for sustaining a future musculoskeletal injury.\textsuperscript{35}

Research has shown that individuals still experience lingering gait deficits, including decreased gait speed, cadence, and stride length during dual-task activities following resolution of concussion symptoms.\textsuperscript{19,47} When these impairments are linked with dual-task conditions, athletes may not be able to coordinate or focus as easily as they were able to prior to their concussion. The addition of a cognitive load may further compound the neurocognitive deficits these individuals already possess and experience. This may lead them to compensatory movement patterns that place stress on body structures that are unable to support this force, and thus make the individual more susceptible to injury. Research indicates that concussed individuals change their gait strategy by spending more time in double-leg stance compared to single-leg stance and possess lower mean gait velocity at 72 hours post-injury compared to non-concussed athletes.\textsuperscript{48,49} Furthermore, research has shown that individuals with a history of a concussion possess gait abnormalities up to 90 days following a concussion.\textsuperscript{50,54} With these individuals possessing an altered gait strategy days or weeks after experiencing a concussion, this may serve as a possible indication of the systems of movement that continue to be affected by the injury.

Another possible explanation for the increased injury risk is that individuals with a history of concussion may adopt new movement patterns,\textsuperscript{22} which may help them “pass” the clinical assessments, such as static balance tasks, in the RTP concussion protocol. It has been suggested that individuals with a history of a concussion maintain upright posture by using more top-down control than bottom-up control compared to individuals without a history.\textsuperscript{33} Even though the athletes are able to complete the clinical evaluation, it does not necessarily mean that they performed it with the same skill level or motor strategies prior to their concussion. Stride length during gait is significantly shorter for up to 14 days after concussion with a dual-task condition compared to a single-task condition, and gait velocity is significantly slower for up to 28 days post-injury with a dual-task condition compared to a single-task condition.\textsuperscript{52}

Concussed athletes also demonstrate lasting balance impairments following RTP, particularly deficits in dynamic balance.\textsuperscript{48,50,51,53–55} Authors have shown that athletes with a history of a concussion, upon RTP, are able to perform static balance tasks without any difficulty, but struggle to perform dynamic balance tasks.\textsuperscript{56} Reduced balance performance indicates that an individual is less capable of responding to perturbations and sensing their body’s position in space, potentially leading to mispositioning of the lower extremity. Thus, a balance deficit can place athletes at an increased risk of sustaining an injury. Reduced single-leg balance performance is associated with eight times greater risk of ankle sprain injury.\textsuperscript{57,58} Returning to baseline values for single-leg balance is an assessment that may not be sensitive enough to detect lingering impairments in concussed athletes.
FUTURE DIRECTIONS

Healthcare professionals should be aware that collegiate athletes are at increased risk for lower extremity musculoskeletal injury following a concussion, even after being cleared for RTP. Many of the RTP concussion protocol tests are important, but some are subjective, such as the symptom checklist. Research has suggested that current concussion evaluation methods may not possess sufficient sensitivity to detect any lingering concussion-related abnormalities that persist after symptom resolution.59,60 Research should work to identify new methods to evaluate athletes during the RTP concussion protocol to ensure that they are fully prepared to return to their sport and are not experiencing subtle or lingering deficits when returning to participation. It also needs to be determined which lingering deficits or impairments are the cause of this increased risk of injury. If a history of concussion is the factor responsible for increasing the injury risk in these athletes, future research should look to further investigate the neuromuscular changes that are brought about by concussions. Per the sub-analysis findings, it is also important to evaluate college athletes at different time points following RTP after a concussion.

Finally future research can place a larger focus on female collegiate athletes and examine the effect of concussion on lower extremity injury risk on these individuals. Studies can also investigate the effect of concussion in other populations, such as athletes in the secondary school setting and those in recreational or community leagues.

LIMITATIONS

This systematic review had a few limitations. Even though the concussed athletes were matched with control groups by sport and position, there are other factors, such as behavior or personality traits of the athletes that could have affected the results.32 If an athlete is more aggressive or partakes in riskier athletic behavior, it may place that athlete at a higher risk of sustaining a musculoskeletal injury.52 Many different sports were explored in each study, thus limiting the ability to draw conclusions regarding the effect of concussion on lower extremity injury risk in specific sports. Not all studies examined athletes of both sexes, making it difficult to make a determination about the effect of concussion on lower extremity injury risk for males and females separately. Another limitation is that the criteria for classifying a lower extremity musculoskeletal injury differed across studies. This could affect the injury risk reported in the included studies, as some studies may have included an injury that another study excluded.

CONCLUSION

The results of this systematic review and meta-analysis indicate that history of a concussion appears to increase the risk of suffering a lower extremity musculoskeletal injury in college athletes. Although not statistically significantly different, following RTP, increased risk is strong at three months post-concussion, but not at one year. Further research is needed to explore and determine the neuromuscular mechanism behind this increased risk of injury and to develop return-to-play criteria that are capable of identifying those at increased risk of lower extremity injury after concussion.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

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A Systematic Review of the Effectiveness of Core Stability Exercises in Patients with Non-Specific Low Back Pain

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Keywords: Core stabilization exercise, lumbar stabilization, low back pain, nonspecific

Background
Low back pain affects millions of people worldwide and can be a difficult condition to manage clinically. Many cases do not have a discernable etiology, further increasing the complexity of finding an effective intervention. Core stabilization exercises (CSE) strengthen the musculature that provides stability to the spine and show promising outcomes.

Purpose
To examine the efficacy of CSE exercises in the treatment of NSLBP in adult patients.

Study Selection
Studies were included if they had patients diagnosed with NSLBP, used CSE as a treatment for NSLBP, and were a clinical trial. Exclusion criteria were studies that did not utilize an objective pain scale, patients who had a specific diagnosed pathology contributing to the NSLBP or received treatment for their NSLBP within the prior six months.

Methods
The literature was systematically searched in the PubMed, Sports Medicine & Education Index, and CINHAL databases, using the search terms core stabilization, low back pain, and exercise. The initial search yielded 229 articles and was refined using search terms 'NOT analysis' in order to target randomized control trials and exclude meta-analyses to narrow the search. Full-text of the articles were assessed for eligibility by utilizing inclusion and exclusion criteria that were included in this review. Articles were assessed for quality using the PEDro scale and relevant data were extracted.

Results
Five moderate-quality studies (PEDRO range: 5-8) support CSE is an effective method to decrease pain, improve functionality, and increase core strength in patients with NSLBP. Although there are other commonly used methods to treating NSLBP, CSE have shown to be a beneficial method to treating NSLBP.

Conclusion
Grade B evidence suggests core stabilization exercises can be considered a favorable method for treating pain in patients with NSLBP.

Level of Evidence
1b
INTRODUCTION

Low back pain (LBP) is a debilitating condition that can affect anyone, from the most talented athletes to those beginning to learn fundamental movement skills.\(^1\) It is estimated that two thirds of adults will have been or will be affected by NSLBP at some point in their life.\(^2,3\) This condition can cause a person to have poor performance in their occupation, sport, or activities of daily living (ADLs) as it limits their ability to maintain basic movement mechanics to ensure optimal performance. LBP can be defined as any painful stimulus in the region between the floating ribs and the gluteal folds that can cause common or even debilitating conditions with or without leg pain.\(^4\) LBP can be specific or nonspecific, however only approximately 10% of LBP is actually specific and has a clear answer as to why the pain is present, leaving the remaining 90% as NSLBP.\(^4\)

While the etiology of LBP is still debated, it is thought that the pain arises from several different factors depending on whether it is specific or nonspecific. Specific LBP will have a diagnosed pathology such as a muscular strain, infection, fracture, or a spinal disease.\(^5\) On the other hand, NSLBP has no definitive pathology regarding what is causing the pain but has been theorized to be caused by factors including poor posture, impaired flexibility, previous history of injury, heavy lifting, mental pain, and obesity.\(^5,6\) Other potential causes of NSLBP are also common impairments identified in patients, such as deep trunk muscle weakness, poor coordination, and muscular imbalances.\(^6\)

The treatment approach to manage NSLBP varies depending on clinician and patient tolerance.\(^7\) Common treatments have similar goals, as massages aim to promote relaxation of the musculature, while modalities can be used to decrease pain levels. Treatment approaches including massage, medication, and modalities have demonstrated short-term effects of reducing pain.\(^5,8\) Each of these management strategies requires specific equipment, recurring healthcare visits, or prescriptions. Additionally, treatment frequency may influence the patient’s financial burdens and a feeling of dependence on the provider and the services provided.

While debate remains surrounding the best management strategy, staying physically active has positive effects in decreasing NSLBP.\(^9\) Using exercises to activate and strengthen the core (i.e. CSE) have shown to be a promising method for treating NSLBP.\(^4,6,10,11\) The goal of CSE is to improve and recover the ability to control the spine.\(^8\) This approach is geared towards reeducating deep trunk muscle function, and coordination of deep and superficial trunk muscles during static, dynamic, and functional tasks.\(^4\) CSE place focus on the core musculature that includes the transverse and rectus abdominis, the internal and external obliques, paraspinals, as well as musculature of the gluteals, pelvic floor, and hip. A CSE program may promote patient independence with a home exercise program (HEP). Subsequently, CSE may also represent a cost-effective approach for patients to manage their NSLBP after initial treatments. Allowing a patient who has NSLBP to better manage their own symptoms after rehabilitation sessions and become self-sufficient which may decrease reliance on healthcare providers.

The purpose of this systematic review is to examine the efficacy of CSE in the treatment of NSLBP in adult patients.

METHODS

SEARCH STRATEGY

The electronic databases of PubMed, Sports Medicine & Education Index, and CINAHL were accessed on January 20, 2022, to find previous research on the effectiveness of CSE in patients with NSLBP. The search terms utilized were “core stabilization”, “low back pain”, and “exercise”. To funnel the search, “trial” and “NOT meta-analysis” were added in order to target RCTs and reject meta-analyses, in addition to utilizing the inclusion and exclusion criteria to eliminate any meta-analysis and include only clinical/controlled trials.

INCLUSION AND EXCLUSION CRITERIA

A manual review of the remaining article titles and abstracts was performed by two independent reviewers (ZRS, SLW) to exclude non-relevant articles. Consensus was reached on all articles meeting the a priori criteria before methodological quality assessment and any disagreements were resolved by a third party (CJB). For an article to be included, it must have: 1) included patients between 18-64 years old; 2) patients with NSLBP; 3) used CSE as an intervention; 4) been written in English. Exclusion criteria for articles included: 1) studies with patients who had previously diagnosed or current specific spinal pathology; 2) studies with patients who had received other treatment for their NSLBP within the prior six months; 3) studies that did not incorporate a pain scale.

ASSESSMENT OF METHODOLOGICAL QUALITY

Each of the articles was assessed for quality using the PEDro scale. The PEDro scale is an article rating system used to help determine the validity of studies based on work by Verhagen and colleagues.\(^12\)

RESULTS

The results of the search can be found in Figure 1. The initial search yielded 229 articles which were screened for further inclusion. Additional search terms were included to identify only clinical trials and exclude reviews leading to a total of 83 articles. After full text review, five studies remained that fit the inclusion and exclusion criteria and were used for this systematic review.

METHODOLOGICAL QUALITY

Two independent reviewers (ZRS, SLW) separately assessed each article for quality using the PEDro scale. The PEDro scores for the five studies had a mean value of 6.40, with a range from 5 to 8 (Table 1). All five studies were unable to blind the subjects or therapists due to the nature of the study itself. Another common limitation was not employing an intent-to-treat analysis. The research identified consis-
tent, moderate-quality evidence supporting the efficacy of CSE in people with NSLBP. This would be considered grade B using the strength of recommendation taxonomy.

SYNTHESIS OF RESULTS

Five RCTs were included in this systematic review that included total of 275 patients ranging from ages 18-60, with a total of 125 patients receiving a CSE treatment compared to either a control group or another intervention (Table 2). Four of the five studies used pressure feedback and used the Visual Analog Scale (VAS) for pain,4,10,11,13 with Areeudomwong and colleagues using the Numerical Rating System (NRS) for pain.6 Both pain scales have been seen to be reliable and effective measures of rating pain.14

Akhtar et al. compared CSE versus general physical therapy (PT) exercises in the treatment of NSLBP.4 The treatment of the CSE group aimed at targeting deeper muscles of the abdominals, including transversus abdominis and multifidus, which was combined with tactile feedback. The routine PT group did not use any biofeedback and their intervention consisted of flexibility exercises. In the comparison group, subjects were given baseline ultrasound and TENS treatment in addition to performing exercises three times a week for six weeks, one day a week with a physical therapist and the other two days using a HEP. The researchers concluded both techniques proved to be effective in managing LBP, but CSE displayed greater reductions in pain scores compared to general PT, with a mean VAS change of 3.08 (CSE) vs 1.71 (PT group).4

Bhaduria and Gurudutt compared lumbar stabilization, dynamic strengthening, and Pilates as exercise interventions for LBP.10 According to the authors, lumbar stabilization focused on improving neuromuscular control, strength, and endurance to promote pelvic and lumbar stability.10 The goal of dynamic strengthening was to strengthen the spinal column and supporting structures. Pilates focused on maintaining a neutral spine and pelvis through activation of the core using controlled breathing. They used the VAS for pain, the Modified Oswestry Disabil-
The strengthening group completed exercises that targeted the anterior and posterior musculature (trunk flexors and extensors) in prone and supine positions. The CSE group started with activation of deep muscles and progressed to functional re-education exercises. The other group performed conventional stretching and isometric exercises. Both groups also received equal number of treatments of short-wave diathermy and intermittent lumbar traction. Both groups improved over time, but the CSE group had greater reductions in pain and disability outcomes (change scores: 4.93 on VAS, 14.6 on MODQ).5

A randomized controlled trial by Hlaing et al.13 compared CSE to strengthening exercises and evaluated proprioception (joint repositioning), balance (Romberg test), muscle thickness using ultrasound, and patient-reported outcomes such as VAS (pain) and MQD. A total of 36 patients with NSLBP completed the four-week clinical trial. The CSE protocol was broken into two phases (weeks 1 & 2, weeks 3 & 4), with the first phase focusing on activating the transversus abdominis and multifidus using drawing-in exercises. The second phase focused on incorporating transversus abdominis and multifidus activation during functional exercises in the quadruped position and standing. The strengthening group completed exercises that targeted the anterior and posterior musculature (trunk flexors and extensors) in prone and supine positions. The CSE group showed significantly better improvement than the strengthening group in proprioception, balance, and increase in muscle thickness. However, reduction in pain was not significantly different in the CSE group compared to the strengthening group.

**DISCUSSION**

Each of the five included articles reviewed examined similar outcomes of pain, disability, and function. In addition, each article had similar treatments that focused on core stabilization. The results of the included five studies gave valuable insight on the effectiveness that CSE offers patients who suffer with NSLBP. While there is still no definitive superior treatment for NSLBP, one can conclude that CSE is an effective method for treating NSLBP. All five studies indi-

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<th>Table 1. Results of the methodological quality assessment.</th>
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It was measured pain and disability. After completion of 10 sessions, pain and disability were significantly decreased in the lumbar stabilization group by 6 and 32 points for the VAS and MODQ, respectively. Although all three forms of therapy were beneficial, lumbar stabilization was superior.

Areeudomwong and Buttagat compared CSE, proprioceptive neuromuscular facilitation (PNF) training, and standard therapy regarding their effects on pain intensity, functional disability, and trunk/neuromuscular response during maximal voluntary contractions of the trunk flexors and extensors.6 CSE focused on recruitment of the deep abdominal muscles by utilizing abdominal hollowing techniques and pressure biofeedback. The PNF group progressed exercise difficulty over the course of four weeks starting with isometric contractions and ending with dynamic concentric and eccentric contractions of the trunk flexors and extensors. Lastly, the standard therapy group only did general trunk strengthening with 5-10 minutes of ultrasound performed (1MHz, continuous, frequency: 1.5-2.5 W/cm²); the authors did not specify if the ultrasound was provided before or after the exercises. Each group participated in three weekly sessions that were 30 minutes each for a duration of four weeks. After four weeks of intervention the PNF group demonstrated positive short term pain outcomes assessed as well as long-term pain outcomes assessed at a three month follow up (using the NRS pain scale). Both PNF and CSE showed greater reductions in pain and disability scores and improved patient satisfaction compared to the control, although the authors did not indicate how patient satisfaction was measured. Overall, Areeudomwong and Buttagat found that CSE had greater short-term effects on pain and function with better levels of muscle activation than the control group.6

Inani and Selkar compared the effects of CSE versus conventional exercises on lumbar joint position sense in patients with LBP using the VAS, MODQ. These outcome measures were performed at baseline and after three months.11 One group received four phases of CSE that started with activation of deep muscles and progressed to functional re-education exercises. The other group performed conventional stretching and isometric exercises. Both groups also received equal number of treatments of short-wave diathermy and intermittent lumbar traction. Both groups improved over time, but the CSE group had greater reductions in pain and disability outcomes (change scores: 4.93 on VAS, 14.6 on MODQ).11

A randomized controlled trial by Hlaing et al.13 compared CSE to strengthening exercises and evaluated proprioception (joint repositioning), balance (Romberg test), muscle thickness using ultrasound, and patient-reported outcomes such as VAS (pain) and MODQ. A total of 36 patients with NSLBP completed the four-week clinical trial. The CSE protocol was broken into two phases (weeks 1 & 2, weeks 3 & 4), with the first phase focusing on activating the transversus abdominis and multifidus using drawing-in exercises. The second phase focused on incorporating transversus abdominis and multifidus activation during functional exercises in the quadruped position and standing. The strengthening group completed exercises that targeted the anterior and posterior musculature (trunk flexors and extensors) in prone and supine positions. The CSE group showed significantly better improvement than the strengthening group in proprioception, balance, and increase in muscle thickness. However, reduction in pain was not significantly different in the CSE group compared to the strengthening group.
Table 2. Characteristics of the included studies.

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<td>Pilates=35</td>
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<td>PEDro Score</td>
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RCT=Randomized control trial, MHP=Moist heat pack, IFC=Interferential current, SWD=Short wave diathermy, TENS=Transcutaneous electrical nerve stimulation, LS=Lumbar stabilization, DS=Dynami strengthening, PNF=Proprioceptive neuromuscular facilitation, VAS=Visual analog scale, HEP=Home exercise program, CSE=Core stabilization exercises, CG=Control group, STE=Strengthening Exercises
cated that CSE resulted in lower pain ratings, improved self-reported function, and muscular function.\textsuperscript{4,6,10,11,15}

With this knowledge of the effectiveness of CSE provided in this review, healthcare providers may be better equipped to effectively treat patients with NSLBP. In addition to reducing pain and improving patient-reported outcomes such as the MODQ, CSE may also influence neuromuscular control.\textsuperscript{6} Muscular activation and cross-sectional area of the transversus abdominis and multifidus were improved, as was proprioception and balance, after patients completed various CSE protocols.\textsuperscript{6,13} Placing proper attention to muscle activation, strengthening the spine and core can help to build a strong base of support for the body to aid an individual’s ADLs. Using the findings of this systematic review to influence treatment plans with emphasis on earlier CSE intervention to improve NSLBP symptoms of pain, disability, and function may be beneficial. It is worth noting that most of the included studies combined modalities with CSE. This may suggest that while CSE can lead to improved outcomes, it is unclear if the modalities or exercises were driving patient improvements. While some providers may think rest is the best medicine based on previous literature and clinical knowledge, the incorporation of CSE has been associated with greater benefits than being inactive.\textsuperscript{11}

One key consideration with CSE is varied pain tolerance and ability to perform exercises that exists in patients. Older populations may require supplementary supervision to ensure proper form, engagement and safety as fall concerns may arise when progression occurs. Additionally, older populations may require exercises to be adjusted based on previous history, mental capacity and overall stamina. The studies included in this review indicate that both pain and disability are reduced following CSE across various age groups. Further analysis revealed that similar effect sizes were observed for pain reduction in NSLBP patient samples in their mid-twenties\textsuperscript{6} as well as their mid-forties (Table 2).\textsuperscript{4} This indicates efficacy of CSE across various age ranges. Nevertheless, the concept of engaging and strengthening the spinal and core muscles is a critical component that should be included in CSE interventions for NSLBP.\textsuperscript{14}

The progression of CSE treatments that were identified in this review demonstrate that the appropriate progression may be a critical factor for NSLBP treatment success. Most of the included studies used a two-phase approach to CSE with the first stage focusing on activating the deep abdominal musculature and the second focusing on integrating this activation into functional movements. When beginning, programs should begin with aerobic activity and stretching to warm-up musculature. The next step is educating patients on paying attention to a neutral spine and activation of the core during exercises.\textsuperscript{15} Once core activation is mastered, advancement to exercises that strengthen the surrounding muscles of the spine in varied positions should commence. The exercises progress from supine, to hook lying, to sitting on a physioball and then to standing and functional movements a patient would use every day.\textsuperscript{15} During advanced progression, additional emphasis should also be placed on balance and coordination during movements.\textsuperscript{13,15} Further information on the principles guiding CSE can be found in Aukuthota et al.\textsuperscript{15}

Patients may benefit from reduced financial burdens and improved self-efficacy in managing their symptoms with CSE. One study incorporated an HEP into their CSE plan of care, finding that CSE was effective at decreasing pain and had greater core activation.\textsuperscript{4} Those results aligned with the findings of this systematic review that CSE is effective at reducing pain. This SR also established that CSE has the potential to increase the long-term cost effectiveness for patients as it allows them to perform CSE outside of a rehabilitation setting once properly instructed. During initial sessions, clinicians should work towards improving a patient’s ability to self-manage their symptoms to decrease unneeded visits and costs for patients. Clinicians should also consider educating patients on appropriate posture, ergonomics and what to do if their NSLBP recurs after discharge. In turn, it may be possible that CSE could decrease cost to third party payers and patients. However, costs of treatment were not evaluated in any of the studies and cost-effectiveness remains an important unanswered question in this field.

While the long-term effects of CSE are still unknown for patients with NSLBP, the positive short-term results found in this review provide optimism for long-term results. The lack of long-term studies may be due to the inability to follow patients through life along with conflicts with schedules, or compliance with long-term HEPs. Future studies should further evaluate the effects that CSE may have on long-term NSLBP regarding pain and function. In addition to long-term effects, future studies should examine the role of CSE in short and long-term effects for specific LBP as beneficial results were seen in patients with NSLBP.

Many treatment options exist for LBP, and only a handful were compared to CSE in this systematic review. While some methods such as the McKenzie Method may have greater success in reducing pain with chronic LBP, this method has not been shown to be superior for treatment of patients with acute LBP.\textsuperscript{16} The McKenzie Method also requires clinicians to take costly classes that may not be reasonable at the time for some providers. Pilates is another technique used for treatment of NSLBP, although the evidence does not support that it is better than CSE for the treatment of NSLBP.\textsuperscript{6,17} Another intervention strategy for NSLBP is Tai Chi, which may be a better solution for elderly patients due to the slow movements and benefits of reducing depression symptoms.\textsuperscript{18} While stretching and strengthening have seen success as well, these are commonly recommended to be combined with CSE for improved patient outcomes.\textsuperscript{10,19}

A major limitation of the current literature is that results for CSE are only supported for the short term. Very few studies have looked at the long-term effects of CSE at treating NSLBP with most studies following patients for less than three months with no future follow ups. There is a critical gap for long-term outcomes in future research as the longest follow-up was three months in the studies that were identified.\textsuperscript{9,11} Many of the included studies (4 of 5) paired CSE with another modality, limiting the ability to draw conclusions specific to the efficacy of CSE in isolation. Since most modalities were used to control pain, it remains a possibility that the modalities were a driving factor in the reduction of pain following CSE interventions. Future re-
search should aim to investigate the efficacy of CSE in isolation. Lastly, the five studies also had no blinding of the subjects or therapists. This may be due to the similar treatment approaches between the control groups and the experimental groups for each. Future researchers may want to consider employing more rigorous experimental designs to better understand the short- and long-term impact of CSE on patients with NSLBP.

CONCLUSION

Core stabilization exercises have been widely used and become more popular over the years with healthcare providers for treatment of NSLBP. Based on the results of this systematic review, there is grade B evidence to support the use and efficacy of using CSE to decrease symptoms and improve patient function in patients with acute NSLBP. While the clinical benefit of CSE has was demonstrated in the short term, the long-term effects remain unclear.

CONFLICTS OF INTEREST

None to declare.

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REFERENCES


Scoping Review

Inertial Flywheel Resistance Training in Tendinopathy Rehabilitation: A Scoping Review

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Keywords: Flywheel training, Tendinopathy, Resistance training, Exercise, Physiotherapy, Tendon

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Background
Inertial Flywheel Resistance Training (IFRT) has recently emerged as a beneficial rehabilitation option for some musculoskeletal disorders. Although the use of resistance training as treatment for tendinopathy has become widespread, it is unclear if IFRT has efficacy as a treatment option for tendinopathies.

Objective
To identify current evidence on IFRT in the treatment of tendinopathy, evaluating intervention parameters and outcomes.

Methods
This scoping review was reported in accordance with the PRISMA Extension for Scoping Reviews (PRISMA-ScR). Databases searched included MEDLINE, CINAHL, AMED, EMBase, SPORTDiscus, Cochrane library (Controlled trials, Systematic reviews), and five trial registries. Two independent reviewers screened studies at title, abstract and full text. Following screening, data were extracted and charted, and presented as figures and tables alongside a narrative synthesis. Any study design conducted on adults, investigating the effects of IFRT for tendinopathy were included. Data were extracted on intervention parameters and outcomes of IFRT interventions.

Results
Four studies on patellar tendinopathy were included. A variety of outcomes were assessed, including pain, function, strength, power, and tendon morphological and mechanical properties, particularly changes in tendon thickness. IFRT intervention parameters were largely homogenously prescribed, with slight variances.

Conclusion
Despite a paucity of studies to date on the effects of IFRT for treating tendinopathy, preliminary evidence for beneficial effects of IFRT on clinical outcomes in patellar tendinopathy is encouraging. As IFRT is a relatively new and unexplored method in tendinopathy rehabilitation, definitive conclusions, and recommendations cannot be made at present, which should be addressed in future research, due to the potential therapeutic benefits highlighted in this review.

INTRODUCTION

The use of flywheel devices in resistance training can be dated back over one hundred years, with an increased interest since 1994 due to the development of flywheel devices to counteract muscle strength loss and atrophy for astronauts undertaking space flight. Inertial flywheel resistance training (IFRT) has been found to be a beneficial alternative or compliment to traditional resistance training methods in both healthy athletic populations and in reha-
bilitation for some musculoskeletal injuries. The beneficial effects of flywheel training in athletes for increasing muscle strength and hypertrophy have been well documented, but only recently has evidence emerged regarding its beneficial applications in the rehabilitation setting. Inertial Flywheel Resistance Training (IFRT) incorporates the use of inertial resistance via a rotating flywheel device that requires increased muscle contraction speeds compared to standard resistance training, which with repeated training over time can lead to increases in muscular power and strength. During maximum effort concentric movements, rotation of the flywheel generates kinetic energy, which when braked during the return eccentric movement causes increased eccentric resistance to working muscles and tissues. Due to the isoinertial type of resistance involved, greater eccentric muscle activation can occur compared to traditional resistance training using free weights. A plethora of beneficial effects have been demonstrated on muscle tissue with flywheel training, including increased muscle power, strength, length, muscle activation, hypertrophy, and an increase in fast twitch muscle fibers. Improvements in athletic performance indicators such as change of direction ability, post activation potentiation, maximal running speed and vertical jump height has also been demonstrated in athletes. Despite eccentric overload of muscles occurring during flywheel training, muscle adaptations have been found to occur without increased pain or risk for musculoskeletal injury during training. Eccentric biased training such as flywheel training activates the stretch-shortening cycle more efficiently than traditional isotonic resistance training, which can increase muscle adaptation through the addition of sarcomeres known as sarcomerogenesis, which can lead to greater adaptations if applied during injury rehabilitation. The use of IFRT has been found to not only improve athletic performance but it may also decrease the risk of musculoskeletal injury during competition in athletes. Due to its beneficial effects on muscle tissue, IFRT can also be used in isolation or in combination with traditional rehabilitation methods, which may lead to enhanced outcomes, particularly for acute muscle injuries and degenerative muscle conditions such as sarcopenia. Muscle weakness and atrophy can also be reduced during post-surgical early rehabilitation for joint injuries, such as after anterior cruciate ligament reconstruction, when muscle atrophy is a common problem. Studies have shown that IFRT can be used in all stages of musculoskeletal injury rehabilitation to increase muscle strength and functional performance, from postsurgical to return to sport phases.

Tendinopathy represents a spectrum of tendon pathology, associated with changes to the structural tendon collagen matrix, presence of various inflammatory cells and clinical symptoms of pain and impaired performance, with potential for progression to a chronic degenerative condition. Tendinopathy is common in athletes with high training demands and is associated with repetitive tendon microtrauma, with Achilles and patellar tendinopathy having the highest prevalence in athletes. Traditional eccentric training has been the gold standard first-line management approach for tendinopathies for the last two decades, due to its documented beneficial clinical effects for both upper and lower limb tendinopathies. Despite the largest body of evidence existing for eccentric training, heavy slow resistance training (HSRT) involving both concentric and eccentric actions has been shown to have comparable positive clinical outcomes. Due to these findings, some experts have suggested there is no scientific rationale for eliminating concentric actions in tendinopathy rehabilitation, with IFRT a potentially efficacious rehabilitation method due to having both a concentric and eccentric overload component and therefore requiring less overall training exposure, which may improve adherence. Despite this, there are a lack of recommendations for the use of IFRT and it is not routinely used in clinical rehabilitation for tendinopathies. The effects of flywheel training on healthy and pathological tendons are not well documented, with some evidence indicating improvements in tendon stiffness. Due to a paucity of research, it is unclear what effects IFRT may have on tendons, but the induced muscular adaptations also suggest mechanical tendon properties, collagen metabolism and tendon remodelling may be enhanced due to the eccentric overload effect. The application of progressive tendon loads during rehabilitation is essential to not compromise tendon healing, with the precise dosing parameters of resistance training loading a critical consideration. Prolonged time under tension with traditional heavy loads and increased training frequency during the early phase of tendon rehabilitation could be counterproductive and compromise tendon healing. Despite the potential applicability and possible beneficial physiological mechanisms of IFRT on tendon healing, the method of training has received a dearth of attention in tendon rehabilitation, despite the clinical benefits found for other musculoskeletal conditions and the knowledge of resistance training being the most evidence-based treatment available for tendinopathies. Therefore, the objective of this scoping review is to evaluate current research on the use of IFRT for treating tendinopathies. The scoping review will be guided by addressing the following review questions on specific aspects of IFRT interventions within tendinopathy rehabilitation: 1. What outcomes have been reported for IFRT in rehabilitation for tendinopathy and which outcome measures have been used? 2. What IFRT intervention and device parameters have been used in published studies? 3. What physiological mechanisms explaining effects of IFRT for tendinopathy have been investigated in published studies?

**METHODS**

Due to the exploratory nature of the research questions of this review, a scoping review was conducted as they are recommended for mapping key concepts, evidence gaps and types of evidence within a particular field and can help guide future research and the possibility of conducting systematic reviews on the topic. The scoping review is reported in accordance with the Preferred Reporting Items for Systematic reviews and Meta-analysis extension for Scoping reviews (PRISMA-ScR).
ELIGIBILITY CRITERIA

The inclusion criteria for the scoping review were guided by a modified PICO (PICOcCo), which is recommended for scoping reviews. The review considered studies with adult participants aged eighteen years or older with a diagnosis of any tendinopathy for any time duration. All lower and upper limb tendinopathies were considered for inclusion, such as gluteal, hamstring, patellar, Achilles, rotator cuff and lateral elbow. Any tendon condition characterized by common tendinopathy symptoms, in the absence of a full thickness tendon rupture were considered for inclusion. A clinician’s diagnosis based on verifiable clinical features including pain location, response to palpation or tendon loading with specific tendinopathy tests were accepted for inclusion. Studies including participants with other concurrent injuries or medical conditions were excluded. The concept of interest was IFRT for the treatment of any tendinopathy, including any type or format. Therefore, any muscle contraction type performed with IFRT, including eccentric, concentric, isometric, isometric, plyometric, general strength training, or combinations of these exercise types were considered. The IFRT intervention could be used as a first or second-line intervention and may be delivered in isolation or combined with other treatments. The context considered for inclusion included any setting in which IFRT was delivered by health or exercise professionals, in a supervised or unsupervised manner, using any methods for training progression and compliance. This scoping review considered both experimental and quasi-experimental study designs for inclusion, including randomized controlled trials, non-randomized controlled trials, prospective and retrospective cohort studies, case series and case reports. Unpublished studies, systematic or narrative reviews or reports were not considered for inclusion.

SEARCH STRATEGY

The search was carried out using a uniform search strategy across all databases (Appendix 1) and it included key words from two main concepts: IFRT (‘flywheel’, ‘inertial’, ‘isoinertial’, ‘eccentric overload’), and Tendon (‘tendon’, ‘tendinopathy’, ‘tendon injury’). The Boolean operators “Or” and “And” were used to link the key words from each concept and to link the concepts themselves, respectively. A 3-step search strategy was implemented in this scoping review. It incorporated the following: 1) a limited search of MEDLINE and CINAHL using initial keywords as, followed by analysis of the text words in the title/abstract and those used to describe articles to develop a full search strategy; 2) The full search strategy was adapted to each database and applied to MEDLINE, CINAHL, AMED, EMBase, SPORTDiscus, and the Cochrane library (Controlled trials, Systematic reviews). The following trial registries were also searched: ClinicalTrials.gov, ISRCTN, The Research Registry, EU-CTR (European Union Clinical Trials Registry), ANZCTR (Australia and New Zealand Clinical Trials Registry). Databases were searched from inception to January 18th, 2022 (Search performed on January 18th, 2022). The search for relevant grey literature included Open Grey, MedNar, Cochrane central register of controlled trials (CENTRAL), ETHOS, CORE, and Google Scholar. 3) For each article located in steps 1 and 2, a search of cited and citing articles using Scopus and hand-searching where necessary, was conducted. Studies published in a language other than English were only considered if a translation was available as translation services are not available to the authors.

STUDY SELECTION

Following the search, all identified citations were collated and uploaded into RefWorks and duplicates removed. Titles and abstracts were screened by two independent reviewers and assessed against the review inclusion criteria. Potentially relevant studies were retrieved in full, with their details imported into Covidence software (Veritas Health Innovation, Melbourne, Australia). Two independent reviewers assessed the full text of selected articles in detail against the review inclusion criteria. Any disagreements that arose at any stage of the study selection process were resolved through discussion or by input from a third reviewer. The results of the search are reported in accordance with the PRISMA-ScR. In accordance with guidance on conducting scoping reviews, critical appraisal was not conducted.

DATA EXTRACTION

Data were extracted from sources included in the scoping review by one reviewer, with independent data extraction by a second reviewer for at least 10% of studies. The data extracted included specific details regarding the population, study methods and key findings relevant to the review questions. The data extracted included dimensions such as study type, purpose, population & sample size, methods, details of the IFRT intervention, specific exercises, outcome measures used and clinical outcomes. Details of the IFRT interventions included type, dosage, device and intervention parameters, and methods used to progress the training stimulus. Data were also extracted on any physiological mechanisms such as effects on tendon morphological and mechanical properties, which have been investigated to explain the effects of IFRT in tendinopathy. The extracted data are presented in Table 1 with an accompanying narrative synthesis.

RESULTS

INCLUDED STUDY CHARACTERISTICS

The literature search yielded 130 articles, reduced to 84 after removing duplicates, of which four met the inclusion criteria and were included in the review, with the search results summarised in the PRISMA flow chart (Figure 1). An overview of the characteristics, IFRT parameters and outcomes of the included studies are provided in Table 1. The four studies investigated the effects of IFRT on patellar tendinopathy, including one randomized controlled trial (RCT), one case series, and two cohort studies. No studies investigating the effects of IFRT on other tendinopathies were found in the literature search. The sample sizes of included studies ranged from 10-42, with a total of 125 participants with patellar tendinopathy. All in-
Table 1. Characteristics, intervention parameters and outcomes of included studies

<table>
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<tr>
<th>Author, Study design, population</th>
<th>Intervention, exercises, duration</th>
<th>Training parameters</th>
<th>Device parameters</th>
<th>Outcome measures</th>
<th>Outcomes, results</th>
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<tr>
<td>Ruffino et al. 2021, RCT, n=42, patellar tendinopathy</td>
<td>1. Heavy slow resistance training (squat, hack squat, leg press). 2. Inertial Flywheel training (squat, leg press, knee extension). 12 weeks</td>
<td>Sets: 4, Reps: 12(10 max effort), Freq: 1 x WK, Prog: NR, Int: 8-RM, reps 1–2 were used for increasing the inertial resistance, and reps 3–12 were executed with maximal effort. Rest: 2-3 MIN between sets. Session time: 20 MIN</td>
<td>Three custom inertial flywheel machines: 2-legged squat, leg press and knee extension (Ivolution, Sunchales, Argentina). Each coupled concentric and eccentric actions were completed with a repetition cycle of about 3 seconds. Inertia loads were: 2.5 kg flywheel (moment inertia 0.05 kg/m²) from week 1-6 and 4 kg flywheel (moment inertia 0.10 kg/m²) from week 6-12.</td>
<td>Pain &amp; function (VISA-P), Patient Specific Functional Scale (PSFS), health status (EuroQol-5D), patient impression of change on pain and function, adverse events, pain provocation test for the patellar tendon (0-10), physical tests (strength &amp; power), patellar tendon thickness and doppler signal on ultrasound.</td>
<td>Both groups improved clinical outcomes, with no significant difference between groups in clinical outcomes, physical tests (strength &amp; power), or tendon thickness &amp; neovascularization. Adherence: diary, 88% (HSRT), 90% (Flywheel).</td>
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<td>Romero-rodriguez et al. 2011, case series, n=10, patellar tendinopathy</td>
<td>1. Isoinertial flywheel ECCT, maximal effort, leg press. 6 weeks</td>
<td>Sets: 4, Reps: 10, Freq: 1 x WK, Prog: NR, Int: 8-RM, reps 1–2 were used for increasing the inertial resistance, and reps 3–10 were executed with maximal effort. Rest: 2 MIN between sets. Session time: 20 MIN.</td>
<td>Leg press device, provided by the manufacturer (YoYo Technology AB, Stockholm, Sweden). The concentric phase was executed from about 90º degrees knee angle to almost full extension about the knee joint. Subjects were instructed to resist gently during the first two thirds of the eccentric action and then apply maximal force to bring the wheel to a stop at approximately 90º. Thus, eccentric overload was achieved in the last third of any eccentric action.</td>
<td>Pain (VAS), function (VISA-P), lower limb maximal strength and vertical counter movement jump (CMJ) height. Surface electromyography (SEMG)</td>
<td>Intervention was effective for improving clinical outcomes. Eccentric strength increased but power (CMJ) did not. Adherence: NR</td>
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<td>Abat et al. 2014, cohort, n=33, patellar tendinopathy</td>
<td>1. Intratissue Percutaneous Electrolysis (EPI) + Flywheel training, Isoinertial leg press training machine. 12 weeks</td>
<td>Sets: 3, Reps: 10, Freq: 2 x WK, Prog: always maximum intensity, Int: 10-RM.</td>
<td>Isoinertial resistance machines (YoYoTM Technology AB, Stockholm, Sweden). Each repetition was performed with the concentric phase with both extremities whereas the eccentric phase was only performed with the affected limb at a maximum 60º of knee flexion.</td>
<td>Pain &amp; function (VISA-P), Tegner scale, Roles and Maudsley scale.</td>
<td>Significant improvement in pain &amp; function. Adherence: supervised, %NR</td>
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<tr>
<td>Abat et al. 2015, cohort, n=40, patellar tendinopathy</td>
<td>1. Intratissue Percutaneous Electrolysis (EPI) + Isoinertial ECCT, leg press machine. 12 weeks</td>
<td>Sets: 3, Reps: 10, Freq: 2 x WK, Prog: NR, Int: 10-RM.</td>
<td>Resistance isoinertial leg press machine (YoYoTM Technology AB, Stockholm, Sweden). Each repetition was performed with the concentric phase with both extremities whereas the eccentric phase was only performed with the affected limb at a maximum 60º of knee flexion.</td>
<td>Pain &amp; function (VISA-P), Tegner score, Blazina's classification, Roles and Maudsley scale.</td>
<td>Combination was effective for improving clinical outcomes. Adherence: supervised, %NR</td>
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Abbreviations: RM: repetition maximum, MIN: minute, NR: not reported, Int: intensity, Freq: frequency, Prog: Progression, RCT: randomised controlled trial, VAS: visual analogue scale, VISA-P: Victorian Institute of Sport Assessment Patellar, n: number, WK: week, Heavy slow resistance training: HSRT.
Included studies investigated the effects of an IFRT intervention, one in isolation,\textsuperscript{42} one compared with HSRT,\textsuperscript{41} and two combined with intratissue percutaneous electrolysis (EPI).\textsuperscript{43,44} The duration of IFRT interventions ranged from 6-12 weeks. The most common exercises used for the IFRT interventions were, leg press in four studies, squats in one study, and knee extension in one study.

**OUTCOME MEASURES**

All four studies assessed patient reported pain and function as an outcome measure with IFRT using the Victorian Institute of Sport Assessment Patellar (VISA-P) for patellar tendinopathy. One study used the VAS scale for pain, two studies used the Tegner scale, two studies used the Roles and Maudsley scale, one study used the Blazina scale, and one study used the Patient Specific Functional Scale (PSFS). One study also assessed quality of life using the EuroQol-5D. Two studies assessed the effects of IFRT on strength and power, using methods such as maximal strength testing and the counter movement jump test. One study used ultrasound to assess patellar tendon thickness and doppler signal to measure tendon neovascularization. One study also used surface electromyography (EMG) to assess muscle function.

**OUTCOMES**

The four studies included in this review that assessed the effects of IFRT on clinical outcomes in patellar tendinopathy all found significant improvement in pain and function as measured by the VISA-P. However, only two studies used IFRT in isolation,\textsuperscript{41,42} whereas the other studies implemented IFRT combined with EPI, which may have affected outcomes.\textsuperscript{43,44} The two studies that assessed strength outcomes, all found increases in strength and power following the IFRT intervention. The only RCT in patients with patellar tendinopathy,\textsuperscript{41} found equal improvement compared to HSRT, in terms of pain, function, strength, power, patellar tendon thickness and neovascularization.

**TRAINING PARAMETERS**

The four included studies all used specific IFRT devices in their interventions, with three using leg press machines from the same manufacturer (YoYo Technology AB, Stock-
holm, Sweden). Whereas these studies focused on one specific exercise and device, the other study included three specific devices (Ivolution, Sunchales, Argentina) to allow three different exercises in the intervention; leg press, knee extension and squat. Despite some variances in the sets and repetitions of prescribed exercises, exercise prescription was largely homogenous across the included studies. Two studies prescribed 4 sets of 10 repetitions, once per week, with the first two repetitions used for increasing the inertial resistance, and repetitions 3–10 were always executed with maximal effort. The studies following this same protocol allowed for two minutes of rest between sets. The other two studies prescribed 3 sets of 10 repetitions, twice per week, all repetitions were performed with maximum intensity for 10 repetition maximum (RM).

**DISCUSSION**

The main findings from this scoping review are that despite the paucity of research on IFRT as a treatment for tendinopathy, the available albeit preliminary evidence indicates that IFRT is a potentially clinically effective management option for patellar tendinopathy, particularly in athletic populations. All studies found in the literature were conducted on patellar tendinopathy, with two studies findings pain and function improvement with IFRT in isolation, and two studies finding clinical improvement with IFRT combined with EPI. Two studies also found significant strength and power improvement with IFRT, with one study finding positive tendon adaptations on ultrasound. The findings from the RCT included in this review may be of particular significance to the clinical rehabilitation and prevention of patellar tendinopathy, particularly in athletes.

For several decades, heavy eccentric and more recently, heavy slow resistance training have been considered the conservative cornerstone of managing lower limb tendinopathies, as supported by evidence. However, the preeminent HSRT protocol in patellar tendinopathy, known as the Kongsgaard protocol in reference to the authors who developed it, which has shown efficacy in several RCTs, was found to be no more effective than IFRT, for improving pain, function, strength, power, and tendon properties. The RCT highlighted how several clinical and physical outcomes could be improved by IFRT at a comparable level to the gold standard HSRT protocol. Somewhat surprisingly, this RCT was the only study included in this review that assessed tendon properties as an outcome measure, finding improvements in tendon thickness and neovascularization as assessed by ultrasound and doppler signal. Despite this, previous studies examining the effects of IFRT on healthy tendons, have shown potential beneficial changes in tendon structure, suggesting the same is true for pathological tendons. Although further confirmatory research is required to confirm that IFRT induces positive adaptations in tendinopathy, the preliminary findings from this RCT are encouraging. Further studies with larger sample sizes are required to confirm the efficacy of IFRT as a patellar tendinopathy treatment, with the evidence from studies included in this review suggesting possible clinical benefits. There is also a clear scientific rationale for IFRT having potential clinical benefits in tendinopathy, due to the previously highlighted physiological mechanisms it induces, particularly the muscular and tendon responses induced by eccentric overload training.

Although the focus of this review was on the use of IFRT in the rehabilitation of tendinopathy, findings from other studies have suggested a possible role for IFRT in prevention or in-season management of patellar tendinopathy. In a sample of 81 jumping athletes who were at high risk for developing patellar tendinopathy due to repetitive tendon loading, a once weekly IFRT protocol added to normal in-season sports training led to strength and power improvements, along with no increases in patellar tendon pain or diagnoses of patellar tendinopathy within the sample. Given the high prevalence and incidence of patellar tendinopathy in elite jumping athletes, this evidence of a prophylactic effect of IFRT is a potentially significant finding. Although more studies are required to confirm the efficacy of IFRT in preventing patellar tendinopathy, the evidence is nonetheless encouraging given the lack of preventative patellar tendinopathy interventions available, and the high number of associated risk factors identified in jumping athletes. Despite the potential efficacy of IFRT as a multifaceted tool in the rehabilitation of patellar tendinopathy, current evidence may be limited to athletic populations and not generalizable to other populations, until further evidence emerges.

No studies have investigated IFRT in rehabilitation with any other tendinopathies, so no recommendations can be made for IFRT with any tendinopathy other than patellar at present. Although IFRT may have potential therapeutic benefits in the management of any tendinopathy, Achilles tendinopathy would seem an obvious choice as an immediate candidate for investigation. While eccentric training is recommended as a treatment for most tendinopathies, this method originated with eccentric calf raise training in Achilles tendinopathy, and currently the best evidence of clinical effectiveness of eccentric training is for Achilles tendinopathy, with a plethora of RCTs showing efficacy. Given IFRT is believed to exert clinical benefit and induce positive muscle and tendon adaptations through training with eccentric overload, it may have benefit as an Achilles tendinopathy treatment and should therefore be investigated in future research. Squat training utilising a flywheel squat device has been found to increase Achilles tendon cross-sectional area and the pennation angle of the medial aspect of the gastrocnemius muscle, suggesting eccentric overload training with flywheel devices is feasible for the Achilles tendon. Although the study by Sanz-Lopez et al. was conducted with healthy Achilles’ tendons and did not assess clinical benefit in Achilles tendinopathy, it serves to highlight the potential for positive Achilles tendon adaptations with IFRT, which may confer similar benefit to Achilles tendinopathy as seen with IFRT for patellar tendinopathy.

This review has several limitations, particularly the paucity of available research on IFRT for tendinopathy, with only four studies included, and only one RCT, highlighting the need for future high-quality studies with larger sample sizes. Future studies should also investigate the effects on specific subgroups known to be at increased risk for tendinopathy, including running as well as jumping ath-

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letes and the general sedentary population. Although the IFRT parameters implemented in studies were largely homogenous, there were some variances in sets, repetitions, and training frequency. Therefore, future studies should consider standardized methods and reporting of IFRT interventions in tendinopathy rehabilitation to enhance clinical translation of the research interventions. The longest follow-up times of included IFRT interventions were 12 weeks, with much longer follow-up times required to assess the long-term adaptations and outcomes of IFRT in tendinopathy patients. Methods for monitoring and recording adherence to IFRT should also be emphasized in future studies as several included studies did not report the adherence level to IFRT, which may vary due to individual compliance, which may affect reported clinical outcomes.

CONCLUSION

Despite the paucity of research conducted to date on the effects of IFRT as a treatment option for tendinopathies, a small body of evidence is forming suggesting that IFRT may be an effective multifaceted tool at the clinician's disposal, for use in the rehabilitation of patellar tendinopathy. While the evidence is preliminary, the included studies in this review all found beneficial clinical, physical, and tendon outcomes with IFRT in subjects with patellar tendinopathy. One high quality RCT has shown comparable efficacy for multiple outcomes to the currently considered gold standard method of HSRT. Further high quality RCTs with larger sample sizes are required to confirm the efficacy of IFRT in patellar tendinopathy and explore its efficacy with other tendinopathies such as Achilles tendinopathy. Evidence from studies included in this review, alongside the known scientific rationale for muscle and tendon adaptations with IFRT, is suggestive of potential clinical benefits as a tendinopathy treatment and possible alternative or complement to current management methods.

CONFLICTS OF INTEREST/COMPETING INTERESTS

None declared.

FUNDING

No sources of funding were used to assist in the preparation of this article.

DATA AVAILABILITY STATEMENT

All data relevant to the study are included in the article or uploaded as supplementary information.

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REFERENCES


APPENDIX 1: SEARCH STRATEGY

INFORMATION SOURCES AND SEARCH STRATEGY.

Databases: MEDLINE (PubMed), CINAHL, AMED, EMBase, SPORTDisscus CENTRAL of Cochrane Library

Search fields: Title, abstract, key words
Search terms (database subject headings)
1. "Flywheel" OR "inertial" OR "isoinertial" OR "eccentric overload"
2. "tendon" OR "tendinopathy" OR "tendon injury"
3. 1 AND 2
The classic model of non-contact ACL injury includes environmental, anatomical, hormonal and biomechanical risk factors which directly impact either the amount of stress placed on the ligament or the relative capacity of ligament to withstand the forces placed on it. However, cognition also clearly plays a role in successful athletic performance, yet diminished cognitive function is rarely considered a risk factor for injury.

Objective
To examine the existing literature to determine the extent to which cognitive function (both cognitive ability and task cognitive load) influences non-contact lower extremity injury risk in male and female athletes with a broad variety of athletic expertise.

Study Design
Scoping Review

Methods
An electronic search was conducted of CINAHL, SPORTDiscus, Google Scholar, and MEDLINE using the PRISMA method. Search terms included Boolean combinations of "cognition", "concussion", "ImPACT", "cognitive deficit", "mild traumatic brain injury (mTBI)", and "neuropsychological function" as cognitive descriptors and the terms "injury risk" and "lower extremity injury" as injury descriptors. Inclusion criteria included papers written in English published between 2000-2021. Exclusion criteria included neurological and cognitively atypical populations, except for concussion (included). Included articles were appraised using the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies.

Results
Fifty-six studies utilizing across the spectrum of levels of evidence met inclusion criteria. Forty-one articles had good, fourteen had fair, and one had poor methodological quality. Studies examined baseline cognitive function in healthy athletes (n=7); performance during dual-task paradigms (n=13); and the impact of concussion on dual-task performance (n=4), LE injury risk (n=22), or post-concussion testing (n=10). Six articles examining cognitive function and all dual-task studies (including concussion studies) found altered biomechanics associated with injury or increased processing demands.
Studies related to concussion and injury incidence consistently found an increased risk of LE injury following concussion. Half of the studies that examined concussion and post-concussion cognitive testing demonstrated significant effects.

**Discussion**

Consistent across participant demographics, tasks, and dependent measures, fifty-one of fifty-six assessed articles concluded that decreased cognitive ability or increased cognitive load led to risky LE mechanics or a direct increase in non-contact LE injury risk.

**Conclusion**

The robustness of results across gender, performance level, sport, cognitive ability, task cognitive load suggest that the inclusion of cognitive training in the design of optimal LE injury prevention programs warrants further study.

Level of Evidence: Ia

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**INTRODUCTION**

As the saying goes, “an ounce of prevention is worth a pound of cure.” Indeed, it has long been the goal of rehabilitation professionals to develop effective injury prevention programs for athletes due to high injury rates. In the United States, competitive and recreational athletes reported 8.6 million injuries annually with up to 42% of them involving the lower extremity. One common non-contact lower extremity injury, anterior cruciate ligament (ACL) rupture, is often the target of prevention programs. However, these prevention programs have room for further improvement. For example, Noyes & Barber-Westin found that to prevent one non-contact ACL rupture, 70 athletes need to participate in the prevention program. These current programs largely target improving the physical and biomechanical aspects of movement related to injury prevention. One possible missing component is the contribution of cognitive impairment on injury risk.

Participation in sport requires the integration of many different inputs to successfully accomplish a task. Athletes must sort through high amounts of sensory information, while avoiding or challenging an opponent, and attempting to achieve the goal (e.g., score or prevent the score). A possibility of increased injury risk exists where participants respond to unanticipated events or undertake rapid visual-motor decision making - such is the case during athletic participation. Indeed, cognitive integration clearly plays a role in task achievement during sport. The idea that the addition of cognitive load could result in riskier biomechanics during a relatively simple physical task relates to a concept known as the "capacity model of attention". The cognitive process of attention is considered the bottleneck of information processing, creating a natural limit to an individual’s capacity to perform mental and motor tasks, and different activities impose different demands on this limited capacity. Thus, lower attentional and/or cognitive reserves due to innate natural abilities, previous head injuries, or task load, may leave athletes at a higher risk for non-contact injuries. Widening clinical attention from simply a physical, biomechanical approach to more of a holistic viewpoint could boost the effectiveness of injury prevention programs, at least for some athletes.

To fully understand the effects of cognitive function on lower extremity non-contact injury risk, it is important to define cognition and its relation to kinetics and kinematics.
METHODS

LITERATURE SEARCH STRATEGY

Search terms included Boolean combinations of "cognition", "concussion", "ImPACT", "cognitive deficit", "mild traumatic brain injury (mTBI)" and "neuropsychological function" as cognitive descriptors. The terms "injury risk" and "lower extremity injury" as injury terms (Appendix 1). The following electronic databases were searched: CINAHL, SPORTDiscus, Google Scholar, and MEDLINE with the most recent search conducted in August 2021.

STUDY SELECTION CRITERIA

Inclusion criteria consisted of English-language studies with a publication range from 2000–2021. Exclusion criteria consisted of neurological and cognitively atypical populations including diagnoses such as Attention Deficit Hyperactivity Disorder (ADHD), traumatic brain injury (TBI), cerebral palsy (CP), multiple sclerosis (MS), amyotrophic lateral sclerosis (ALS) and Autism Spectrum Disorder. One notable exception was the inclusion of concussion as a diagnostic category for this scoping review. Concussion (AKA mild traumatic brain injury or mTBI) is a unique example of potentially impaired cognitive capacity that potentially could increase LE non-contact injury risk. Articles that fell into this category were analyzed separately from all other articles.

Using the article selection strategy suggested by Smith,13 the initial search yielded 5,355 results (Figure 1). After removing duplicates, 4,824 studies remained. Authors divided the 4,824 articles among themselves and individually assessed whether they met the inclusion criteria or violated the exclusion criteria. Articles that did not clearly meet the inclusion criteria were discussed by the entire group and a determination made by consensus. Studies not meeting the inclusion criteria or violating the exclusion criteria were removed; first by article title (4,688 articles), next by abstract (61 articles) and finally by full text content (19 articles). These articles were removed during full-text screening because they did not satisfy the purpose of this study. Following full-text screening, article references were reviewed for additional content that met the inclusion criteria (nine articles). Finally, 56 articles were included for review (Figure 1).

DATA SYNTHESIS

Data from each article including experimental design, sample size, participants, task, dependent measures, and results/conclusions were extracted (Appendix 2). Fifty-six articles were classified into five categories based on participant demographics and dependent measures: natural cognitive ability in a healthy population, performance during dual-task paradigms in healthy populations, performance during dual-task paradigms in participants with a history of concussion, LE injury risk in participants with a history of concussion, and Lastly, cognitive testing performance in participants with a history of concussion.

Methodological risk of bias was assessed using the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies from the National Institutes of Health,14 which includes 14 items. While not all articles fell in the observational and cohort and cross-sectional study categories (see Table 1), the authors chose to use a single quality assessment tool for consistency across all included articles. Each publication was given an overall score of ‘good’, ‘fair’, or ‘poor’ (Table 1) based on this tool. Initial scoring was performed by a single author (MR, MP, TW or DL), then the first four authors (MR, MP, TW and DL) discussed all included papers and reached consensus on scoring.

RESULTS

RISK OF BIAS

Discussion and strict adherence to the quality appraisal tool was utilized to come to consensus for all included studies. Forty-one out of the fifty-six articles had strong methodological quality, while fourteen articles had fair methodological quality, and one article had poor quality (Figure 2). Common reasons for articles not having strong methodological quality included: small sample size (based on a lack of a sample size justification, power description, or variance effect size data), insufficient time between exposure and outcome (determined on a case-by-case basis for each paper), and lack of blinding to participants and researchers.

METHODOLOGICAL DESIGN

Methodological design of the included papers determines the level of evidence for this scoping review. Figure 3 illustrates the number of articles by topical category and experimental approach (Refer to Table 1 for the specific articles that fell into each category). Sixteen studies utilized a prospective cohort design. Twelve studies were retrospective cohort design. Ten studies were prospective quasi-experimental design. Twelve studies used a prospective cross-sectional design. Five studies used retrospective cross-sectional design. One study used a retrospective case control design. The specific demographic data, methods and conclusions for each study are provided in Appendix 2.

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Baseline Cognitive ability. Seven articles examined athletes’ natural cognitive function and its relationship to task performance and injury risk.7–9,12,15–17 These studies investigated the relationship of a person’s baseline cognition, as defined by each researcher, to injury risk. Six of the seven articles found athletes with lower baseline cognitive function had significantly altered mechanics.7–9,12,16,17

Four studies utilized the IMmediate Post-concussion Assessment and Cognitive Testing (ImPACT) scores to relate cognitive function and injury risk.8,9,12,15 As the name suggests, the ImPACT is a measurement tool designed to assist with return-to-play decisions post-concussion.18 Since it gives such a broad cognitive screen, the use of the ImPACT to identify post-concussion cognitive deficits is debated in literature. The test consists of six neuropsychological tests designed to target different aspects of cognitive functioning including attention, memory, processing speed and reac-
From these six tests, four composite scores are generated including verbal memory, visual memory, visuo-motor speed and reaction time. Although this test was designed for concussion management, the domains of the IMPACT may also prove useful as a measurement of baseline cognition. Three studies found a positive relationship between cognitive function and LE injury risk with lower IMPACT score.\textsuperscript{8,9,12} These studies varied significantly in participant populations including male football players at one university,\textsuperscript{9} recreational female college athletes,\textsuperscript{12} and male and female athletes at different universities.\textsuperscript{8} The study
<table>
<thead>
<tr>
<th>No.</th>
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<th>Appraisal</th>
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<td>1</td>
<td>Almonroeder (2017). Poorer Performance on a Clinical Test of Reaction Time is Associated With Higher Landing Forces During Lateral Cutting</td>
<td>Baseline Cognition</td>
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<td>Prospective Cross-Sectional Study</td>
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<td>3</td>
<td>Herman, et al. (2016). Drop-jump Landing Varies with Baseline Cognition</td>
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<td>Prospective Quasi-Experimental Study</td>
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<td>4</td>
<td>Rosen, et al. (2020). Males with Chronic Ankle Instability Demonstrate Deficits in Neurocognitive Function Compared to Controls and Copers</td>
<td>Baseline Cognition</td>
<td>Good</td>
<td>Retrospective Case Control Study</td>
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<td>5</td>
<td>Shibata, et al. (2018). The Influence of Differences in Neurocognitive Function on Lower Limb Kinematics, Kinetics, and Muscle Activity During an Unanticipated Cutting Motion</td>
<td>Baseline Cognition</td>
<td>Good</td>
<td>Prospective Quasi-Experimental Study</td>
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<td>6</td>
<td>Swanik, et al. (2007). The Relationship Between Neurocognitive Function and Noncontact Anterior Cruciate Ligament Injuries</td>
<td>Baseline Cognition</td>
<td>Good</td>
<td>Retrospective Case Control Study</td>
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<td>7</td>
<td>Wilkerson, et al. (2012). Neurocognitive Reaction Time Predicts Lower Extremity Sprains and Strains</td>
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<td>8</td>
<td>Almonroeder, et al. (2017). The Focus of Attention Influences Lower Extremity Mechanics During Cutting in Female Athletes</td>
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<td>Good</td>
<td>Prospective Cross-Sectional Study</td>
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<td>13</td>
<td>Ross, et al. (2008). Procedural Reaction Time and Balance Performance During a Dual or Single Task in Healthy Collegiate Students</td>
<td>Dual Task</td>
<td>Good</td>
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<td>14</td>
<td>Schnittjer, et al. (2017). The Effects of a Cognitive Dual Task on Jump-Landing Mechanics</td>
<td>Dual Task</td>
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<td>Simon, et al. (2019). Neurocognitive Challenged Hops Reduced Functional Performance Relative to Traditional Hop Testing</td>
<td>Dual Task</td>
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<td>Prospective Cross-Sectional Study</td>
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<td>16</td>
<td>Shinya, et al. (2011). The Effects of Choice Reaction Task on Impact of Single Leg Landing</td>
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<td>17</td>
<td>Talarico, et al. (2016). Static and Dynamic Single Leg Postural Control Performance During Dual Task Paradigms</td>
<td>Dual Task</td>
<td>Good</td>
<td>Prospective Cross-Sectional Study</td>
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<td>18</td>
<td>Fino, et al. (2016). Decreased High-Frequency Center-of-Pressure Complexity in Recently Concussed Asymptomatic Athletes</td>
<td>Concussion + Dual Task</td>
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<td>Prospective Quasi-Experimental Study</td>
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<td>19</td>
<td>Howell, et al. (2017). The Utility of Instrumented Dual Task Gait and Tablet-Based Neurocognitive Measurements After Concussion</td>
<td>Concussion + Dual Task</td>
<td>Good</td>
<td>Prospective Cohort Study</td>
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<td>20</td>
<td>Howell, et al. (2018). Worsening Dual-Task Gait Costs after Concussion and Their Association with Subsequent Sport-Related Injury</td>
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<td>Good</td>
<td>Prospective Longitudinal Cohort Study</td>
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<td>21</td>
<td>Lynall, et al. (2016). Functional Movement Deficits in Relation to Sport-Related Concussion</td>
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<td>Good</td>
<td>Prospective Quasi-Experimental Study</td>
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<td>24</td>
<td>Burman, et al. (2016). Concussed Athletes are More Prone to Injury Both Before and After their Index Concussion: A Data Base Analysis of 699 Concussed Contact Sports Athletes</td>
<td>Concussion + Risk Prediction</td>
<td>Fair</td>
<td>Retrospective Cohort Study</td>
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<td>25</td>
<td>Cross, et al. (2015). Professional Rugby Union Players have a 60% Greater Risk of Time Loss Injury After Concussion: A 2-season Prospective Study of Clinical Outcomes</td>
<td>Concussion + Risk Prediction</td>
<td>Good</td>
<td>Prospective Longitudinal Cohort Study</td>
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<td>26</td>
<td>Fino, et al. (2019). Effects of Recent Concussion and Injury History on Instantaneous Relative Risk of Lower Extremity Injury in Division I Collegiate Athletes</td>
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<td>Good</td>
<td>Retrospective Cohort Study</td>
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<td>28</td>
<td>Harada, et al. (2019). Multiple Concussions Increase Odds and Rate of Lower Extremity Injury in National Collegiate Athletic Association Athletes After Return to Play</td>
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<td>29</td>
<td>Herman, et al. (2016). Concussion may Increase the Risk of Subsequent Lower Extremity Musculoskeletal Injury in Collegiate Athletes</td>
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<td>Houston, et al. (2018). Sex and Number of Concussions Influence the Association Between Concussion and Lower Extremity Injury</td>
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<td>Fair</td>
<td>Retrospective Cross-Sectional Study</td>
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<td>34</td>
<td>Krill, et al. (2018). Effect of Concussions on Lower Extremity Injury Rates at a Division I Collegiate Football Program</td>
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<td>Prospective Observational Cohort Study</td>
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<td>37</td>
<td>Nordstrom, et al. (2014). Sports Related Concussion Increases the Risk of Subsequent Injury by About 50% in Elite Male Football Players</td>
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<td>Good</td>
<td>Prospective Cohort Study</td>
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<td>47</td>
<td>Myashita, et al. (2017). Correlation of Head Impacts to Change in Balance Error Scoring System Scores in Division I Men's Lacrosse Players</td>
<td>Concussion + Testing</td>
<td>Good</td>
<td>Prospective Longitudinal Cohort Study</td>
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<td>48</td>
<td>Shiflett, et al. (2015). The Effects of Subconcussive Impacts on Postural Stability</td>
<td>Concussion + Testing</td>
<td>Poor</td>
<td>Prospective Longitudinal Cohort Study</td>
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<td>49</td>
<td>Hunzinger, et al. (2020). Diagnosed Concussion is Associated with Increased Risk for Lower Extremity Injury in Community Rugby Players</td>
<td>Concussion + Risk Prediction</td>
<td>Fair</td>
<td>Retrospective Cross-Sectional Study</td>
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<td>51</td>
<td>Monfort, et al. (2019). Visual-spatial Memory Deficits are Related to Increased Knee Valgus Angle During a Sport-specific Sidestep Cut</td>
<td>Dual Task</td>
<td>Fair</td>
<td>Prospective Cross-Sectional Study</td>
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<td>52</td>
<td>Murray, et al. (2020). Baseline Postural Control and Lower Extremity Incidence Among Those with a History of Concussion</td>
<td>Concussion + Risk Prediction</td>
<td>Good</td>
<td>Prospective Cohort Study</td>
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that reported null differences between groups studied 14-17 year old ski and snowboard athletes.\textsuperscript{15}

The robustness of findings across participant groups matched the variety of dependent measures included in these studies. Slower reaction times on the ImPACT test correlated with increased vertical ground reaction force with unanticipated jumping conditions\textsuperscript{12} and an increased likelihood of lower extremity injury during one football season.\textsuperscript{9} Other factors of the ImPACT test including verbal memory, visual memory and processing speed were worse in participants who sustained a non-contact ACL injury.\textsuperscript{8} Out of the studies looking at ImPACT scores and baseline cognitive function, one study did not find significant differences on pre-season ImPACT testing for the injured group and non-injured group.\textsuperscript{15} This study may have a different result due to the ages of participants being younger (14-17 v. 18-24 year-olds) or the difference in the environmental demands of downhill skiing (snow conditions may have led to a non-impact ACL injury versus football and unanticipated jumping with relatively stable playing surfaces).

Three studies utilized other methods to define baseline cognitive function. One study utilized the Concussion Resolution Index (CRI) which examines memory, reaction time, speed of decision making, and speed of information processing in a computer test like ImPACT.\textsuperscript{7} Herman and Barth found that low performers had increased peak anterior tibial shear force, knee abduction moment, knee abduction angle, and decreased trunk flexion angle on a drop-landing task,\textsuperscript{7} often considered mechanics that lead to ACL rupture. Another tool used to measure cognitive function is the CNS Vital Signs computer-based cognitive tests. A group with chronic ankle instability had significantly lower composite memory, visual memory, and simple attention compared to the control group.\textsuperscript{17} Finally, female jumping and cutting athletes with a lower score on the Symbol Digit Modalities Test had significantly increased quadriceps activity before and after ground contact and decreased cocontraction ratio only after ground contact with unanticipated cutting tasks and single leg landing.\textsuperscript{16} Together, these results indicate that across sports (note the exception of skiing / snowboarding\textsuperscript{15}) measures of cognition and measures of kinetics / kinematics, a negative relationship exists with poorer biomechanical performance and/or increased injury rates in athletes with lower baseline cognitive performance.
THE EFFECT OF COGNITIVE LOAD ON LOWER EXTREMITY MOVEMENT IN HEALTHY ATHLETES

Dual Task Activities. While one approach to determine the role of cognitive ability on lower extremity injury risk is to measure natural baseline function, it may not consider the additional resources needed in game time situations. Another approach is to add a second cognitive operation in addition to performing a motor task. The use of single motor tasks to assess athletic performance, such as a drop vertical jump, balance measures, and reaction time have not been specific enough to determine which athletes would ultimately sustain a lower extremity injury. Single motor tasks may not be challenging enough from a cognitive perspective and do not replicate the full demands of sport participation. Dual task paradigms explore the impact on performance when a cognitive task, such as trail making, serial 7’s, word spelling, or reciting months in reverse order, is combined with a physical task, such as maintaining postural stability during perturbations, walking, balancing, or cutting activities. The addition of a cognitive demand, and thus the utilization of dual-task paradigms, has shown increases in the incidence of more risky lower extremity mechanics.20 The decrease in cognitive or physical performance during dual task paradigms compared to performance during single physical tasks is termed dual-task cost.21

Ten articles in this category utilized jump landing tasks to examine participants’ ability to maintain controlled lower extremity mechanics to decrease injury risk.4,12,19,20,22–27 Five utilized a similar method of introducing cognitive demand, including counting, math, memorization, and visual distractions,4,23–25,27 while the other five articles12,19,20,22,26 used decision-making and sport activities (cutting, passing, overhead goal, dribbling a soccer ball) to increase cognitive demand. In all cases, the ten studies demonstrated that when a second simultaneous task was added, lower extremity mechanics changed including increased number of failed trials,4,15 decreased overall jump height,4,23 higher peak vertical ground reaction force,12,24,28 decreased knee flexion,12,22,28 decreased postural stability,25 and increased knee valgus.22,26 These altered lower extremity mechanics are classified as “risky” mechanics leading to increased lower extremity injury risk.

Three included articles took a different approach to quantify athlete’s ability to maintain safe mechanics during activities other than jump landings, such as balance assessments and repeated hop tests.31 These three articles introduced additional cognitive demand through the use of more reactive tasks such as the Auditory Procedural Reaction Time (APRT) test and the Procedural Reaction Time Throughput (PRTT) test,29 modified Stroop test and the Brooks Spatial Memory Test,30 and reaction to color identifying initiation of hopping task.31 The APRT and PRTT increase cognitive demand through the participant reacting to auditory (APRT) or visual (PRTT) stimuli to assess reaction time. The Stroop test increases cognitive demand through higher level processing to report the color of the work presented which is typically also a color (the word ‘red’ presented in blue font). The Brooks Spatial Memory Test involves a person describing a set of numbers on a grid to a participant and the participant must then report the order of the numbers on a grid from memory, increasing cognitive load during other tasks. Under dual task conditions, reaction time decreased.29,51 mechanics were modified to maintain stability,29,30 and athletes had more difficulty maintaining balance control,30 potentially leading to increased injury risk compared to single task conditions.

THE EFFECT OF COGNITIVE ABILITY AND COGNITIVE LOAD ON LOWER EXTREMITY MOVEMENT IN CONCUSSIONED ATHLETES

In recent years, a considerable number of studies have addressed the impact of a concussive event on lower extremity injury risk and the presence of altered lower extremity mechanics post-concussion. These authors focused on the effect of concussion itself on injury risk. A slightly different perspective on this patient population can be taken. Rather than focusing on the diagnosis of concussion, these studies included as concussions lead to short-term cognitive deficits32,33 and potentially represent lower cognitive ability. However, due to the transient nature and significant variability of concussion effects,34,35 the results of these articles were summarized separately from the other categories.

Concussion and Dual Task Performance. Four articles21,36–38 examined the effect a positive history for concussion on participant performance during dual task paradigms. These studies included division 1 collegiate athletes21,36 and recreational athletes.37,38 Cognitive tasks included the Standard Assessment of Concussion (SAC) test, Trail Making A and B, processing speed tasks, spelling five letter words backwards, subtracting by serial 7s from a randomly presented 2-digit number, and reciting the months of the year in reverse order. Participants performed these cognitive tasks while maintaining postural stability, performing an 8- or 10-meter walk test and performing tandem gait tests, functional movement tasks such as jump landing tasks and cutting tasks.39 Three studies21,37,39 explored the dual task cost when cognitive assessment tasks were performed simultaneously during gait tasks while one study examined dual task during quiet stance.36 All four papers found a decreased level of performance in the recently concussed cohort compared to healthy controls.21,36,37,39 Participants with a recent concussion not only reported more symptoms, but also walked significantly slower during dual task conditions and responded with slower simple reaction times. Although the differences were less significant during functional tasks, the control group displayed better reaction time than the concussed group during the anticipated cutting and the concussed group displayed greater trunk flexion while cutting.39 Recently concussed athletes exhibited less postural stability compared to healthy controls, even when tested 6-weeks post-concussion and beyond the resolution of symptoms.36

Concussion and Risk Prediction. Twenty-two articles10,11,36,38,40–57 examined the influence of concussion on lower extremity injury rates. Researchers across these studies examined participant data longitudinally and included a wide variety of participant characteristics: both male and female participants, recreational, university, and professional athletes, soldiers, high school-aged athletes,
retired professional athletes, participants from multiple countries, and participants across many sport activities. All twenty-two studies reported an increased risk of lower extremity injury after experiencing one or more concussive events. A history of concussion can increase the risk of sustaining a lower extremity injury between 1.60 times\textsuperscript{42} to 7.37 times.\textsuperscript{40} Injury rates remained increased far beyond the resolution of symptoms and even remained increased following an appropriate return to play (RTP) protocol. A 38% greater risk of lower extremity injury up to two years post-concussion has been reported.\textsuperscript{47} Time to lower extremity injury after RTP, was significantly shorter in concussion groups than in control groups.\textsuperscript{36,52} Lastly, multiple concussions were often associated with higher incidence or greater odds of sustaining a lower extremity injury.\textsuperscript{38,45,48,51,52} with one study reporting a 34% increase in odds of sustaining a lower extremity injury for every previous concussive event.\textsuperscript{38}

**Concussion and Baseline Testing.** Ten papers\textsuperscript{58–67} examined the effect that a history of concussion has on motor performance. Tests in this category included rapid alternating movement,\textsuperscript{58} the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP),\textsuperscript{61,62} the modified Romberg test on foam,\textsuperscript{63} the Balance Error Scoring System (BESS), the Y-balance test,\textsuperscript{64,65,67} balance tasks,\textsuperscript{66} and the functional movement screen (FMS).\textsuperscript{59,67} Participants varied in age range and participation level, including children aged 7-16 years old,\textsuperscript{61,62} high school athletes,\textsuperscript{65,66} recreationally active college students,\textsuperscript{59,66} and Division I collegiate athletes.\textsuperscript{58,63,64,67}

Five of the ten articles reported significant test performance deficits by participants who had a history of at least one concussive event. Performance test deficits included greater inhibition of the primary motor cortex during a balance task,\textsuperscript{58} altered lower extremity stiffness during landing,\textsuperscript{60} decreased performance on the BOTMP,\textsuperscript{61,62} and increased errors on the BESS test.\textsuperscript{62} The remaining five articles did not find statistically significant differences between concussed and non-concussed groups when examining performance during testing.

**DISCUSSION**

Cognition most likely contributes to lower extremity injuries when the system is taxed beyond capacity. Exceeding cognitive limits can occur either due to limited cognitive ability or to increased task demands. Articles addressing both components of cognitive function (ability and demand) were included in this scoping review to assess the robustness of any cognitive contributions to LE injury risk. No constraints were placed on sport, gender or experience level for the same reason. Additionally, studies that directly measured both the predictive ability of cognitive function on lower extremity rates and ones measuring biomechanical factors known to lead to ACL injury were included to cast a wide net. Consistent across participant demographics, tasks, and dependent measures, fifty-one of fifty-six assessed articles concluded that decreased cognitive ability or increased cognitive load led to risky LE mechanics or a direct increase in non-contact LE injury risk. The six studies that did not support the previous statement had some commonalities: four of six had fair or poor methodological quality and five of six fell under the concussion and baseline testing category. Limitations of these latter five articles included: investigating sub-concussive events,\textsuperscript{64} fair methodological quality,\textsuperscript{63,65} poor methodological quality due to non-matched cohorts,\textsuperscript{64} club level athletes as participants,\textsuperscript{59} and small sample size.\textsuperscript{64}

The results from the 51 papers provide some insight on how clinicians might further consider how to optimize current injury prevention and return-to-sport protocols. A cognitive component contributing to decreased reaction time, decreased attentional resources, and altered LE mechanics leading to increased risk of non-contact injury has largely been ignored in both research and clinical practice settings. Dual task conditions, which are common in sport, challenge cognitive reserve which then results in decreased physical and cognitive performance during biomechanical tasks in both healthy and previously concussed populations.\textsuperscript{21} Further research is needed to evaluate the effectiveness of novel prevention and intervention programs that address cognitive functional deficits in addition to biomechanical considerations. Future studies should include methods to quantify the risk associated with altered cognitive function.

**LIMITATIONS**

In such a broad, scoping review, decisions for article inclusion to increase the robustness of the findings also created some limitations. The intent of the present study to uncover cognitive contributions to lower extremity non-contact injury risk led to casting a wide net by including athletes with impaired cognitive function (concussion), athletes with a natural variance in typical cognitive function and also athletes undergoing tasks with higher cognitive load (dual-task paradigms). Cognition is impacted both by an individual’s cognitive capacity and the cognitive demands of a task. In sport, the cognitive demands are typically high in sports where most non-contact ACL injuries occur (e.g., soccer, basketball). Add to that diminished cognitive ability, either through a natural baseline or through brain injury, an athlete might be at higher risk of injury. It is explicitly for this reason, populations with differences in cognitive ability and populations undergoing tasks with higher cognitive loads were included to determine if both cognitive ability and cognitive demands had a similar impact on injury risk. Far more research exists on the effect of concussion on injury risk than typical baseline function, so this population was included in the present scoping review. These cases of concussion were intentionally evaluated separately in case the results deviated from healthy individuals, which ended up not being the case.

Attempting to define cognitive ability (whether natural variance or after brain injury) is difficult. In this manuscript, the definition provided by Herman and Barth\textsuperscript{7} was used, which includes multiple domains presumed not to affect motor function (social interactions, intelligence) and others that do (reaction time, attention, working memory). The findings of this manuscript do not allow the reader to identify the specific cognitive domains most critical for efficient lower extremity function. Future work is needed to...
pinpoint domains most ripe for intervention to prevent injury.

Studies investigating actual risk (AKA reporting injury rates in sub-populations) and studies measuring lower extremity mechanics thought to lead to non-contact ACL injury were included in the present scoping review. It is important to distinguish between the two. Research evaluating actual risk were confined to the categories of baseline cognitive function and athletes who have experienced concussion, whereas at least one paper in each category included in this scoping review evaluated changes in lower extremity mechanics based on cognition (either cognitive capacity or task cognitive load). Caution must be taken in the interpretation of changes in mechanics as it may not directly lead to injury.

Although 56 articles were included in the present scoping review, not enough articles existed to allow any conclusions to be made specific to gender, age, or level of sport. Interestingly, in spite of the significant variation in researched sport, level of competition and gender, the results were surprisingly consistent that cognition did appear to play a factor. An interesting line of future research would be to explore any one of these categories relative to cognition and injury risk.

Some may consider another limitation of the present scoping review is that of including eleven doctoral dissertations, although others would not. While these documents would have not gone through blinded peer-review, they would have been extensively reviewed by a dissertation committee that would presumably consist of experts in the research area. The methods of the dissertations were reviewed in the same manner as the published articles to ensure methodological quality using the NIH checklist. None of them exhibited poor or fair quality.

Overall, the literature is dominated by concussion studies, and more research needs to focus on cognitively typical populations. Of the studies that do study cognitive function and dual tasks, large variability exists in the objective measures used to demonstrate decreased cognitive function, allowing for limited capability in comparing measures among studies. Future research will need to determine cut-off scores for cognitive tests and dual task performance tests to better define what constitutes an at-risk athlete based on cognitive performance.

CLINICAL IMPLICATIONS

Determining the impact of cognitive function on non-contact LE injury will guide rehabilitation professionals to develop innovative, evidence-based prevention strategies to decrease risk of non-contact LE injury in a wide variety of populations that may have a cognitive component to injury risk. Training cognitive factors may serve as the missing link in highly effective and robust injury prevention programs and warrants further study.

CONCLUSIONS

Results of this scoping review demonstrate decreased cognitive function and increased cognitive load related to task demands are associated with increased lower extremity injury risk via decreased attentional resources, slowed reaction time, and altered LE mechanics. Further investigation is needed to understand how cognitive function can be improved to decrease the risk of future non-contact LE injury, address these deficits and to better understand how baseline cognition and dual task conditions can impact and improve functional rehabilitation protocols. Additionally, it will be important to determine how functional rehabilitation protocols can maximize performance in individuals with a history of concussive event(s) or otherwise lower cognitive function.

GRANT SUPPORT

None.

FINANCIAL DISCLOSURE AND CONFLICT OF INTEREST

Authors have nothing to report.

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APPENDICES

APPENDIX 1. SPECIFIC ELECTRONIC SEARCHES USED IN PUBMED, EBSCO – CINAHL, SPORTDISCUS AND GOOGLE SCHOLAR.

“neurocog*” AND (“lower extremity injury” OR “leg injury”)
   (“concussion” OR “mTBI”) AND “impact testing” AND “lower extremity injur*”
   (“neurocognitive deficits” OR “mTBI”) AND “lower extremity injury”
   (“neuropsychological function” OR “neurocog*” OR “neuropsych*”) AND (“lower extremity injury” OR “lower extremity” AND injur*)
   (“leg injur*” OR “lower extremity injur*”) AND (“neuropsych*” OR “neurocog*”)
   (“concussion” OR “mTBI”) AND “impact testing” AND “lower extremity injur*”
   (“lower extremity” AND “injur*”) AND (“neurocog*” OR “neuropsych*”)
   (“Lower Extremity injur*”) AND (“Brain Concussion” OR “mTBI”),

International Journal of Sports Physical Therapy
## Appendix 2. Summary of study demographics, methods, and results.

<table>
<thead>
<tr>
<th>No.</th>
<th>Participants</th>
<th>Task</th>
<th>Dependent measures</th>
<th>Results / Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Recreational active females aged 18-25 (n=45) competing in sports involving landing and cutting (basketball, soccer, tennis)</td>
<td>ImPACT and biomechanics testing including a forward jump with pre-planned and unplanned conditions. Unplanned conditions included: (1) lateral cut from non-dominant limb (2) single leg landing on non-dominant limb without subsequent cut (3) bilateral landing and vertical jump. Participants unaware of which maneuver would be performed until after initiation of the trial. Planned trials included only the lateral cut stimulus.</td>
<td>ImPACT reaction time; hip, knee, ankle joint angles and net joint moments; hip flexion, knee flexion and knee abduction initial contact angles and range of motion (ROM= peak angle-angle at initial contact); peak knee abduction moments and peak vGRFs.</td>
<td>Participants with slower reaction times demonstrated higher peak vGRFs compared to participants with faster reaction times, regardless of cognitive demands. Landing with higher vGRFs may increase injury risk.</td>
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<td>2</td>
<td>134 athletes (93 with injury, 41 without) aged 14-17 in local ski and snowboard club in 2009-2012 seasons</td>
<td>ImPACT scores (administered prior to each competitive season) and injury records.</td>
<td>Components of ImPACT and each sub-component score including reaction time (RT), verbal memory, visual memory, visual motor speed (VMS), and cognitive efficiency index and injury rates.</td>
<td>No significant difference between non-injured and injured females or males in RT and VMS. RT for injured females was 4.7% faster while males without injury had a 5.8% slower reaction time. Females with injury had a 4.1% higher mean VMS score while males without injury had a 14.4% higher VMS score.</td>
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<td>3</td>
<td>Recreational athletes 18-30 years (n=28) who (1) participate in jumping or squatting sports at least 3 times a week or (2) participate in jump/squatting sports at least once per month and participated at the high school varsity or collegiate club levels.</td>
<td>Concussion Resolution Index (CRI). Based on CRI scores, subjects were placed into high performers (n=14) and low performers (n=14) groups. Task consisted of a forward jump onto a force plate with an immediate rebound to a second target that was assigned 250 ms before landing on the force plate.</td>
<td>Three-dimensional kinematic and kinetic data of the dominant limb were collected while performing an unanticipated jump-landing task</td>
<td>The low performers group demonstrated significantly altered neuromuscular performance during the landing phase of the jump-landing task, including significantly increased peak vGRF, peak anterior tibial shear force, knee abduction moment, knee abduction angle, and decreased trunk flexion angle.</td>
</tr>
<tr>
<td>4</td>
<td>Physically active university-aged males (n=41) (14 with no history of ankle sprain, 13 with history of 1 ankle sprain, 14 with chronic ankle instability [CAI])</td>
<td>CNS Vital Signs computer-based neurocognitive tests (verbal memory, visual memory, finger tapping, symbol digit coding, Stroop, and shifting attention)</td>
<td>CNS Vital Signs score</td>
<td>CAI group had significantly lower composite memory, visual memory, and simple attention compared to control group. Single ankle sprain group demonstrated poorer visual memory compared to controls.</td>
</tr>
<tr>
<td>5</td>
<td>Female athletes (n=15) (age 20.1 +/- 1.3 years) who engage in university athletic club</td>
<td>Symbol Digit Modalities Test (SDMT) and unanticipated cutting tasks. Participants were asked to fill out 110 boxes under symbols</td>
<td>Joint angles and moments measured muscle activity of dominant leg during unanticipated cutting task using a</td>
<td>Subjects with a lower SDMT score had significantly increased quadriceps activity before and after ground contact and decreased co-contraction ratio only after ground contact. Dominant quadriceps activity has been...</td>
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<td>6</td>
<td>160 athletes (80 noncontact ACL injuries, 80 controls) from 18 universities. Of the 80 noncontact ACL Injury (NCACL) athletes, 45 women (age 20.6 +/- 1.7 years) and 35 men (age 20.8 +/- 1.1 years). Control group was randomly matched based on similar characteristics.</td>
<td>Participants completed the 4 subtests of the ImPACT version 2.0 and injury data.</td>
<td>Pre-season ImPACT score results from ImPACT subtests, including verbal memory, visual memory, processing speed, and reaction time</td>
<td>Statistical differences were found between the non-contact ACL-injury group and the matched controls on all 4 neurocognitive subtests. Non-contact ACLs are associated with errors in coordination. Neurocognitive differences identified between groups may predispose athletes to non-contact injuries.</td>
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<td>7</td>
<td>NCAA-FCS collegiate football players (n=76) (19.8 +/- 1.5 years) participating in the 2011 pre-season practice sessions</td>
<td>Pre-season ImPACT test results and injury data</td>
<td>ImPACT test score results and injury statistics</td>
<td>Participants with increased RT were at increased risk of sustaining a LE injury. Thus, athletes who exhibit slower neurocognitive reaction time, as determined by computer-based testing, may derive the greatest benefit from activities designed to enhance responsiveness to visual stimuli.</td>
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<tr>
<td>8</td>
<td>Recreational college females (n=20) age 18-25 with experience in organized basketball</td>
<td>Landing jump plus lateral cutting trials conducted in 3 different conditions (1) pass: while carrying a basketball and execute a chest pass immediately upon landing, (2) ball: carrying a basketball with no chest pass, (3) cut: lateral cut without hold ball or performing chest pass</td>
<td>Peak vGRFs for the plant limb; angles of hip flexion, peak knee flexion and peak knee abduction at initial contact for plant or landing limb; hip flexion ROM, knee flexion ROM and knee abduction ROM. (ROM measured by the difference between peak joint angle and the angle at initial contact for each trial). Knee abduction infers a 'valgus collapse' of the knee, characterized by the knee moving medially while the distal end of the shank angles away from the midline of the body.</td>
<td>Participants landed with less knee flexion and greater knee abduction (valgus) when required to focus attention on a chest pass following a cut. Requiring participant to focus attention on performing a chest pass resulted in a landing pattern that would likely increase demands on the ACL.</td>
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<td>9</td>
<td>Recreational college females (n=20) age 18-25 with experience in organized</td>
<td>Drop vertical jump (DVJ) task with 4 conditions (1) without decision making or overhead goal, (2) with decision making but no 2D and 3D knee ankle (KA) ratio measure (KA: horizontal distance between knee joint centers divided by horizontal distance</td>
<td>Participants demonstrated decrease in the KA ratio, indicating increased knee valgus, when the overhead goal condition is added to a DVJ, relative to the baseline. Including an overhead goal has the potential to influence</td>
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<td>10</td>
<td>Recreational college females (n=20) age 18-25 with experience in organized basketball</td>
<td>overhead goal, (3) without decision making with an overhead goal, (4) with both decision making and overhead goal.</td>
<td>between ankle joint centers).</td>
<td>landing mechanics. Landing in this manner may place an individual at high-risk for ACL injury since it corresponds with valgus collapse of either one or both knees.</td>
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<tr>
<td>11</td>
<td>Recreationally active males (n=11) and females (n=9) aged 20-23 who play one of five sports: basketball, football, rugby, soccer, or lacrosse</td>
<td>Tasks were randomized for each participant: Jump landing tasks with no concurrent cognitive task, jump landing task with dual task condition consisting of: Stroop Color Word Test (SCWT), Symbol Digits Modalities Test (SDMT), and Brooks Visuospatial Task (BVT)</td>
<td>(1) LESS score, (2) Reaction time in sec, (3) Speed and % error performance of cognitive variables (SCWT, SDMT, BVT)</td>
<td>Movement quality, as assessed by LESS, did not change during dual task conditions. Gross RT was slower during dual-task conditions. Cognitive task completion speed increased during dual task conditions. Test accuracy decreased (more errors) for all cognitive dual task conditions (SCWT, SDMT, BVT) compared to baseline testing. Increased number of failed trials in SCWT, SDMT and BVT dual task conditions compared to baseline trials. Participants sacrificed reaction time and accuracy on the cognitive task to produce a consistent movement pattern. Increased cognitive task speed during dual task conditions compared to baseline can be explained by increase in attention during dual task conditions.</td>
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<td>12</td>
<td>Recreationally active athletes (n=38) who play sports involving jump landings</td>
<td>Drop jump task lateral to 50% standing height followed by a maximum vertical jump. Three reps performed solo, counting backwards by 1, and counting backwards by 7.</td>
<td>First 100 ms of first landing: knee kinematics, vGRF, knee valgus, posterior GRF, jump height, stance time.</td>
<td>Participants demonstrated decreased knee flexion angles at initial contact for the counting by 1 condition compared with the no counting condition. Participants showed increased peak posterior GRF and vGRF during early landing and decreased jump height for the counting by 1s and counting by 7s conditions compared with the no counting condition. The authors had minimal criteria for counting trials, and the number of trials that had to be performed to get a ‘correct’ trial increased with the increased demands of the task.</td>
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<td>13</td>
<td>Healthy, physically active 18-25 (20.43 +/- 1.33) year old males (n=14) and females (n=16)</td>
<td>Participants completed the Sensory Organization Test (SOT), Balance Error Scoring System (BESS), Procedural Reaction Time Throughput (PRTT), and Auditory Procedural Reaction Time (APRT) in both single and dual task conditions.</td>
<td>Scores on SOT, BESS, PRTT, APRT, and cost to balance and auditory (% change in performance from single task to dual tasks on SOT and BESS)</td>
<td>Balance performance on the BESS (14.236 ± 31.003) showed a greater percentage cost compared to balance performance on the SOT (1.993 ± 4.873) during a dual task. Combining a cognitive test aimed at processing speed and attention with the BESS and SOT has the potential to be a more sensitive test than these same measures performed during a single task.</td>
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<td>14</td>
<td>10 male, 10 female age</td>
<td>Participants completed a tuck-jump trial over 3</td>
<td>Overall tuck jump score; peak vertical ground</td>
<td>There was a significant increase in tuck jump score from baseline to easy</td>
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<td>22.4+/-.314 years who participated in exercise at least 3 hours a week</td>
<td>cognitive conditions (control, easy, difficult). The easy cognitive task consisted of digit recall of a string of 5 numbers and the difficult task consisted of use of arithmetic of a string of 5 numbers.</td>
<td>reaction force</td>
<td>cognitive task and baseline to difficult cognitive task, but no significant increase from easy to difficult. There were no significant differences in mean vGRF; it may be possible that the easy and difficult cognitive tasks may have been distracting enough to decrease jump height, resulting in a decrease in vGRF.</td>
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<tr>
<td>15</td>
<td>9 male, 13 females aged 20.9 +/- 2.5 years who were healthy and active for 3 days/week with no LE injury or surgery within the past 6 months.</td>
<td>Four single-leg (SL) hops (traditional condition): (1) SL hop for distance (2) 6-m SL hop for time (3) SL cross-over hop for distance and (4) SL triple hop for distance. Participants also performed the four types of SL hops with a neurocognitive condition implemented using the FitLight system with colors indicating when to hop.</td>
<td>Quickest reaction time, maximum hop distance.</td>
<td>The crossover hop, triple hop and 6-m were statistically different between traditional and neurocognitive conditions. No significant difference between SL hops traditional or neurocognitive condition.</td>
</tr>
<tr>
<td>16</td>
<td>Healthy male subjects (n=12) age 24.4 +/- 3.0 years</td>
<td>Participants stood on a force platform holding button switches marked for left and right directions. There was a choice reaction task, a landing task, and a dual task. In the choice reaction, participants responded to a left or right LED light and were instructed to push the corresponding button as fast as possible. In the landing task, participants made a small vertical jump as soon as possible. The dual task was a combination of choice reaction and landing tasks.</td>
<td>vGRF and RT</td>
<td>Greater vGRF and acceleration was observed during SL landing under the conditions in which the participants were required to react to visual stimuli. High impact during landing is known to be related to sprains. Results suggest that athletes are exposed to higher impact forces in a real sport environment than during a controlled landing task, in which they can cognitively focus on absorbing the impact.</td>
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<tr>
<td>17</td>
<td>Convenience sample of healthy college students. 22 female, 8 male; age 20.8 +/- 1.6 years</td>
<td>SL stance and SL squat tasks on a force plate individually (single task) and concurrently (dual task) with two cognitive assessments, a modified Stroop test and the Brooks Spatial Memory Test.</td>
<td>Center of pressure speed, 95% confidence ellipse, squat depth, and speed and cognitive test measures.</td>
<td>Not all dual task paradigms have the same effect on postural control. Squat performance is compromised during dual task conditions. RT is slowest during dynamic movement with a dual task added. Individuals alter their biomechanics during dual task conditions to maintain stability and correctly complete the cognitive assessments.</td>
</tr>
<tr>
<td>18</td>
<td>6 recently concussed NCAA DI athletes, 25 healthy athletes with no concussion history, 25 healthy physically active non-athletes with no concussion</td>
<td>Concussed and healthy participants stood barefoot with feet together on a force platform and instructed to stand still for 2 minutes. Three additional quiet standing trials with additional instructions were then performed randomly: (1) co-contraction (2) cognitive</td>
<td>Center of pressure (COP) displacement, COP oscillation regularity, motor execution speed, long-interval intracortical inhibition, cortical silent period</td>
<td>Concussed athletes exhibited less postural stability complexity compared to healthy athletes, providing evidence that postural stability complexity remains affected by concussive deficits 1-6 weeks post-concussion. Post-concussion postural deficits persist beyond the recovery of clinical signs and symptoms. Non-athlete participants demonstrated an increase in postural stability complexity during co-contraction task. This study did not find an effect of an added cognitive</td>
</tr>
<tr>
<td>No.</td>
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<td>19</td>
<td>Division 1 collegiate athletes with recent concussion and larger matched control group (18 tested within 5 days of concussion, 41 tested as part of a baseline examination)</td>
<td>Participants completed the Standard Assessment of Concussion (SAC), Trails A and B Test, a processing speed task (Symbol Digit Modalities), simple reaction time task, choice reaction time task, dynamic visual acuity test, and dual task conditions) for a 10-meter walk as follows: (1) spelling a five-letter word backwards, (2) subtracting by 6s or 7s from a randomly presented 2-digit number, or (3) reciting months of the year in reverse order starting from a randomly chosen month.</td>
<td>SAC score, Trail Making A time, Trail Making B time, processing speed with number of correct answers, simple reaction time, choice reaction time, visual acuity line difference, and average gait speed.</td>
<td>Participants with concussion reported significantly more severe symptoms, walked significantly slower during dual-task conditions, and responded with significantly slower simple reaction times.</td>
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<td>20</td>
<td>Recreational athletes with subsequent injury (n=15) and with no subsequent injury (n=27) that sustained a concussion were evaluated for dual task gait outcomes within 3 weeks and after recovery</td>
<td>Post-Concussion Symptom Scale (PCSS) evaluated symptom severity and dual task conditions during an 8-meter walk test as follows: (1) spelling a five-letter word backwards, (2) subtracting by 6s or 7s from a randomly presented 2-digit number, or (3) reciting the months in reverse order starting from a randomly chosen month and calculated dual task cost between no task and dual task conditions.</td>
<td>Dual-task gait cost</td>
<td>Significant dual-task gait cost worsening throughout concussion recovery was associated with time-loss injuries during sport performance in the year after a concussion.</td>
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<td>21</td>
<td>Recreational athletes with recent concussion and matched controls (concussion n=15, control n=15)</td>
<td>Tandem gait with varied conditions: (1) eyes open, no distraction (2) eyes closed, no distraction (3) eyes open, with cognitive distraction (Brooks Visuospatial Task), and (4) eyes closed, with cognitive distraction. Joint kinematics and reaction time data during jump-landing, anticipated-cut, and unanticipated cut.</td>
<td>COP data, joint kinetics and kinematics, velocity on tasks, and reaction time</td>
<td>The recently concussed group demonstrated slower velocity during tandem gait compared to the control group. Greater dual-task cost was observed for COP speed, such that the concussion group reduced their COP speed to a greater extent than the control group during the eyes closed dual-task condition as compared to the eyes closed, no cognitive task condition. There were no between-group differences in reaction time during cutting tasks, but the control group displayed better reaction time cost than the concussed group during anticipated cutting. The concussed...</td>
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<td>22</td>
<td>NCAA D1 athletes; 116 males, 48 females, 82 recently concussed athletes (58 males, 24 females) were randomly matched with one non-concussed subjects by sex, sport, position, calendar year, and BMI.</td>
<td>Medical records pertaining to any documented LE musculoskeletal injury that had occurred in the 90-day period prior to the concussed subjects’ sport-related concussion and in the subsequent 180-day period after the concussed athlete returned to play was collected and analyzed and compared to matched controls. All athletes performed ImPACT testing.</td>
<td>Documented musculoskeletal injury data</td>
<td>The frequency of LE musculoskeletal injury during the 180-day observation window following return to play was greater in concussed athletes (62.2%) when compared with matched controls (25.6%). The odds for an athlete with a history of concussion, sustaining a LE musculoskeletal injury after returning to play following a concussion is 7.37 times greater in the same period compared to athletes who have not sustained a LE injury.</td>
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<td>23</td>
<td>58 male and 17 female athletes with 87 total cases of concussion participating in NCAA D1 football, soccer, hockey, softball, basketball, wrestling, or volleyball from 2011-2014 matched with 182 control athletes without a history of concussion in the previous year.</td>
<td>Concussion diagnosis, onset, return-to-play date and MS injury diagnosis and onset were collected through the SIMS database. During the 90-day period after return-to-play for each case was reviewed for LE MS injury as well as the year before enrollment to account for previous injury history and was compared with the same 90-day period in up to 3 control athletes.</td>
<td>Lower extremity injury incidence rate</td>
<td>Concussed athletes have increased odds (17%) of sustaining an acute lower extremity MS injury during the 90-day return to play than non-concussed matched controls (9%). No difference in time to lower extremity injury in controls and concussed athletes.</td>
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<td>24</td>
<td>Participants were athletes who suffered a concussion (n=4,961) aged 15-35, and played either ice hockey, football (soccer), floorball, and handball in the data base of the University Hospital in Umea, Sweden during the years 1993-2009. Control group of athletes (n=1,259) with ankle sprain, obtained from the same data base and played the same sports.</td>
<td>Injury data from 24 months before and 24 months after the index injury (conclusion for study group; ankle sprain for control group) were analyzed.</td>
<td>Injury data</td>
<td>Athletes with concussion had higher risk for injury both before and after the index injury, compared with the control group (OR 1.98 before and 1.72 after). Athletes with concussion suffered two or more times the number of injuries before and after concussion compared with control group. No significant increase in overall number of injured individuals after the concussion compared with before. Athletes who sustained concussion were more injury prone, in general.</td>
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<td>25</td>
<td>First-team players in 12 highest level club rugby teams in England (n=810)</td>
<td>Incidence of concussions and 24-hour time-loss injuries recorded by medical personnel</td>
<td>Incidence rate for injury before concussion and following RTP from concussion</td>
<td>Of 810 players in study, 150 reported 181 concussions. Following a concussion, players were 1.6 times more likely to suffer a match injury of any type than players who had not sustained a concussion. Pre-concussion incidence for injury not significantly different between groups.</td>
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<tr>
<td>26</td>
<td>76 male and 34 female NCAA D1 athletes with average age 20.1 years that were matched with non-concussed controls.</td>
<td>Medical records reviewed on 110 concussed athletes and 110 matched controls for LE injuries within the year before and year after concussion.</td>
<td>Previous injury in last year, time from concussion to LE injury.</td>
<td>The concussed group had a 67% greater instantaneous relative risk of LE injury compared with controls after adjusting for the presence of a previous LE injury.</td>
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<tr>
<td>27</td>
<td>College athletes (n=335) (17 different NCAA and NJCAA member institutions) from 13 sports at the end of their athletic career</td>
<td>Self-report questionnaire indicating total number of reported, unreported, and potentially unrecognized concussions as well as LE injuries including ankle sprains, knee injuries, and muscle strains.</td>
<td>LE injury data</td>
<td>Significant associations found between concussion and lateral ankle sprain, concussion and knee injury, and concussion and LE muscle strain.</td>
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<tr>
<td>28</td>
<td>NCAA DI athletes (n=48) from one institution who sustained multiple concussions between 2001-2016.</td>
<td>Athletes with multiple concussions (MC) were matched with athletes with single concussion (SC) and to athletes with no concussion history (NC). Incidence of time to and location of injury were recorded after RTP from first reported concussion until completion of collegiate career.</td>
<td>LE injury data (rate to injury and odds of future injury) after RTP.</td>
<td>Incidence of LE injury after RTP was significantly greater in MC cohort than SC and NC athletes. Odds of LE injury were significantly greater in the MC cohort than in SC and NC athletes. Time to LE injury was significantly shorter in the MC group compared with matched controls.</td>
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<tr>
<td>29</td>
<td>NCAA DI athletes from M football, W basketball, W soccer, and W lacrosse with in-season concussion between 2006-2013. (52 males, 21 females)</td>
<td>Injury surveillance data from the University of Florida Athletic Association</td>
<td>LE injury data</td>
<td>LE musculoskeletal injuries occurred at a higher rate in concussed athletes than in non-concussed athletes. Odds of sustaining a musculoskeletal injury were 3.39 times higher in concussed athletes.</td>
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<td>30</td>
<td>NCAA DI and DIII athletes (n=468)</td>
<td>Retrospective self-report questionnaire reporting concussion, knee, and ankle sprains.</td>
<td>Concussion and LE injury history</td>
<td>Females with concussion history had greater odds of reporting an ankle sprain or knee injury compared to females with no concussion history. No difference found for males with or without concussion. Athletes reporting multiple concussions had the greatest odds of ankle sprain or knee injury history.</td>
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<tr>
<td>31</td>
<td>NCAA DI athletes with sport-related concussion (n=24) compared with</td>
<td>Electronic medical record review for concussion and LE injuries</td>
<td>Number and type of musculoskeletal injuries sustained after concussion</td>
<td>Participants with concussion were 2.95 times more likely than non-concussion group to sustain a LE musculoskeletal injury within 1 year of sport participation clearance. Participants with concussion were 2.9</td>
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<td>32</td>
<td>Active-duty US Army soldiers from 2005 to 2011 that sustained a concussion (n=11,522) and matched control that did not have a concussion (n=11,522).</td>
<td>Retrospective review of medical records following concussion identifying ICD-9 codes for lower extremity injury following a concussion</td>
<td>LE musculoskeletal injuries sustained after initial concussion and during same time period for matched controls</td>
<td>Within 2 years of concussion, the hazard of LE injury was 38% greater in concussed compared to control soldiers, while the 15-month hazard was 45% greater.</td>
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<tr>
<td>33</td>
<td>US high school athletes with concussion, ankle sprain, or knee sprain (n=1,613)</td>
<td>Retrospective review using AT-PBRN database for knee sprains, ankle sprains, and concussions</td>
<td>LE musculoskeletal injury data consisting of knee or ankle sprain</td>
<td>Sport related concussions, and the number of concussions, were associated with increased knee and ankle sprains.</td>
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<tr>
<td>34</td>
<td>NCAA DI male collegiate football athletes, 12 of which sustained a concussion, 50 without concussion</td>
<td>Cohort analysis of collegiate football athletes over a 5-year period to track incidence of concussion and lower extremity injury</td>
<td>LE injury data</td>
<td>No significant difference in LE injury rates between the athletes post-versus pre-concussion or between the post-concussion and no concussion (control) athletes. There was an increased LE injury risk beyond 12 months in the post-concussion group compared with the no concussion group. Line position players had an increase in LE injuries after a concussion compared with linemen with no concussion.</td>
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<td>35</td>
<td>College athletes with concussion (n = 44) and matched non-concussed college athletes (n = 58).</td>
<td>Compared acute LE musculoskeletal injury rates before and after concussion in athletes with concussion and their matched control over a 2-year period.</td>
<td>Musculoskeletal injury rates 90, 180, and 365 days post-concussion for both study cohorts. Risk ratios were calculated for all time periods.</td>
<td>Within one year after concussion, the group with concussion was 1.97x more likely to have experienced an acute LE injury after concussion than before concussion and 1.64x more likely to have experienced an acute LE injury after concussion than their matched non-concussed cohort over the same time period. Up to 180 d after concussion, the group with concussion was 2.02x more likely to have experienced an acute LE injury after concussion than before concussion.</td>
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<td>36</td>
<td>High School athletes (n=18,216)</td>
<td>Retrospective analysis of National Athletic Treatment, Injury and Outcomes Network</td>
<td>(1) any LE injury, (2) a time-loss LE injury, or (3) a non–time-loss LE injury after concussion</td>
<td>For every previous concussion, the odds of sustaining a subsequent time-loss LE injury increased 34% (odds ratio [OR] = 1.34). The number of previous concussions had no effect on the odds of sustaining any subsequent LE injury (OR = 0.97) or a non–time-loss injury (OR = 1.01).</td>
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<td>37</td>
<td>Senior professional male football (soccer) players (n=1,665) from 10 European countries (mean age of 26 +/- 1 years) were followed prospectively for 172 team-</td>
<td>Analysis of exposure to and occurrence of concussions and LE injuries.</td>
<td>LE risk following injury</td>
<td>During the follow-up period, 66 players sustained concussions and 1,599 players sustained other injuries. Compared with the risk following other injuries, concussion was associated with a progressively increased risk of subsequent injury in the first year.</td>
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<td>38</td>
<td>Former NFL players (n=2,429) who retired between the years of 1930 and 2001</td>
<td>Participants completed a survey detailing their injury history while participating in the NFL.</td>
<td>History of concussions and musculoskeletal injuries</td>
<td>Nearly 61% of participants who responded had experienced a concussion while competing in the NFL. Compared with players who did not sustain a concussion, players who did sustain concussion were more likely to have sustained various musculoskeletal injuries. A history of concussions was associated with higher odds of reporting musculoskeletal injuries.</td>
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<td>39</td>
<td>University level football players (age 19-26) who sustained concussion (n=21), who had not sustained concussion (control n=15)</td>
<td>Rapid alternating-movement task on force platform</td>
<td>COP displacement, COP oscillation regularity, motor excursion speed, long-interval intracortical inhibition, cortical silent period</td>
<td>Previously concussed athletes demonstrated persistently lower COP oscillation randomness, normal performance on a rapid alternating-movement task, and more M1 intracortical inhibition. Results demonstrate neurophysiologic and behavioral evidence of lasting, subclinical changes in motor system in concussed athletes.</td>
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<td>40</td>
<td>55 male (n=38) and female (n=17) healthy collegiate club sport athletes aged 20 +/- 1.49 years active in M/W rugby, M lacrosse, ultimate frisbee and cheerleading.</td>
<td>11 item health questionnaire assessed current and past health history. Functional Movement Screen (FMS) includes 7 tests: deep squat, hurdle step, inline lunge, shoulder mobility test, active SLR, trunk stability test, rotary stability test. FMS performance was compared with concussion history.</td>
<td>FMS composite score</td>
<td>No difference in composite FMS score in those with or without a history of concussions, nor were individual FMS tests correlated with concussion history. After controlling for BMI and age, the hurdle step did have a small significant correlation to history of concussion.</td>
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<td>41</td>
<td>NCAA DI male football players during competitive seasons 2007-2011. 13 with concussion matched with 26 uninjured players with no history of concussion</td>
<td>Motion Capture System recorded subject jumping on one limb from a 25.4 cm high step onto a force plate. Hip, knee, and ankle joint stiffness were calculated from initial contact to peak joint flexion using the regression line slopes of the joint moment versus joint angle plots. Both limbs were tested, and participants were tested both pre-season and post-season.</td>
<td>Joint moments, peak flexion angles at initial contact, peak external flexion moments (kg) for hip, knee, and ankle.</td>
<td>At pre-season, there were no differences in stiffness measures between groups. From pre- to post-season, the concussion group showed an increase in hip stiffness, a decrease in knee and leg stiffness, and no change in ankle stiffness. The concussion group demonstrated altered stiffness from pre-season to post-season when compared to the uninjured group. Decreased hip peak moments and increased hip angular excursion at post-season testing may result in increased hip flexion, thus increasing hamstring activation while decreasing quadriceps activation.</td>
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<td>42</td>
<td>76 children aged 7 to 16 years, n=38 in each group. Children with mTBI who were considered normal neurologically at the time of hospital discharge in experimental group. Control group were</td>
<td>Bruininks-Oseretski Test of Motor Proficiency (BOTMP)</td>
<td>Response time using the response speed subtest of the Bruininks-Oseretski Test of Motor Proficiency (BOTMP)</td>
<td>BOTMP raw score revealed no statistically significant differences between the groups across all testing sessions although a strong tendency could be observed. The mTBI children performed than those non-injured only at 1-week post-injury. The injured children presented with lower scores in the first week when compared to those of the fourth and of the 12th week.</td>
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<td>43</td>
<td>76 children aged 7 to 16 years, n=38 in each group. Children with mTBI who were considered normal neurologically at the time of hospital discharge in experimental group. Control group were friends of those with mTBI.</td>
<td>Balance subtest of BOTMP, Pediatric Clinical Test of Sensory Interaction for Balance (P-CTSIB), and the Postural Stress Test (PST)</td>
<td>Scores on BOTMP balance subtest, PTST, and P-CTSIB</td>
<td>Children with mild TBI performed significantly worse than the non-injured group on the BOTMP balance subtest, PST, and the eyes-closed conditions in the P-CTSIB tandem position.</td>
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<td>44</td>
<td>High school athletes (n=12 concussion, n=12 control)</td>
<td>Subjects performed four randomized tests: Automated Neuropsychological Assessment Metrics (Simple Reaction Time, Matching to Sample, Continuous Performance, and Stanford Sleepiness Scale), Standardized Assessment of Concussion, Trail Making A &amp; B, and Modified Romberg on foam.</td>
<td>Scores on testing</td>
<td>Test measures were unable to detect differences between groups; however, the injured groups' scores were initially lower and remained lower over the course of the study</td>
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<td>45</td>
<td>20 subjects recruited from high schools, colleges, and universities in Pennsylvania, n=10 healthy control, n=10 mild head injury.</td>
<td>Descriptive study that analyzed relationship between concussion, neurocognitive function, and postural stability (single leg standing with eyes open/closed conditions)</td>
<td>Neurocognitive function within 7 days of the injury using ImPACT test. Postural stability was measured using a 3D kinematic motion analysis system and a force platform.</td>
<td>There were no significant differences in postural stability or neurocognitive function between groups. No relationship existed between postural stability and neurocognitive function. There may be trends to suggest that visual memory and reaction time are different between groups.</td>
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<td>46</td>
<td>NCAA DI collegiate athletes Concussed participants included 23 males, 22 females (n=45) age 19 +/- 1.3 y, controls (n=45) were matched by gender, sport, and age.</td>
<td>Participants completed a static (Balance Error Scoring System) and dynamic (Y-Balance Test) balance assessment</td>
<td>Scores on the BESS and Y-Balance</td>
<td>Static and dynamic balance performance did not significantly differ between groups.</td>
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<td>47</td>
<td>Division I men's lacrosse players (n=34) age 19.56 +/- 1.44 years</td>
<td>Participation in one lacrosse season (15 games, 45 practices), Pre and post season BESS performance; linear acceleration, head injury criteria, and Gadd Severity Index scores were recorded using Warrior Sports Regulator II helmets</td>
<td>BESS scores</td>
<td>The number of errors from pre- to post-season increased during the double leg stance on foam, tandem stance on foam, on total numbers of errors on a firm surface, and on total number of errors on a foam surface. There were significant correlations only between total errors on a foam surface and linear acceleration, head injury criteria, and Gadd Severity Index.</td>
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<td>48</td>
<td>15 NCAA DI football athletes that were diagnosed with concussion and 13 non-contact athletes instrumented with a GForce Tracker sensor internally fixed to the crown of the helmet.</td>
<td>The effects of concussion on postural stability in NCAA DI athletes using BESS pre- and post-season</td>
<td>BESS scores</td>
<td>No clinically significant deficits in postural stability were measured over the course of a single season.</td>
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<tr>
<td>49</td>
<td>59.0% male, (612/1037), age: 31.6 ± 11.3 years, rugby players (10.1 ± 8.1 years played) 85 item health questionnaire, 55 of them from the reliable Gilbert injury history questionnaire. 30 questions were demographic.</td>
<td>participants did 70 counter movement jumps with planned and unplanned single leg landings. The planned or unplanned nature was received from the participant by visual stimulus, they then landed on a pressure plate to test cognitive function and unplanned landing costs.</td>
<td>ankle sprain, multiple ankle sprain, knee injury, fractured LE bone, LE muscle strain, ACL injury, LE-MSI</td>
<td>significant association found between concussion and LE-MSI for both males and females. Significant association for specific LE-MSI outcomes except ACL injury.</td>
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<td>50</td>
<td>male sex, age between 20 and 40 years, engagement in regular physical activity, a minimum of 12 school years (= at least upper secondary education), and a minimum counter-movement jump (CMJ) height of 30 cm (corresponding to a flight time of about 500 ms).</td>
<td>participants did 70 counter movement jumps with planned and unplanned single leg landings. The planned or unplanned nature was received from the participant by visual stimulus, they then landed on a pressure plate to test cognitive function and unplanned landing costs.</td>
<td>time to stabilization (TTS), center of pressure (COP-path length) and the vertical peak ground reaction force (pGRF)</td>
<td>no significant difference in landing stability or error counts observed, thus, no substantial fatigue or learning affects. Unplanned landing jumps had significantly lower flight time than planned. Unplanned landing had higher COP path length and significantly more standing errors. No difference for TTS and pGRF.</td>
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<td>51</td>
<td>current members of a men's collegiate club outdoor soccer team or had been members in the past 2 months. No history of traumatic knee or ankle injury in the past 3 months that limited their participation in soccer. Required to have a score 7 on the Tegner Activity Scale and a score 12 on the Marx Activity Scale. No concussion in the past 10 weeks. Kinetic and kinematic data taken from non-dominant leg during single task non-ball handling and dual task ball handling. These were done while running and cutting at a 45-degree angle in a single step. They also completed the ImPACT cognitive assessment.</td>
<td>Greater pKVA values were associated with worse visual spatial memory. BH had a significant group effect on pKVA.</td>
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<td>52</td>
<td>division one student athletes between the ages of 18-25</td>
<td>injury records were looked at following the athletic season. The participants did 3 trials documented injury, postural control</td>
<td>association between concussion history and injury was significant.</td>
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<td>53</td>
<td>adolescent athletes between the ages 12-15 playing on youth club sports teams in the sports of volleyball, baseball, soccer, softball, basketball, track and field, lacrosse, swim, and ice hockey.</td>
<td>A survey with a comprehensive injury history was filled out. Then subjects with concussions were matched with those who did not have concussions and a statistical analysis was done on the data from the two groups.</td>
<td>LE injury data</td>
<td>History of concussion in the athletes was associated with LE injuries but was different between males and females.</td>
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<tr>
<td>54</td>
<td>male elite college athletes. 14 basketball, 22 rugby, 11 baseball, 15 ice hockey, 15 soccer. No orthopedic acute injury or concussion in the past 6 months. Participate in training and competition.</td>
<td>First the Korean version of SAC was used for the neurocognitive evaluation. It consisted of a mental test, memory test, concentration test, and a delayed memory test. Then postural control of the lower extremities was evaluated using LESS, BESS, and SEBT. The data was then analyzed and assessed for correlations.</td>
<td>test results</td>
<td>weak to moderate correlation between SAC and SEBT. SAC, LESS, BESS and SEBT do not influence the occurrence of lower extremity injuries.</td>
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<td>55</td>
<td>National Collegiate Athletic Association Division I Football Bowl Subdivision football players from two consecutive seasons. Season 1 players 113 (age= 19.7 + or - 1.4 years, height = 188.0 + or - 6.8 cm, mass = 106.9 + or - 22.7 kg), and season 2 players totaled 112 (age = 19.7 + or - 1.4 years, height = 187.2 + or - 6.8 cm, mass = 108.3 + or - 22.3 kg)</td>
<td>The athletes started by doing a preparticipation screening that classified them as low risk or high risk for injuries in the upcoming season based on how they scored on a neurocognitive test and a plank test. Then data was collected over the next two seasons on who was injured.</td>
<td>Injury data</td>
<td>players with increased risk of injury were proven to score FPH less than or equal to 120 seconds, verbal memory score less than or equal to 87, composite reaction time greater than or equal to 560 milliseconds, and starter status. Players with 2 or more of the 4 risk factors demonstrated 44% sensitivity and 91% specificity.</td>
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<td>56</td>
<td>students from the university’s sports science Bachelor’s and Master’s programs. Most participants were involved in either soccer, as the amount and degree of visual distraction increases, recall precision and landing biomechanics decrease.</td>
<td>Participants used a capacitive pressure platform to do 30 bilateral counter movement jumps. After each jump the participants measured how long they could maintain a stable one-flight time, landing errors, recall errors, peak ground force reaction, time to stabilization, and center of pressure trace lengths.</td>
<td></td>
<td>as the amount and degree of visual distraction increases, recall precision and landing biomechanics decrease.</td>
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Effect of Concussion on Reaction Time and Neurocognitive Factors: Implications for Subsequent Lower Extremity Injury

Tyler Ray, Daniel Fleming, Daniel Le, Mallory Faherty, Carolyn Killelea, Jeffrey Bytoms, Tracy Ray, Larry Lemak, Corina Martinez, Michael F. Bergeron, Timothy Sell

Background
Recent evidence has demonstrated that athletes are at greater risk for a lower extremity injury following a return-to-sport (RTS) after sport-related concussion (SRC). The reason for this is not completely clear, but it has been hypothesized that persistent deficits in neurocognitive factors may be a contributing factor.

Hypothesis/Purpose
This study assessed simple reaction time, processing speed, attention, and concentration in a group of athletes, post-concussion upon clearance for RTS for potential deficits that may result in slower reaction time, processing speed, attention, and concentration. The researchers hypothesized that the concussion group would demonstrate worse scores on both assessments compared to a sex-, age-, and sport-matched cohort.

Study Design
Case-controlled study

Methods
Twelve participants who had suffered a SRC and eight healthy individuals who were matched to the concussed group by age, sex, and sport were evaluated. Those with a concussion had been cleared for RTS by a licensed healthcare provider. Each participant underwent neurocognitive tests that included a simple reaction time test (SRT) and the King-Devick Test (K-D). Independent t-tests were performed to compare the groups with significance set a priori at p<0.05.

Results
There was a significant difference (p =0.024) between groups for SRT with the concussed group demonstrating a better SRT than the control group. There were no significant differences (p =0.939) between the groups for the K-D.

Conclusion
With no significant differences between groups in the K-D assessment and, surprisingly, the concussed group having a better SRT compared to the healthy group, our hypothesis was not supported.
Clinical Relevance
These specific measures, compounded with extensive post-concussion time lapse until RTS clearance, may have limited capacity in revealing potential persistent deficits in relevant neurocognitive characteristics.

Level of Evidence
Level of Evidence 5

INTRODUCTION
Sport-related concussions (SRC) continue to be a rising and prominent global concern in contact and non-contact related sports, especially in youth. According to the 2017 Youth Risk Behavior Survey (YRBS) conducted by the Centers for Disease Control and Prevention (CDC), out of all the student athletes in the United States (U.S.), "15.1% of students (about 2.5 million) reported having at least one concussion related to sports or physical activity, and 6% reported having two or more (about 1 million students)." In a study across 20 high school sports during the 2013-2014 to 2017-2018 school years, 9,542 concussions were reported for an overall rate of 4.17 per 10,000 athlete exposures (AE) (95% CI: 4.09 to 4.26). In this sample, 64% occurred during competition and the rest during practice.2

Recent evidence suggests that athletes who have suffered a concussion may be at a greater risk for a lower extremity (LE) injury following a return to sport (RTS). The association between increased instantaneous relative risk of LE injury in the 365 days after incurring a concussion in Division I college athletes has been demonstrated across 15 sports.3 In a military population, a greater risk of musculoskeletal (MSK) injury post-concussion was demonstrated in U.S. Army soldiers, which remained elevated for more than a year.4 This has been corroborated in a recent systematic review indicating that athletes who had a concussion had two times greater odds of sustaining a MSK injury than athletes without having incurred a concussion (OR, 2.11; 95% CI, 1.46 - 3.06).5 Whereas there may be observed differences in gait strategy, this study and others suggest that an underlying prominent contributing factor may be persistent deficits in neurocognitive factors.6,7

Impaired neuromuscular control in these post-concussion scenarios may be evidenced through deficits in cognitive performance, including via measured reaction time, processing speed, and verbal and visual memory.8 As a diagnostic tool, the King Devick (K-D) test has been successfully utilized in detecting SRC.9 The K-D test may also be effective in identifying witnessed and unwitnessed episodes of SRC in youth sports, as demonstrated in junior rugby over continuous seasons.10 Additionally, because K-D test performance may be influenced by attention, concentration, reaction time, and processing speed, it may provide valid insight to these same overlapping domains that can inhibit an athlete’s neuromuscular control.11 A test of simple reaction time (SRT) has also been utilized in those who have suffered a concussion, with this straightforward metric of clinical reaction time (RT_clin) showing close alignment and validity to computerized measured reaction time (RT_comp) in athletes.12 Clinical reaction time (RT_clin) also reveals an athlete’s ability to protect one’s head in a lab-simulated athletic environment demonstrating functional relevance.13 Notably, prolonged reaction time is one of the most sensitive indicators of neurocognitive change following concussive injury, and thus this utility is incorporated in many concussion evaluation instruments.14 For example, simple reaction time (SRT) is a featured metric in the Automated Neuropsychological Assessment Metrics (ANAM) commonly used to evaluate concussions in the U.S. military.15 In military cadets recovering from a concussion, a prolonged increase in SRT did not return to baseline upon return to active duty.16 Further practical benefits of the K-D and RT_clin include being able to administer these uncomplicated tests to a large group of athletes in a comparatively small amount of allotted time with minimal cost and no requirement for highly trained and certified testers. Accordingly, the convenient, practical, and valid K-D and RT_clin tests were utilized for this study to measure reaction time and indirectly reveal potential deficits in attention, concentration, and processing speed as potential contributing factors that can hinder neuromuscular control in a post-concussion population, thus leading to higher risk of LE injury. These observed changes in neuromuscular control and MSK injury risk challenge physicians and other providers when attempting to screen post-concussion patients easily and effectively and identify when athletes are ready to return to sport.

The evident connection between SRCs and the subsequent impact on musculoskeletal injury risk underscores a practical clinical concern regarding athletic readiness and the decision to clear an athlete for RTS – competition and/or training. Therefore, the present study assessed simple reaction time, processing speed, attention, and concentration in a group of athletes, post-concussion upon clearance for RTS for potential deficits that may result in slower reaction time, processing speed, attention, and concentration. The purpose of this research was to examine the effects of SRC on neurocognitive and neuromuscular performance by utilizing the K-D test and a simple reaction time assessment after clearance for RTS. The researchers hypothesized that the concussion group would demonstrate measurable deficits on both assessments compared to a sex-, age-, and sport-matched healthy cohort. These findings should provide new perspective into the relationship between concussion and LE MSK injury and the utility of these two assessments during RTS decision-making which may help provide additional tools for clinicians who must assess clinical readiness for safe RTS. The practical utility of these readily accessible, easily assessable, and cost-effective neurocognitive and reaction time metrics could also be instrumental in screening and identifying athletes who are more likely to experience a LE MSK injury following a SRC.

International Journal of Sports Physical Therapy
METHODS

PARTICIPANTS

Twelve participants (7 boys, 5 girls; age: 16.1 ± 1.4 years; height: 172.3 ± 11.3 cm; weight: 65.7 ± 15.3 kg) who had suffered a sports-related concussion and eight healthy (no concussion history) individuals (4 boys, 4 girls; age: 16.5 ± 2.1 years; height: 172.2 ± 10.9 cm; weight: 67.9 ± 15.4 kg) were matched by age, sex, and sport. Participants were voluntarily recruited through the university's concussion clinic. Each participant had been cleared for RTS (60.9 ± 54.0 days following concussion) by a licensed healthcare provider. The evaluated subjects played a range of sports including soccer, basketball, volleyball, and football. Each subject under the age of 18 required a parent's or guardian's informed voluntary assent to enroll in the study. Subjects at or over the age of 18 signed a written informed voluntary consent form as well. The study protocol and consent forms utilized in this study were approved through Duke University Office of Research Support Institutional Review Board committee. Individuals who reported a history of surgery or any injury (concussions excluded for the concussion group) within the prior six months were excluded from the study. Each subject underwent neurocognitive tests that included a King-Devick Test (K-D) and simple reaction time test (SRT).

KING-DEVICK ASSESSMENT

The King-Devick assessment (K-D) is a timed rapid number naming assessment that assesses saccadic eye movements, attention, and processing speed. In a large sample of collegiate athletes across 16 sports, the K-D test was reliable from trial to trial (ICC=0.888) and when taking the test between years (ICC=0.827). Furthermore, the test can help in assessing ocular and cognitive effects of concussion. After being cleared for RTS by a licensed healthcare provider, each subject was scheduled for testing individually. The K-D test was given to each individual study participant to challenge the athlete's attention and eye movement in a rapid manner. Each participant was given standardized instructions and asked to read aloud a series of single-digit numbers from left to right on three test cards. The participant was then given one demonstration card for practice, followed by the three test cards that were used for recording scores. The three tests became progressively more challenging as testing continued. Targets on test card 1 are separated with guide lines. On test card 2, these guide lines are removed, and the numbers are spread out; and, on card 3, vertical crowding of number targets occurs. Before reading from left to right as quickly as possible, each participant was informed to read as fast as possible without making any mistakes. The participants were also informed that they could go back and correct any mistake. If this was done, the error was not recorded. The amount of time to read from the three test cards and the number of errors made while reading were recorded by a member of the study team. The test administrator had an answer sheet during the test to catch any errors. This test was repeated a second time and an average of the two trials was calculated.

REACTION TIME

Clinical Reaction Time (RT_{clin}) was measured by having participants attempt to grasp a falling small apparatus as quickly as possible. The participant sat with his or her non-dominant forearm resting on a table and with the dominant hand held over the table’s edge in an open position. An examiner held the apparatus (80-cm inflexible stick wrapped in friction tape attached to a rubber disc) directly above the participant’s outstretched, dominant hand. The participant’s dominant hand enclosed the rubber disc without touching it while the attached stick portion was held vertically above the rubber disc lying perpendicular to the plane of the outstretched hand. After waiting a preset delay time of two to five seconds, the examiner released the stick and the participant then tried to catch it as quickly as possible by closing his or her dominant hand around the rubber disc. After each trial, an RT_{clin} value reported in milliseconds (ms) was calculated, using the formula for a falling body affected by gravity or d=0.5gt. The distance the device fell measured in centimeters was utilized in the formula for d and used to calculate the reaction time or t for each individual trial. A total of eight trials were collected and scores averaged.

STATISTICAL ANALYSIS

Descriptive data including means, minima, maxima, and standard deviations were calculated for all variables. Normality of both variables were assessed utilizing a Shapiro-Wilk test. A two-sample Wilcoxon rank-sum test was used to examine differences between the two groups if data did not demonstrate a normal distribution. Independent t-tests were utilized to examine group differences when the data were normally distributed. Significance was set a priori at p<0.05 for all statistical tests. All statistics and analyses were performed with Stata Statistics Data/Data Analysis software (version 14.2, StataCorp, College Station, TX).

RESULTS

Descriptive statistics for the key outcome metrics are presented in Table 1. The results of the Shapiro-Wilk assessment of normality indicated that SRT was normally distributed; whereas the K-D scores were not normally distributed. The statistical significance of the group comparisons is also presented in Table 1. There was a significant difference (p=0.024) in SRT between groups with the concussed group (14.6 ± 4.2 cm) demonstrating a better SRT than the control group (18.7 ± 2.5 cm). No difference (p= 0.939) was observed between groups for the K-D test (concussed = 46.7 ± 18.2 seconds; healthy = 43.8 ± 6.6 seconds).

DISCUSSION

This study provides new perspective into the relationship between concussion and LE MSK injury risk and the practical utility of these two simple oculomotor and reaction time assessments during RTS decision-making. Notably, average K-D time among the concussed population was a little
slower compared to the healthy group, but not statistically significant. This suggests possible lingering oculomotor and related neurocognitive deficits post-concussion, even after being cleared for RTS, which can arguably bias affected athletes to a potential greater LE injury risk. However, with no distinctive between-group differences in K-D and SRT values (in fact, the concussed group had a better SRT compared to the healthy group), the hypothesis was not supported. Accordingly, any (if they existed) lingering oculomotor and related neurocognitive deficits and/or poorer reaction time following a SRC after being cleared for RTS were either resolved or were not detectable using these tests.

The lack of difference between the two groups in K-D scores may be attributable to the extensive time elapsed between concussion and clearance for RTS which was, on average, two months following the concussion. In a national database of high school athletes, the average time for concussion symptoms to resolve was seven days or less with, generally, an additional 8-11 days before RTS; whereas when the recovery period was 14 or 28 days, the affected athletes tended to RTS almost immediately after their symptoms were no longer present. Moreover, these specific measures in our study may not be sensitive and/or specific enough to reveal other potential persistent deficits in neurocognitive capacities that may place an individual at greater risk for MSK injury following RTS. Previous literature has supported recent concussion being related to risk of LE injury in an athletic population. However, the proposed contributing factors for greater LE injury risk included potential neuromuscular control deficits, postural control being altered, or general LE stiffness which would be beyond the expected capability of our SRT or K-D tests to reveal. Although, to date, the addressable clinical features aligned with these proposed LE injury risk contributing factors remain unclear.

Whereas clinicians typically utilize a broad array of neurocognitive test batteries to assess SRC patients, we chose to measure the expected lingering neurocognitive effects post-concussion with SRT and the K-D test, because of their ease of administration, quick results, and overall cost effectiveness. K-D has also been utilized to identify athletes without traditional symptoms of concussion. Poor oculomotor function caused by concussion is one of the strongest predictors of mild traumatic brain injury present within 65-90% of patients experiencing some form of mild traumatic brain injury. This prolonged RT is one of the most common signs post-concussion. Accordingly, RT is featured as a component in nearly all computerized neurocognitive test battery assessments for concussion, because of its high sensitivity for detecting concussion. Whereas RT is measured through a computerized application in most of these assessments, there is supporting evidence in the ability of our manual SRT to differentiate between concussed and non-concussed athletes and to determine a concussed athlete’s level of recovery by cognitive RT. Previous findings also indicate that post-concussion SRT assessments consisting of simple finger or hand movement in a static setting do not accurately assess functional, sport-like reaction time needed for optimal and safe sport performance.

Prior relevant research on athletes who were involved in combative sports, such as boxing and Mixed Martial Arts (MMA), had significantly higher post fight K-D scores for those with head trauma during the match. Whereas others observed that using the RT method for measuring SRT in a concussed population appeared to distinguish concussed and non-concussed athletes with similar sensitivity and specificity to other commonly used concussion assessment tools.

LIMITATIONS

The primary limitations to this study are the small sample size and time to RTS varying highly among individuals. Accordingly, the unexpectedly better SRT scores in the concussed group may be due to biased sampling in the small cohorts. The widely varying RTS resolution time among individuals could have led to better performance for some on the RT method and K-D testing. Thus, with more participants, several narrower specific ranges for RTS could have been utilized in assessing and more clearly revealing these potential contributing factors to LE injury risk following clearance. Screening patients prior to and after incurring a concussion using the Vestibular/Ocular-Motor Screening (VOMS) testing that analyzes ocular smooth pursuits, saccades horizontal and vertical, convergence, and Vestibular Ocular Reflex (VOR) horizontal and vertical could further assist in detecting prior ocular motor deficits and clarifying any injury-induced changes. For future studies, these considerations and having a more precise inclusion and exclusion criteria would likely be beneficial in controlling for practical confounding variables that can hinder K-D and SRT utility in detecting related potential deficits and LE injury risk. Finally, the researchers did not examine subsequent MSK injury in the participants, so direct inferences cannot be made from the results of this study and future injury risk in concussed athletes who have been cleared for RTS.
CONCLUSION

This study provides new perspective on post-concussion MSK injury risk and the utility of the K-D and SRT assessments during RTS decision-making. The concussed group performed the K-D test a little slower, however, this difference was not statistically significant. At the same time, the concussed group had a significantly better SRT compared to the non-concussed group. Both results suggest that any neurocognitive and reaction time deficits potentially resolved, or detection was confounded by other influencing factors. These findings also spotlight the possibility that any lingering affected neurocognitive and/or reaction time deficits after being cleared for RTS are not detectable using these tests, even in the potential presence of neuromuscular control deficits, postural control being altered, and/or general LE stiffness contributing to greater risk of LE injury after a SRC.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

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REFERENCES


Original Research

Don’t Peak Too Early: Evidence for an ACL Injury Prevention Mechanism of the 11+ Program

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Keywords: Cluster analysis, injury prevention, knee, biomechanics, soccer

Background
The 11+ program prevents anterior cruciate ligament (ACL) injuries in athletes through unknown mechanisms.

Purpose
The aim of the current study was to evaluate the effects of The 11+ intervention program, performed by female soccer players during a single season, on the frequency of Early Peaks during athletic tasks.

Methods
Three teams (69 players) of collegiate female soccer athletes (Divisions I and II) were recruited. Two teams (49 players) volunteered to perform The 11+ three times per week for one season (~22 weeks plus three weeks pre-season), and one team (20 players) served as controls. The athletes performed three repetitions of a cutting maneuver, side shuffle direction change, and forwards to backwards running direction change before and after the competitive season and were recorded using marker-based 3D motion capture. Knee valgus moment time series were calculated for each repetition with inverse kinematics and classified as either "Very Early Peak", "Early Peak" or "other" using cluster analysis. The classification was based timing of the peak relative to the timing of ACL injuries. The effect of the intervention on the frequency of Very Early Peaks and Early Peaks was evaluated with a mixed Poisson regression controlling for the movement task and pre-season frequency.

Results
The 11+ intervention reduced the frequency of Early Peak knee valgus moment in one intervention team (coefficient = -1.16, p = 0.004), but not the other (coefficient = -0.01, p = 0.977). No effect was observed on the frequency of Very Early Peak knee valgus moment.

Conclusions
Reduced frequency of knee valgus moment Early Peak during athletic tasks may explain the mechanism by which The 11+ program decreases risk of ACL injury. Prospective studies with a much larger sample size are required to establish a link between Early Peak knee valgus moments and risk of ACL injury.

Level of evidence
2b
INTRODUCTION

Anterior cruciate ligament (ACL) injuries can be career-ending for athletes,1 and have life-long health consequences2 and economic costs.3 As such, prevention of ACL injuries has immense potential benefits which have fueled enough research to support both a meta-analysis of meta-analyses4 as well as a Clinical Practice Guideline.5 One of the most effective programs, The 11+ has been shown to have a numbers needed to treat value of 70,6 preventing about one injury every three seasons for a 20 person male roster. This benefit comes from the investment of 20 minutes into a warm-up program which is performed before training and games.5 Unfortunately, coaches see the high cost of implementation as a barrier.7,8 Since the majority of coaches who implement prevention programs only implement parts of programs9 the time required to perform the program is likely perceived by coaches as too long.

Prevention programs would be more efficient if high-risk athletes could be directly targeted. Targeting is theoretically possible as the mechanisms of ACL injury are well understood.10 The complex interplay of forces that tear the ACL10 as well as the gameplay situations and kinematics occurring during the injury event are well described.11–15 Prospective studies have not, however, identified strong risk-factors that are consistent with the injury mechanism.16–19 There is a gap between injury mechanism studies and prospective risk factor studies as the latter have not accounted for the timing of injury in their search.16–19

Two variables are crucial in the injury mechanism and should be accounted for: time and force. The ACL injury occurs quickly after ground contact11 and one of the forces that tear the ACL is the knee valgus moment.20 A cluster analysis method has been developed that has identified early peaks in knee valgus moments (simply referred to as Early Peaks in this manuscript) with timing consistent with the ACL injury21 and therefore is a potential risk factor for ACL injury. It has been shown that kinematics observed during ACL injuries are associated with the frequency of Early Peaks,22 further strengthening the case for Early Peaks as a risk factor for ACL injury. As ACL injuries are relatively rare with only about two injuries per 10000 hours of participation for females,23 prospective studies require either large sample sizes or very long follow-ups for statistically robust results. Strong evidence for potential risk factors built from basic science on ACL injury mechanisms should precede prospective risk factor studies.

The case for Early Peaks as a potential risk factor would be strengthened if intervention programs known to decrease the risk of ACL injury could decrease the frequency of Early Peaks observed using laboratory-based motion analysis. The aim of the current study was to evaluate the effects of The 11+ intervention program, performed by female soccer players during a single season, on the frequency of Early Peaks during athletic tasks. It was hypothesized that The 11+ program decreases the frequency of Early Peaks in valgus moments in female collegiate soccer players.

METHODS

This is a secondary analysis of a completed prospective cohort study on the effects of The 11+24 on kinetics and kinematics of several tasks.25 All procedures were approved by the Institutional Review Board at the University of Delaware. Subjects were given written and verbal descriptions of all study protocols and signed an informed consent. A convenience sample of 10 female collegiate soccer teams were invited to participate in the study. Three teams (NCAA Division I and II) accepted, out of which two (Division I) volunteered to implement The 11+ program and one team (Division II) volunteered to serve as a control. The teams were therefore not randomized but assigned based on their own preference. All participants for whom data was available for both pre- and post-season motion capture were used for this analysis.

DATA COLLECTION

Anatomical markers were placed on the pelvis (iliac crests), thigh, shank, and feet to create a lower extremity musculoskeletal model. Tracking markers attached to rigid shells were placed on the pelvis, thighs, and shanks and secured with elastic wraps. Tracking markers were additionally placed on the heels of the shoes. An overview of the markers and musculoskeletal model is provided in Figure 1. All markers were placed by the same person for all data collections. The person placing the markers had additionally passed the reliability training measures used by the lab to ensure consistency. Marker trajectories were tracked at 240 Hz using eight-camera motion capture system (Vicon, Oxford Metrics Ltd, London, England). Force data were captured with a 6-component embedded force plate (Bertec, Worthington, Ohio, USA) sampling at 960Hz.

The athletes hit the force plate three times with each leg for each of three different change of direction tasks. Greater approach speed has been shown to influence the knee valgus moment during cutting maneuvers.20 Approach speed during the tasks was therefore not controlled but athletes were encouraged to perform the movements with maximum speed and intensity. The movements were:

a) Running forward-to-running backward change of direction. The athlete ran forward about 5m until they reached a force plate and pushed off it to change direction and run backward as fast as possible.

b) Lateral shuffle change of direction. The athlete did lateral shuffles for about 4 strides until they reached a force plate and pushed off it to switch directions to do lateral shuffles in the opposite direction. The leading leg was used to change directions and was the trailing leg after the direction change.

c) Cutting maneuver. The athlete ran forwards for about 3m until they reached a force plate and pushed off it to achieve a 90° cut away from the stance leg.

INTERVENTION

The 11+24 intervention was led by team personnel (coach / athletic trainer). Teams were instructed to perform the intervention as described by FIFA Medicine Handbook.
The cluster analysis. The amplitude of the ground impact is a low pass filter cutoff of 6Hz was necessary to perform content was contained in frequencies below 24Hz. However, randomly selected trials. It was found that most of the signal transform spectrum analysis was carried out on two randomized trials. The amplitude of the ground impact is required for the cluster analysis step. A fast Fourier ground impact while also reducing the complexity of the filter cut-off frequency that retains the curve shape of the moment is described in this analysis.

Knee joint moments were calculated using inverse dynamics on raw marker and force plate data and normalized by weight (kg) * height (m). The external knee joint moment is described in this analysis.

Marker trajectories were used to fit a seven-segment musculoskeletal model using the six degree-of-freedom method. Knee joint moments were calculated using inverse dynamics on raw marker and force plate data and normalized by weight (kg) * height (m). The external knee joint moment is described in this analysis.

The calculated moment was low pass filtered. A low pass filter cut-off frequency that retains the curve shape of the ground impact while also reducing the complexity of the signal is required for the cluster analysis step. A fast Fourier transform spectrum analysis was carried out on two randomly selected trials. It was found that most of the signal content was contained in frequencies below 24Hz. However, a low pass filter cutoff of 6Hz was necessary to perform the cluster analysis. The amplitude of the ground impact is therefore greatly affected by the filter. However, the shape of the waveform is retained.

CLUSTER ANALYSIS

Injuries to the ACL occur shortly after ground contact. The first 80ms of stance was used for cluster analysis to allow identification of knee moment peaks at or before 60ms. Cluster analysis was conducted similarly to previous studies where the time series were first transformed into the signed difference. Thus, the only information being clustered on was changes in direction of the signal (increasing or decreasing). The Euclidean distance was used as the distance metric and the ward d2 algorithm used to create clusters.

The C-Index was used to determine the fit of the clustering process and the appropriate number of clusters created. The C-Index is the ratio of the sum of distances within clusters minus the smallest distance observed, to the difference between the largest and smallest distances in the data set. Values closer to zero represent better clustering. The number of clusters to analyze was chosen as the ‘elbow’ of the C-Index plot, the point where adding more clusters starts to have diminishing returns in fit.

The relevant waveform for the ACL injury mechanism is an early peak in the knee valgus moment. Previous studies with cluster analysis on knee valgus moment data have shown that some of the clusters identified will show the relevant early peak shapes, and some will not. Furthermore, the timing of the peak knee valgus moment can be variable. For those reasons, a visual inspection was used to create subgroups which are similar in terms of whether or not an early peak knee valgus moment is present. For this analysis, subgroups of waveforms was also created depending on if the timing of the peak is before or after 40ms, which has been identified as the timeframe where an ACL injury is most likely to occur.

STATISTICS

The main outcome measure was how frequently cluster waveforms with peaks before 80ms were observed. Since differences between legs were not important for this analysis, legs were pooled for the analysis. To determine the effects of the intervention on the number of Early Peak knee valgus moments, a mixed linear regression with a Poisson link function was used. A regression model was calculated for each Early Peak type identified with potential relevance for ACL injury. The number of times each waveform was observed (integer scale of 0-6) after the intervention season was the dependent variable. Independent variables were the teams (three categories), the number of times each waveform was observed at the pre-season data collection (integer scale of 0-6), and the movement task (three categories). All independent variables were tested as main effects and no interactions were included in the statistical models. The random variable was each individual athlete as a random intercept. Primary hypothesis testing was done comparing models with and without the inclusion of the effect of team using a Chi squared test. The primary effect size is the increase in fixed-effect R^2 (lognormal) of adding the effect...
Figure 2. Flow of subjects through the study.

Athletes were excluded from the analysis if they were unable to complete both follow-ups, or had no usable data.

RESULTS

SUBJECTS

A total of 69 athletes were recruited. The intervention teams confirmed that the intervention was carried out an average of 2.2 times per week. Three subjects enrolled in the study but did not attend any data collections. One data file was missing. Data from 65 subjects was available for the pre-season motion testing: 20 control athletes, 22 from intervention team 1, and 23 from intervention team 2. An overview of the flow of subjects through the study is shown in Figure 2. Eight subjects (three controls, four intervention) did not attend the post season testing due to injury and one subject did not complete any of the test movements analyzed in this study. All available data were used for the cluster analysis, 2190 trials from 67 subjects. A total of 57 athletes had complete data for both pre- and post-season testing and were used for the statistical analysis.

CLUSTER ANALYSIS

Consistent with previous studies, 21 seven clusters were formed (Appendix A, Figure 1) with a C-index of 0.05 (Figure 3) for the seven cluster solution. Visual inspection revealed three distinct shapes (Figure 4) two of which had potential relevance to the ACL injury mechanism. Similar clusters were therefore merged into the categories Very Early Peaks (peaks occurring within 40 ms, two clusters) and Early Peaks (peaks occurring between 40 and 60ms, one cluster). The remaining four clusters were categorized as ‘other’. The mean frequency of each cluster by season and team are shown in Table 1.
Table 2. Mixed Poisson regression for the frequency of Very Early Peak knee valgus moments.

<table>
<thead>
<tr>
<th>Model effects</th>
<th>Coefficient</th>
<th>Std. Error</th>
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<td></td>
<td></td>
<td></td>
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<td>Upper</td>
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<tr>
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<td>0.11</td>
<td>0.17</td>
<td>-0.22</td>
<td>0.46</td>
</tr>
</tbody>
</table>

Frequency of Very Early Peaks at the post-season data collection is the dependent variable. Intervention team coefficients are compared to the control team. The cutting maneuver and lateral shuffle are compared to the anterior-posterior direction change.

Table 1. Mean frequency of Very Early Peaks (within 40 ms after ground contact) and Early Peaks (between 40-60 ms after ground contact) of knee valgus moments for each team.

<table>
<thead>
<tr>
<th></th>
<th>Very Early Peaks</th>
<th>Early Peaks</th>
<th>Others</th>
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</thead>
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<td>Post-season</td>
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</tr>
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<td></td>
<td>Team</td>
<td>Pre-season</td>
<td>Post-season</td>
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<td>0.75</td>
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</tr>
<tr>
<td>Intervention team 1</td>
<td>0.54</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>Intervention team 2</td>
<td>0.29</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Team</td>
<td>Pre-season</td>
<td>Post-season</td>
</tr>
<tr>
<td>Control</td>
<td>2.41</td>
<td>3.37</td>
<td></td>
</tr>
<tr>
<td>Intervention team 1</td>
<td>4.12</td>
<td>3.75</td>
<td></td>
</tr>
<tr>
<td>Intervention team 2</td>
<td>3.65</td>
<td>4.46</td>
<td></td>
</tr>
</tbody>
</table>

Note: Numbers are the average frequency of each knee valgus moment cluster. Frequencies are averaged across three different movement tasks and both feet within the team.

FREQUENCY OF VERY EARLY PEAKS

The model for Very Early Peaks (within 40ms of ground contact) had an R^2 of 0.57 for the full model, and 0.17 for the fixed effects. The R^2 increase of adding the intervention effect was 0.15 (p = 0.004). Full model results are reported in Table 3. Early Peaks were more common for lateral shuffles than the other movement tasks. Pre-season frequency was associated with post-season frequency. One of the two intervention teams had a lower frequency of Early Peaks following the intervention, but the other did not.

DISCUSSION

The main results of the study were that The 11+ intervention reduced the frequency of Early Peaks for intervention team 2, but not intervention team 1. The effect was modest, explaining just shy of 20% of the variance in Early Peak frequency. No intervention effect was observed on the number of Very Early Peaks. Adherence to the intervention may explain why only one of the teams had a reduced frequency of Early Peaks. The teams were asked how often they performed the intervention. However, the adherence to the program in terms of the number of exercises completed or other parameters regarding the specific execution of the program was not evaluated.

The 11+ program has been shown to reduce the relative risk of ACL injuries in male soccer players to about 1/4th that of control athletes,9 and the risk of acute severe knee injuries in female athletes by almost half.24 Although the efficacy of the program to prevent female ACL injuries has, to the author’s knowledge, not been reported, the injury preventative effects are similar in magnitude to the reduction in Early Peak frequency observed in intervention team 2; a 45% decrease post-intervention (Table 1). Two previous analyses from the same sample did not find evidence of a mechanism of effectiveness of The 11+.25,32 but those studies used peak values during weight acceptance.25,32

Extracting peak values is common practice in biomechanics studies and is how risk factors have been identified by prospective studies.13,16,17 Two characteristics of ACL injuries makes the peak extraction method problematic: timing and rarity. The extracted peaks generally occur later in the stance phase than an ACL injury would.33 And since the ACL injury is a rare event during a common movement,23 it is likely that some element of rarity also applies to potential risk factors. After all, if the risk factor occurs all the time, why doesn’t the ACL injury? The Early Peaks in the current study are not limited by these aspects. The tim-
Two clusters were merged for form Very Early Peaks. Early Peaks were a single cluster (no merger). The remaining four clusters were merged into Other. Clusters were created using signed differences, but the figure shows the normalized knee moment. Light gray shades show the range, dark gray shades show 1 standard deviation, black line shows the mean. Y-axis scales are varying to emphasize the different shapes.

**Table 3. Mixed Poisson regression for the frequency of Early Peak knee valgus moments.**

<table>
<thead>
<tr>
<th>Model effects</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>95% CI</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-1.19</td>
<td>0.34</td>
<td>-1.36</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Intervention team 1</td>
<td>-0.01</td>
<td>0.31</td>
<td>-0.91</td>
<td>0.977</td>
</tr>
<tr>
<td>Intervention team 2</td>
<td>-1.16</td>
<td>0.40</td>
<td>-1.76</td>
<td>0.004</td>
</tr>
<tr>
<td>Pre-season frequency</td>
<td>0.31</td>
<td>0.10</td>
<td>0.04</td>
<td>0.22</td>
</tr>
<tr>
<td>Cutting maneuver</td>
<td>0.03</td>
<td>0.34</td>
<td>0.01</td>
<td>0.919</td>
</tr>
<tr>
<td>Lateral Shuffle</td>
<td>0.79</td>
<td>0.28</td>
<td>0.42</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Frequency of Early Peaks at the post-season data collection is the dependent variable. Intervention team coefficients are compared to the control team. The cutting maneuver and lateral shuffle are compared to the anterior-posterior direction change.

The lateral shuffle had the highest frequency of Early Peaks in this study. The lateral shuffle change of direction includes a strong hip-abduction but no rotational component. Studies have suggested that hip abductor muscles are able to reduce the knee valgus moment. Although speculative without direct evidence, higher demand on those muscles may explain the higher frequency of Early Peaks. The lateral shuffle was also the only test movement not specifically trained in The 11+, which may contribute to a higher frequency of Early Peaks if training the other movements has reduced their Early Peak frequency. Change of direction tasks that place higher demands on the hip abductor muscles may be ideal tasks for biomechanical studies on ACL injury risk. However, this study was not sufficiently powered to examine the interaction between the different tasks and the intervention to assess if the two movements trained with The 11+ had greater reductions in Early Peak frequency than the lateral shuffle change of direction.
LIMITATIONS

This secondary analysis is subject to several limitations that affect the generalizability of the findings. Only one of the two intervention teams saw a large effect consistent with the expected magnitude of change from injury prevention studies, while the other team had no effects. As explained above, this may be due to adherence to the intervention protocol.

Only three trials were collected per movement. As is common with motion capture, not all participants had three valid trials due to technical difficulties which were only evident in post-processing. This results in the potential for under-estimation of the frequency of each waveform since some collections will have a maximum frequency of two but others three. Previous studies have shown that Early Peak waveforms are relatively rare, which was also true for Early Peaks in this study. Collecting three trials per movement is likely not sufficient to reflect the true Early Peak frequency of the athlete.

It is likely that athletes with higher pre-season frequencies of Early Peaks would display greater decreases due to the intervention compared to athletes with baseline lower frequencies since a similar pattern has been observed with the landing error scoring system. This interaction effect between the pre-season knee valgus moment Early Peak frequency during athletic tasks and the intervention was not included in the analysis as the statistical models failed to converge on a solution due to the small sample size.

CONCLUSIONS

Post-intervention reductions in the number of early peak knee valgus moments seen in some athletes during athletic tasks may explain a mechanism of effect of The 11+ intervention program. Future studies are required to establish a link between early peak knee valgus moment counts and risk of ACL injury. Future studies should include tasks more likely to result in a higher frequency of knee valgus moment early peaks, and with enough repetitions to reflect how frequently each athlete displays knee valgus moment early peaks.

CONFLICTS OF INTEREST

The authors have no conflicts of interest.

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REFERENCES


Original Research

Influence of Altered Knee Angle on Electromyographic Activity of Hamstring Muscles Between Nordic Hamstring Exercise and Nordic Hamstring Exercise with Incline Slope Lower Leg Board

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Keywords: Nordic hamstring exercise, Muscular length, Knee angle, Hamstring muscle

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Background

Previous studies have shown that performing the Nordic hamstring exercise (NHE) with different board slope angles can affect hamstring activation. However, changes in muscle length with different board slopes can alter joint angles leading to the moment arm (MA) at the knee changing during the NHE.

Purpose

This study aimed to investigate the influence of changing muscle length on hamstring electromyographic activity during an isometric NHE, while maintaining an equal moment arm.

Study Design

A crossover study design

Methods

Sixteen male volunteers performed two types of conventional NHE, one with knees on the floor (NHE) and one with the legs placed upon an incline slope of a lower leg board (NHEB). To compare between the conventional and inclined NHE, the moment arm at the knee was calculated to be equal by an examiner holding the lower legs at points marked at 77% and 94% of the length of the lower leg. The four sub-groups comprised of: 1) NHE-77%, 2) NHE-94%, 3) NHEB-77%, and 4) NHEB-94%. The hamstring EMG activity was measured at the biceps femoris long head (BFih) and at the semitendinosus (ST) and related compensatory muscles. The RMS data were normalized as a percentage of the maximum isometric values (normalized EMG [nEMG]). Significant main effects findings were followed up with Tukey’s post-hoc test using SPSS software and statistical significance was set at the p < 0.05 level.

Results

The BFih EMG activity values for NHE-77% were significantly higher than those for NHE-94% (p= 0.036) and NHEB-77% (p < 0.001), respectively, while ST during NHE-77% was significantly higher only in NHEB-77% (p < 0.001). In addition, NHEB-94% was significantly greater than NHEB-77% for both BFih (p < 0.001) and ST (p < 0.001).

Conclusion

These results indicate that hamstring electromyographic activity is decreased when the hamstring muscle is lengthened during the Nordic hamstring exercise.

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Level of Evidence

INTRODUCTION

Hamstring injury is a common muscle injury that affects many athletes associated with various sports.\(^1\)\(^-\)\(^3\) It has been acknowledged that the Nordic hamstring exercise (NHE) may prevent injuries to the hamstring, potentially decreasing 51% of all hamstring injuries for athletes competing at different levels and across multiple sports.\(^4\) Van Dyk et al\(^4\) support the use of the NHE in the prevention of hamstring injury programs, however, NHE may only reduce the number of hamstring injuries when executed accurately. Several authors have reported that a potential disadvantage of the NHE is that it is difficult to perform this exercise using the optimal form required for achieving the complete benefit.\(^5\)\(^-\)\(^7\) Athletes who are not strong enough to descend to a fully extended knee position may not be able to take the full advantage of this exercise. Therefore, the conventional NHE may not be optimal for preventing strain to the hamstrings in athletes of all levels.

Researchers have modified the NHE to eliminate its drawbacks.\(^8\)\(^-\)\(^11\) The results of a previous study showed that adjusting the slope of the lower leg support at 20° and 40° allowed the participants to perform the movement through greater amplitude in a controlled manner; peak joint torques being attained at longer hamstring lengths.\(^8\) Additionally, the peak joint torque occurred closer to full knee extension compared to the standard NHE.\(^8\) The movement close to full knee extension during NHE is similar to the movement occurring in hamstring injuries in the final part of the swing phase during sprinting.\(^12\) Since changes in the adjustable incline board or variations in the exercise angle can affect exercise performance and specific muscle activation,\(^9\) there is significant interest in examining muscle activation during the variations of the NHE.

There is controversy regarding whether the contractions during the final phase of the NHE are isometric or eccentric type of contractions. Although it was believed that the NHE produces an eccentric muscle action in all ranges of motion, one study\(^13\) demonstrated that some athletes lower to the extent where they briefly perform pause in the drop-down position. This movement may result in a change from an eccentric contraction to an isometric contraction.\(^13\) It is possible that the hamstrings act predominantly isometrically in the swing phase of kicking, thus incorporating isometric exercises may be more appropriate (than eccentric exercises) because the former strengthens the hamstrings in a specific manner. In addition, the application of the adjustable incline board allows both biceps femoris long head (BFlh) and semitendinosus (ST) muscles to be recruited during the NHE at shallow knee flexion angles, whereas the ST muscle works more during the conventional NHE than the BFlh.\(^11\)

Performing NHE at the point closest to full knee extension is similar to the movement when hamstring injuries occur in the final part of the swing phase during sprinting.\(^12\) Investigating the relationship between muscle length and electromyographic activity of the muscles may be important for preventing hamstring strain injury. However, examining the effect of changes in muscle length during electromyography (EMG), which alters joint angles during motion leading to the moment arm (MA) changing continuously, may be a confounding problem. To overcome this obstacle, it is necessary to compare the differences in hamstring length variations with the same MA at the knee, which is the dominant joint of the NHE. The moment arm of a force being defined as the minimum distance between its line of action and the axis of rotation.\(^14\)

Therefore, the purpose of this study was to investigate the influence of changing muscle length on hamstring electromyographic activity during isometric contraction, while maintaining an equal moment arm. Moreover, isometric training exercise is widely used in the rehabilitation and physical preparation of athletes because of its safety and convenience. Hence, the secondary purpose of this study was to examine the effect of muscle length on isometric contraction during the NHE.

METHODS

SUBJECTS

Sample size was determined using G*Power 3.1.9.2 software (Heinrich Heine University, Dusseldorf, Germany) and 16 male volunteers were recruited to participate in this study. One participant had experienced a previous hamstring strain injury more than two years prior, while none of the others had any relevant past history of hamstring strain injury. The NHE was not included in the participants regular resistance training program, but were familiar with this exercise. The study protocol was approved by the institutional review board of Waseda University’s ethical committee and all procedures in this study were performed in accordance with the Declaration of Helsinki. All subjects were informed of the purpose and procedure of this study, and informed consent was obtained from all subjects.

MEASURES

PROCEDURES

Electrodes were placed on the five target muscles, Biceps femoris (BFlh), semitendinosus (ST), Erector spinae (ES), Gluteus maximus (GM), and Rectus abdominis (RA), using wireless EMG sensors (m-BioLog2 DL-5000, S&ME Co., Ltd., Tokyo, Japan) before performing maximal voluntary isometric contraction (MVIC) and the NHE protocol. The electrodes were placed on these muscles based on the following landmarks: midpoint between the ischial tuberosity and the lateral epicondyle of the tibia (BFlh), midpoint of the line between the ischial tuberosity and the medial epicondyle of the tibia (ST), mid-point between the sacral vertebrae and the greater trochanter (GM), two fingers-width distance lateral from the spinous process of the L1 vertebra (ES), and two fingers-width distance lateral from the midline of the umbilicus (RA). Electrodes were placed parallel
to the lines between these landmarks, as recommended by the Surface Electromyography for the Non-invasive Assessment of Muscles guidelines (SENIAM). To ensure accurate electrode placement on each muscle, the examiner palpated the muscle bellies and used ultrasonography imaging to confirm the location of the muscles.

Prior to electrode placement, the skin overlaying the muscles was shaved and cleaned with alcohol. After electrode placement, the participants were asked to contract the target muscles to test the muscles for accurate EMGs. The volunteers underwent MVICs during a leg curl in the prone position with knee flexion of 30° and 90° for both BFllh and ST. The GM, ES, and RA were measured using hip extension, trunk extension in the prone position, and trunk flexion in the supine position, respectively. These MVICs were used in previous studies that investigated the EMG activity of the hamstring muscles. Each MVIC protocol was for a period of five seconds and was performed twice with the mean value used for data analysis.

The EMG electrodes were pre-amplified (10×) and linked through the EMG mainframe, which further amplified it (100×) to a total gain of 1,000 × and was band-pass filtered (20-500 Hz). The root mean square (RMS) was read from the raw EMG data (the middle section; middle two seconds of the five second exercise) for further analysis. The maximum EMG values during MVIC of each muscle were used to normalize the EMG values during the NHE protocol.

After the MVIC protocol, the participants were prepared for the exercise protocol. A marker was placed on each individual's hip, knee, and ankle joint to measure the length of the lower leg from the knee to the ankle joint. To compare the effect of changing muscle length at an equal moment arm at the knee between NHE and NHEB, the examiner calculated and marked the point at 77% and 94% of the length of the lower leg. An example of these calculations is shown in Figures 1-3. The participants were randomized to perform the experiment protocol consisting of four variations of the NHE as follows: 1) NHE during isometric contraction at 100° of knee extension and the examiner providing stabilization at the mark point at 77% of lower leg length (NHE-77%), 2) NHE during isometric contraction at 100° of knee extension and the examiner providing stabilization at the mark point at 94% of lower leg length (NHE-94%), 3) NHE on the adjustable incline board plane at 20° during isometric contraction at 120° of knee extension (NHEB-77%), 4) NHE on the adjustable incline board plane at 50° during isometric contraction at 150° of knee extension (NHEB-94%). The participants were asked to hold the isometric contraction for five seconds and performed two repetitions of each MVIC test (total of eight repetitions). A manual goniometer was used to monitor the knee joint angle during the NHE protocol. If a participant could not hold the targeted degree angle, the trial was discarded, and the participant was instructed to re-perform the trials.

STATISTICAL METHODS

The average value (+SD) for each variation of NHE was calculated. The RMS data were normalized as a percentage of the maximum isometric values (normalized EMG [nEMG]). Two-way mixed repeated-measures analysis of variance (ANOVA) was used to compare between within-factor (Type of NHE; NHE and NHE on incline board) and moment arm at knee (77% and 94%). In between factors (muscles; between BFllh and ST) were compared. The difference in nEMG between GM, ES, and RA were analyzed using the same procedure. Tukey's post-hoc test was applied for the identification of any significant findings. All statistics were analyzed using SPSS for Windows (version 25.0; IBM Corp., Armonk, NY, USA) and statistical significance was accepted at the p < 0.05 level.

RESULTS

A total of 16 male volunteers (age 24.25 ± 2.04 y, height 170.58 ± 5.46 m, weight 70.01 ± 10.12 kg, mean ± SD) were recruited to participate in this study.

HAMSTRING MUSCLES (BFllh AND ST)

Differences in the nEMG between the four NHE variations and moment arm at the knee in BFllh and ST are shown in Figure 4. The BFllh nEMG activity values for NHE-77% were significantly higher than those for NHE-94% (p<0.056) and NHEB-77% (p<0.001), while in ST a significantly higher nEMG was only found in NHEB-77% (p<0.001). Moreover, NHEB-94% was significantly greater than NHEB-77% for both BFllh (p<0.001) and ST (p<0.001).

RELATED MUSCLES (GM, ES AND RA)

Differences in the NiEMG (%MVIC) between the four NHE variations and moment at in GM, ES, and RA are shown in Figure 5. In GM, ES, and RA, NHEB-94% was significantly greater than NHEB-94% and NHEB-77% was significantly higher than NHEB-77% (p<0.05). Moreover, NHEB-94% was significantly greater than to NHEB-77% (p<0.05).

DISCUSSION

This study aimed to examine the influence of muscle length on the hamstring and related electromyographic activity by modifying the knee angle during isometric NHE.

First, the present study found that the BFllh EMG activity level was not statistically different from ST between NHE-77% of moment arm at 100° of knee extension and NHE on the adjustable incline board plane at 20° of knee extension (NHEB-77%). And, NHEB-94% of moment arm at 100° of knee extension and NHE on the adjustable incline board plane at 50° at 150° of knee extension (NHEB-94%) during isometric contraction. This current study confirmed the results reported by Ditiroilo et al. as the BFllh activity during NHE at 100° of knee extension was very high (NHE77%; nEMG 87.95%MVIC, NHE94%; nEMG 81.85%MVIC). However, this finding contradicts the results of a previous study in which ST was activated to a greater extent during NHE. High BFllh and ST activity have been recorded during the conventional performance of the NHE. This discrepancy in findings may be due to variations in the normalization procedure of the hamstring EMG (e.g.,
maximal isometric voluntary contraction) to examine hamstring activation.\textsuperscript{21}

Second, BF\textsubscript{lh} and ST were recruited to a greater extent during NHE-77\% compared with NHEB-77\% at the same moment arm at the knee. However, the results of the current study did not find a significant difference during the NHE-94\%. The results indicate that performing the NHE on the adjustable incline board plane allowed participants to perform NHE at a greater knee extension angle and stimulate muscle activation at higher extent. Soga et al. reported that increasing the lower leg slope angle (0°–40°) shifted the break point angle (the knee flexion angle at which subjects are no longer able to maintain the required tempo (10°/s) for descent) to the lower knee flexion angle.\textsuperscript{22} Furthermore, Hirose et al. demonstrated that BF\textsubscript{lh} and ST muscles did not statistically different in their activation during NHE at shallow knee flexion angles with the incline board plane, whereas the ST muscle was activated to a greater extent during conventional NHE than the BF\textsubscript{lh} muscle.\textsuperscript{11} A previous study showed that when the moment arm of the knee joint was set to be equivalent, the EMG activity of BF\textsubscript{lh} decreased while this muscle was lengthened during isomet-
Figure 3. Comparison of the same moment arm at the knee joint (77%) between the conventional isometric Nordic hamstring at 100° of knee extension and isometric Nordic hamstring on a 50° inclined leg support platform at 150° of knee extension.

Figure 4. Differences in the nEMG (%MVIC) between NHE variation and moment arm at the knee. NHE-94%, NHE-77%, NHEB-94%, NHEB-77%; BFlh=biceps femoris long head, ST=semitendinosus, MVIC= maximal voluntary isometric contractions. The symbol* indicates a statistically significant difference between conditions.

This previous study explained that when a muscle is lengthened, the passive muscle component produces the force during when hamstring muscle is in this stretched position, leading to fewer motor units being needed to work resulting in decreased EMG activity. Moreover, several authors have demonstrated an inverse relationship between hamstring EMG activity and hamstring length during the NHE, regardless of the intensity during isometric knee flexion and eccentric contraction. A recent study reported that muscle activity levels in the proximal and middle BFlh regions were higher at 30° and 60° of knee flexion rather than at 90° during maximal voluntary contraction of knee flexion. However, no differences in peak EMG activity during maximal voluntary knee flexion between various hamstring lengths was achieved by altering hip angles. This discrepancy in
findings may be related to differences in joint dominance. Chleboun et al., indicated that the moment arm of the hamstrings is greater at the hip joint than at the knee joint affecting hamstring activity. In this study, the hamstring selectively demonstrated greater activity in the shorter muscle length (100° of knee extension during isometric NHE).

The current study found that BFlh and ST were preferentially activated in both 77% and 94% at the knee during the NHE as compared to the NHEB. The results are consistent with those of Sarabon et al., who reported that the peak hamstring activity decreased while the peak knee and hip torques remained similar during modified NHE variations, with increased lower leg support slope than is seen in the standard NHE. Sarabon et al. explained that the non-contractile elements contributed to a larger proportion of the force, owing to the longer length of the hamstrings compared with the standard NHE. However, the present study observed that during NHE, BFlh and ST were recruited at higher level during performing 77% than 94%. A possible explanation is that during 77% of the moment at the knee, the examiner held the lower leg at a point around the gastrocnemius muscle, leading to a compression force. Compression-induced reductions in muscle displacement also correspond to a reduction in muscle activation. Thus, implying that hamstring muscles work harder to compensate for the decrease in gastrocnemius activity.

Among the additional muscles that were studied, the ES was recruited at a high level of nEMG (%MVIC) during the NHE. A previous study showing that when the degree of knee extension angle increased, EMG activity of ES was greater than Gmax and rectus abdominis. This is because when the distance of ES is decreased from ground level, ES has to work to maintain the trunk in an erect position against gravitational force provides more hip extension torque than Gmax. Moreover, ES and GM were recruited to a greater extent in NHE-77% than in NHEB-77%. This result is consistent with that of Sarabon et al., who found that increasing the angle of slope was associated with decrease in ES and GM muscle activity.

This study had several limitations. First, the position of holding the leg was recorded with respect to the calculated moment arm, for comparing the same moment arm between conditions. However, the actual difference in lengths of holding positions between NHE of 77% and 94% were small. Future studies need to identify an effective way to compare the influence of different hamstring lengths at the same moment at the knee.

CONCLUSION

The results of this study indicate that isometric hamstring EMG activity decreased when the hamstring muscles were lengthened during NHE. The passive muscle component produces a force when the hamstring muscle is in a stretched position, and thus fewer motor units are required to work. According to the current results, NHE-77% may be better in terms of recruiting hamstring activity compared to NHEB-77% when the moment at the knee was equivalent.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.
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REFERENCES


Background
Groin pain is frequently reported by soccer players. A prevention program incorporating the Copenhagen adduction exercise (CAE) has been shown effective in decreasing adductor muscle injury in semi-professional soccer players. However, the effect of such programs on groin pain in high school soccer players is unknown. No reports have examined the effects of combining the CAE with other targeted exercises such as the Nordic hamstrings exercise (NHE).

Purpose
To evaluate the preventative effects of exercise on groin pain in high school soccer players in three groups comprising NHE alone, combined NHE and CAE, and a control group.

Design
Randomized Controlled Clinical Trial.

Methods
A cluster randomized controlled trial spanning 16 weeks was conducted on 202 high school soccer players from seven high schools in a Japanese under 18 Soccer League. Players were allocated to either group A (three schools, 66 players) receiving the CAE alone, or group B (two schools, 73 players) receiving the CAE and NHE, or control group C (two schools, 63 players) who performed their usual training. This study compared the number of injuries, injury rate, and severity of the injury of groin pain in these three groups.

Results
The number of players injured was less in group B (4 players) compared to C (18 players), and time-lost to soccer was less in groups A (6 players) and B (3 players) compared to group C (16 players). Injury rates were significantly lower in groups A and B, with the relative risk of injury compared to group C of 0.42 (95% CI 0.19% to 0.90%) in group A and 0.19 (95% CI 0.07 to 0.54) in group B.

Conclusion
A 16-week program incorporating the CAE in training sessions in high school soccer players reduced the incidence of groin pain and which may be related to injury severity according to time -lost to soccer, however the combination of both the CAE and NHE may be more effective than the CAE alone.
INTRODUCTION

Soccer is a sport that requires high-intensity sprinting, kicking, and rapid changes in direction at high speed, which can be important causes of injury. It has been reported that in soccer, the most common injuries are to muscle, particularly the hamstrings and adductor longus.

Injury surveys of soccer players show that groin pain is relatively common and accounts for 11% of all injuries. In addition, 55% of male soccer players are reported to have experienced groin pain in the past. Groin pain in soccer players is typically caused by kicking or running, and is associated with adductor muscle weakness. Furthermore, most groin pain in soccer players has been reported to be minor to moderate with no time loss related to training or games.

With respect to groin pain, the Doha agreement classifies pain into adductor-related, iliopsoas-related, inguinal-related, pubic-related, and hip joint-related pain. Adductor-related pain is considered to be the most common category accounting for 61% of all groin pain, and the most frequent cause in soccer players.

The incidence of groin pain can be reduced by up to 41% through groin pain prevention programs such as the Copenhagen adduction exercise (CAE) in semi-professional soccer players. Despite this, there is a lack of information on the effects of injury prevention programs in younger soccer players. Functionally, the hamstring muscles have an auxiliary effect on the hip adductor muscles. Both muscle groups have been shown to demonstrate high activity during kicking, jumping, and cutting movements that occur specifically in soccer. Despite this, it is unclear whether training the hamstring muscles enhances the effect of the CAE in groin pain injury prevention.

Therefore, the purpose of this study was to evaluate the preventative effects of exercise on groin pain in high school soccer players in three groups comprising NHE alone, combined NHE and CAE, and a control group.

METHODS

STUDY DESIGN AND PARTICIPANTS

Participants were male high school students participating in a Japanese under 18 soccer league. Participants were competing at the highest level in the prefecture and national league, and the top teams were targeted. We contacted 10 schools with teams in this league for potential inclusion. Consent was obtained from the principal and coach from each school. Following such approval all parents and players were required to provide written informed consent. All rights of the participants were protected. This study followed the Declaration of Helsinki and was approved by the University Ethics Committee at the Saitama Medical University, Saitama, Japan (M-98).

RANDOMIZATION

This cluster randomized controlled trial was registered with the University Hospital Medical Information Network at The University of Tokyo Hospital (Registration number 0000536863) and was conducted from August 2019 to December 2019. The authors determined it would be difficult to blind subjects through individual subject randomization, so each high school team formed a cluster group which were then randomized using the envelope method. After a team agreed to participate, the principal investigator opened a sealed envelope revealing their group assignment. Group A received the CAE alone, group B received the CAE and NHE, and group C received no interventions other than continuing their normal practice. The group randomization procedure used is not considered optimum in randomized clinical trials. However, this procedure is widely used and accepted in sports injury prevention trials as a way to limit contamination between intervention and control groups. In addition, each school insisted that any intervention must be offered to team members as a group rather than as individuals. Two high schools that did not respond, one high school that could not start at the right time, and four others absent from club activities for some reason were excluded.

BLINDING

It was not possible to blind players, coaches or the principal investigator to group allocation. Recorded data with encrypted numbers were collected by the principal investigator alone. However, the research assistant was not informed of the randomization, and outcome measures were not available to any party until all data had been collected.

INTERVENTION

The CAE was performed as follows. The athlete lay on their side, their forearm on the ground to stabilize the trunk, while their other arm was placed with their hand on their pelvis. A team mate supported the player’s uppermost leg at the ankle and knee. The athlete was then required to lift their body off the ground, by adducting their upper hip, until the upper leg and trunk were horizontal, following which they lifted their lower leg off the ground to touch ankles. This was counted as one repetition, each lasting three seconds. (Figure 1). Based on previous studies, players were instructed to stop if they experienced more than 3/10 pain while performing the exercise. For the CAE, players were asked to carry out the exercise program 1-3 times a week for 16 weeks as part of their regular warm-up.

For the NHE, the player started in a high kneeling position with their lower legs stabilized by an assistant. The player then slowly lowered their body until parallel with the ground. The exercise was completed once their hands touched the ground. Again, if pain of greater than 3/10 was provoked during the exercise the player was told to stop. For the NHE, players were asked to carry out...
the exercise program 1-3 times a week for 16 weeks as part of their regular warm-up.

The number of repetitions was based on previously reported effective injury prevention programs (Table 1).15,22 The principal investigator explained the exercises to the coach, athletic trainer, and athletes before commencement of the study. During the intervention, the researchers visited each team once a week to observe the exercises and give advice if necessary. Subjects were informed that the exercise had to be conducted under the supervision of a coach or athletic trainer, and that the principal investigator was to be contacted if problems or adverse events occurred during the exercise program.

COMPLIANCE

Exercise compliance was recorded daily by athletes on a recording sheet. To calculate overall compliance, the total number of completed sessions was summed and divided by the number of respondents. Once a week, we contacted managers, athletic trainers, and athlete representatives to keep track of exercise progress. The principal investigator collected recording papers with encrypted numbers.

OUTCOME MEASURES

The intervention period was 16 weeks. Data collection sheets were distributed to athletes and completed by individuals to record their exercise compliance and injuries. Any presentation or development of groin pain was conveyed to the athletic trainer or physiotherapist. The details
Table 1. Training protocol for Copenhagen adduction exercise (CAE) and Nordic hamstring exercise (NHE)

<table>
<thead>
<tr>
<th></th>
<th>Week</th>
<th>Weekly sessions</th>
<th>Sets (per side)*</th>
<th>Repetitions (per side)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAE</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3-5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>3-5</td>
</tr>
<tr>
<td></td>
<td>3-4</td>
<td>3</td>
<td>1</td>
<td>7-10</td>
</tr>
<tr>
<td></td>
<td>5-16</td>
<td>3</td>
<td>1</td>
<td>12-15</td>
</tr>
<tr>
<td>NHE</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>6,7,8</td>
</tr>
<tr>
<td></td>
<td>5-16</td>
<td>2</td>
<td>3</td>
<td>8,9,10</td>
</tr>
</tbody>
</table>

*CAE describes the number and number of sets on one side.

of the injury were self-reported, but when the athlete was uncertain about what to report, he was advised by an athletic trainer or physiotherapist, who was informed of the details by the chief investigator. Reports were collected weekly by the principal investigator. The definition of groin pain in this study was a condition in which pain occurs in the groin during sports activities, regardless of time loss or need for treatment, with reference to previous studies.23,24 The principal investigator explained the Doha classification method to the trainers and physiotherapists of each team and let them determine the type of groin pain for each athlete in pain. The number of injuries and the injury rate indicates the frequency and probability of groin pain. The analysis was performed using an intention-to-treat (ITT) analysis.

EXPOSURE

To calculate the exposure time individually, the athletes were asked to record daily practice time, match time, and time lost due to injury, and the total for each group was summed for each category. Once a week, managers, athletic trainers, and athlete representatives were contacted, and worked closely with the researchers to review the status of the recording and injury report forms. The principal investigator entered and matched the data from record sheet with personal information.

SAMPLE SIZE

The sample size calculation was based on the average prevalence of all groin problems among male football players (29%).25 On the basis of these data, a groin pain rate for this study of 29% in the group C, 17% in the intervention group A, and 12% in the intervention group B was projected. Using these rates, the sample size to determine statistically significant differences by using cluster randomization as well as a 2-tailed test with \( \alpha = .05 \) and \( 1-\beta = .80 \) was calculated. The estimated sample size for this study thus obtained was 189 (63 patients per group).

STATISTICAL ANALYSES

\( \chi^2 \) test was performed to compare the number of injuries to groin pain among the three groups A, B, and C. Following that, Bonferroni correction was performed as a post-hoc analysis for the items for which a significant difference was found. The injury rate per 1000 hours was calculated from the number of injuries. Relative risk (RR) was calculated to show the risks of developing groin pain for groups A and B relative to group C. Injury severity was determined by counting the calendar days lost because of the groin pain. Groin pain was classified as minor (1-7 days lost), moderate (8-21 days lost), or severe (more than 21 days lost), with reference to previous studies.23,24 The effect size for the effect size of the number of injuries was calculated as \( \phi \). Effect size <0.1 is rated as small, 0.3 rated medium, and >0.5 rated large.26 IBM SPSS Statistics for Windows, Version 26.0 (Armonk, NY: IBM Corp Released 2018) was used for statistical analysis.

RESULTS

PARTICIPANTS

A total of seven high school soccer clubs (202 players) were enrolled in the study. The flow of the players through the phases of the study is shown in Figure 3. There was a total of 11 dropouts, four in Group A, one in Group B, and six in Group C. The reasons were retirement, injury, and low compliance. Baseline characteristics for players included in the ITT analysis are shown in Table 2.

NUMBER OF INJURIES

Table 5 shows the number of cases with groin pain. The frequency of groin pain during the intervention period was significantly lower in group B than in group C. The number of players with groin pain who lost time due to injury was significantly less in groups A and B than in group C.

When comparing groups, A and B, a small effect size was observed in groin pain, although there was no significant difference.
Figure 3. Flowchart showing numbers of players participating.

Table 2. Subject Characteristics (N=202)

<table>
<thead>
<tr>
<th></th>
<th>Group A (N=66)†</th>
<th>Group B (N=73)†</th>
<th>Group C (N=63)†</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)*</td>
<td>16.4±0.9 (15–18)</td>
<td>16.0±0.7 (15–18)</td>
<td>16.1±0.9 (15–18)</td>
<td>0.47</td>
</tr>
<tr>
<td>Height (cm)*</td>
<td>170.7±5.7 (156.0–186.3)</td>
<td>169.2±5.2 (157.2–184.0)</td>
<td>170.3±5.1 (160.0–180.0)</td>
<td>0.24</td>
</tr>
<tr>
<td>Weight (kg)*</td>
<td>60.2±7.1 (40–83)</td>
<td>58.4±7.2 (42–80)</td>
<td>58.5±6.5 (45–74)</td>
<td>0.39</td>
</tr>
<tr>
<td>Dominant foot (players)</td>
<td></td>
<td></td>
<td></td>
<td>0.22</td>
</tr>
<tr>
<td>Right</td>
<td>55</td>
<td>67</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>11</td>
<td>6</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Field position (players)</td>
<td></td>
<td></td>
<td></td>
<td>0.74</td>
</tr>
<tr>
<td>Attackers</td>
<td>10</td>
<td>12</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Midfielders</td>
<td>24</td>
<td>27</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Defenders</td>
<td>26</td>
<td>23</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Goalkeepers</td>
<td>6</td>
<td>11</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

*The minimum-maximum is listed.
†Group A Copenhagen adduction exercise alone. Group B combined Copenhagen adduction exercise and Nordic hamstrings exercise. Group C continues as usual.

THE INJURY RATE OF GROIN PAIN AND RELATIVE RISK WITH TIME LOST TO SPORT

Table 4 shows the groin pain injury rate and the injury rate with time lost RR. The incidence of groin pain per 1000 hours was lower in groups A and B than in group C. Furthermore, RR of groin pain was significantly lower in groups A and B than that in group C according to the 95% confidence intervals. The injury rate for groin pain with time lost per 1000 hours was lower in groups A and B than in group
C. Furthermore, RRs of groin pain and groin pain with time lost per 1000 hours were significantly lower in groups A and B than that in group C according to the 95% confidence intervals.

SEVERITY OF GROIN PAIN

Table 5 shows the severity of reported groin pain (mild, moderate, or severe). The average number of days lost was 5.5 ± 5.2 days in group A, 10.3 ± 6.4 days in group B, and 14.4 ± 8.5 days in group C. The rate of minor groin pain in the intervention groups was higher than in the control group (66% in group A vs 53% in group B vs 25% in group C), whereas the rate of moderate groin pain was lower in the intervention group than in the control group (33% in group A vs 66% in group B vs 68% in group C).

Fisher’s exact test was used to determine if there was a significant difference in the distribution of injury severity between both groups (group A and B vs group C). However, due to the low number of players with groin pain in the moderate and severe categories, these categories were combined into one category. No difference was detected in the severity of groin pain between groups (p = 0.21).

COMPLIANCE WITH THE EXERCISE PROGRAM

The CAE compliance rate was 97% in group A and 95% in group B. The NHE compliance rate was 98% in group B.

DISCUSSION

The CAE has been reported to reduce the incidence of groin pain,13 which is consistent with the findings of the current study. In this study, the combined intervention of CAE and NHE reduced the number of injuries, and CAE alone reduced the number of cases with time lost to sport as shown in Tables 3 and 4. This supports the effectiveness of CAE in preventing groin pain in high school soccer players. The results also indicate that CAE and NHE were effective in preventing severe groin pain. From these results, it is likely that the NHE enhances the effect of the CAE. One explanation for this is that the adductor muscle and the hamstrings also assist in hip adductor, and conversely, adductor muscles also assist in hip extension,16,17 so it is possible that NHE enhanced the effect of CAE through this mechanism. Another explanation is combining exercises together likely had an enhanced strengthening effect on the adductor and hamstring muscle groups which reduced the occurrence and severity of injury. From the above, the combination of CAE and NHE exercises may be more effective in preventing groin pain than CAE alone.

In a report of factors related to the occurrence of groin pain and reduction in physical function in professional soccer players, it was reported that isometric strength of the adductor muscle is an important factor.10 The CAE has been shown to improve both eccentric adductor and eccentric abductor muscle strength.17 In addition, it has been reported that muscle damage in the thigh is reduced by the stability of the trunk,27,28 and it is possible that a combination of CAE and NHE programs may increase resistance to injury by increasing the extensibility and stability of soft tissues, including muscles, on the anterior, posterior, medial, and lateral sides of the hip joint and trunk. Since this study did not measure trunk stability or motor control, additional studies from such a viewpoint should be conducted in the future.

Kicking is important in soccer, and during this movement, the adductor muscles show maximum tension from the position of hip extension to flexion in the swing phase.29 In addition, the hamstring muscles are highly active during maximal hip and knee extension and flexion,30 suggesting a potential for injury. From this, it is predicted that the adductor and hamstrings muscles are likely to work strongly together at the same time, and that the hamstrings act cooperatively with the adductor muscle in the hip flexion phase. Strengthening both groups of muscles may enable greater protection during kicking activities which may be effective to prevent pain.

One of the goals of this study was to determine whether a muscle strengthening exercise program utilizing the CAE alone or a combined intervention including the CAE and NHE would reduce the severity of groin pain. The effect of the CAE intervention on groin pain severity has not been previously reported. Previous studies were used to assess severity.31 The results of this study found that CAE and NHE did not affect the severity of groin pain. Specifically, it did not reduce the average number of days lost and did not affect the intensity of groin pain development, which was classified as mild, moderate, or severe. Interestingly, the rate of minor groin pain was greater in the intervention groups vs the control group yet the overall injury rate was lower in the intervention group vs the control. One interpretation of this discrepancy is that CAE reduces the severity of groin pain, so that there are more minor injuries. A similar finding has been reported for the NHE in reducing

Table 5. Distribution of groin pain by severity (categorized by days lost)*

<table>
<thead>
<tr>
<th>Groin Pain</th>
<th>A group†</th>
<th>B group†</th>
<th>C group†</th>
<th>Total (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>Minor</td>
<td>4</td>
<td>66.7</td>
<td>1</td>
<td>33.3</td>
</tr>
<tr>
<td>Moderate</td>
<td>2</td>
<td>33.3</td>
<td>2</td>
<td>66.7</td>
</tr>
<tr>
<td>Severe</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total (n)</td>
<td>6</td>
<td></td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

*There were no significant differences in the severity of groin pain between the three groups. Due to the low number of injuries, minor injuries were compared to the category that combined moderate and severe injuries. Fisher’s exact test, p = 0.21.

†Group A= Copenhagen adduction exercise alone. Group B= combined intervention of Copenhagen adduction exercise and Nordic hamstrings exercise. Group C= continues as usual.
Table 3. Frequency of groin pain by number of groin pain injuries*

<table>
<thead>
<tr>
<th>No. of injuries (%)</th>
<th>Group A† (n=66)</th>
<th>Group B‡ (n=73)</th>
<th>Group C‡ (n=63)</th>
<th>χ2 test p-value</th>
<th>Group A vs Group B</th>
<th>Group A vs Group C</th>
<th>Group B vs Group C</th>
<th>Post-hoc‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groin pain</td>
<td>8 (12.1)</td>
<td>4 (5.5)</td>
<td>18 (28.6)</td>
<td>0.01</td>
<td>0.16</td>
<td>0.20</td>
<td>0.31</td>
<td>B&lt;C</td>
</tr>
<tr>
<td>Time-lost-to-sports</td>
<td>6 (9.1)</td>
<td>3 (4.1)</td>
<td>16 (25.4)</td>
<td>0.01</td>
<td>0.24</td>
<td>0.22</td>
<td>0.30</td>
<td>A.B&lt;C</td>
</tr>
</tbody>
</table>

*χ² test was performed to compare the three groups. The two groups were then compared using the χ² test or Fisher’s exact test. †Group A= Copenhagen adduction exercise alone. Group B= combined intervention of Copenhagen adduction exercise and Nordic hamstrings exercise. Group C= control group. ‡The Bonferroni correction was used as a post hoc test.

Table 4. Injury rate of groin pain and relative risk with time lost to sport

<table>
<thead>
<tr>
<th>No. of injuries</th>
<th>Injury rate/1000 competition hours</th>
<th>Relative risk of injury rate</th>
<th>95%CI</th>
<th>95%CI</th>
<th>95%CI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group A*</td>
<td>Group B†</td>
<td>Group C‡</td>
<td>B/A‡</td>
<td>A/C§</td>
</tr>
<tr>
<td>Groin pain</td>
<td>8</td>
<td>4</td>
<td>18</td>
<td>0.64</td>
<td>0.25</td>
</tr>
<tr>
<td>Time-lost-to-sports</td>
<td>6</td>
<td>3</td>
<td>16</td>
<td>0.48</td>
<td>0.19</td>
</tr>
</tbody>
</table>

*Group A= Copenhagen adduction exercise alone. Group B= combined intervention of Copenhagen adduction exercise and Nordic hamstrings exercise. Group C= continues as usual. The competition hours of groups A, B, and C were 12424.0, 16159.0, 14505.0, respectively. †B/A indicates the ratio of group B to group A. ‡95%CI: 95% confidence interval. §A/C indicates the ratio of group A to group C. **B/C indicates the ratio of group B to group C. ††There was a significant difference in the 95% confidence interval. (P < .05)
the severity of hamstring injuries. The number of cases categorized according to higher severity of injury is small in the current study, hence further study is required to determine the effect of CAE on injury severity.

Comparing intervention groups, A and B, the number of groin pain injuries was lower in group B. Furthermore, the injury rate was lower in group B than in group A, but there was no significant difference in RR. Both groups A and B had a significantly reduced risk of injury compared to group C. This suggests that both forms of exercise may be effective in reducing the incidence of injury, although the CAE alone appears to influence the risk of injury.

LIMITATIONS

This research was conducted using a cluster randomized controlled trial. Even with the mixed-effects statistical analysis that attempts to account for this clustering, this design can result in high Type I error rates. Also, the results may include Type II errors due to the limited sample size. Since the research was targeted only at top-team high school soccer players, it may have led to a selection bias. Also, all injuries were self-reported, which can lead to measurement bias, and results may vary if all injuries were diagnosed by a healthcare professional. Interventions for inguinal pain prevention exercises were limited to 16 weeks, so it is essential to examine the effects of these exercises over a longer period. In addition, a larger and more diverse sample would help to better understand the impact of CAE and NHE on injury rate and loss time.

CONCLUSION

A 16-week program incorporating the CAE in training sessions in high school soccer players reduced the incidence of groin pain and severity of injury according to time-lost to soccer, however the combination of both the CAE and NHE may be more effective than the CAE alone.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

ACKNOWLEDGEMENTS

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Original Research

No Difference in Hip Muscle Volumes and Fatty Infiltration in Those With Hip-Related Pain Compared to Controls

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Keywords: acetabular labrum, hip muscle strength, hip muscle volume, mri, buttocks

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Background
Little is known about muscle morphology in people with hip-related pain, without signs of femoro-acetabular impingement syndrome (FAIS). Identifying changes in hip muscle volume, fatty infiltrate and establishing relationships between muscle volume and strength, may provide insight into potential early treatment strategies.

Purposes
To: (i) compare the volumes and fatty infiltrate of gluteus maximus, gluteus medius, gluteus minimis, tensor fascia latae and quadratus femoris between symptomatic and less-symptomatic sides of participants with hip-related pain; (ii) compare the volumes and fatty infiltrate of hip muscles between healthy controls and symptomatic participants; and (iii) explore relationships of hip muscle volumes to muscle strength and patient-reported outcome measures in people with hip-related pain.

Study Design
Cross-sectional study

Methods
Muscle volume and fatty infiltrate (from magnetic resonance imaging), hip muscle strength, patient-reported symptoms, function and quality of life (QOL) were determined for 16 participants with hip-related pain (no clinical signs of FAIS; 37±9 years) and 15 controls (31±9 years). Using One Way Analysis of Co-Variance tests, muscle volume and fatty infiltrate was compared between the symptomatic and less-symptomatic sides in participants with hip-related pain as well as between healthy controls and symptomatic participants. In addition, hip muscle volume was correlated with hip muscle strength, hip-reported symptoms, function and QOL.

Results
No differences in all the studied muscle volumes or fatty infiltrate were identified between the symptomatic and less-symptomatic hips of people with hip-related pain; or between people with and without hip-related pain. Greater GMED volume on the symptomatic side was associated with less symptoms and better function and QOL \((p=0.522-0.617)\) for those with hip-related pain. Larger GMAX volume was associated with greater hip abduction and internal rotation strength, larger GMED volume was

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associated with greater hip extension strength, and larger QF volume was associated with greater hip abduction strength (rho=0.507–0.638).

Conclusion

People with hip-related pain and no clinical signs of FAIS have hip muscle volumes that are not significantly different than those of matched pain-free controls or their less-symptomatic hip. Larger GMED muscle volume was associated with fewer symptoms and greater strength.

Level of evidence

Level 3a

INTRODUCTION

Hip-related pain is commonly associated with hip chondrolabral pathology, and typically presents as pain in the groin and anterior hip regions. It is a cause of reduced quality of life (QOL)\(^1\) and may progress to hip osteoarthritis (OA).\(^2\) The Doha agreement classified groin pain into five categories, the fifth being "hip-related pain".\(^3\) More recently, a consensus paper has suggested that hip-related groin pain be further subdivided into three sub-categories; femoroacetabular impingement syndrome (FAIS), hip dysplasia, and other (incorporating chondrolabral pathology).\(^4\) Changes in hip muscle function are associated with hip OA\(^5–10\) and FAIS,\(^11–13\) where greater hip muscle weakness and between limb asymmetry is associated with poorer function and lower hip-related QOL.\(^9,14,15\) Little is known about muscle function in patients with hip-related pain that do not have hip OA or FAIS (the ‘other’ category of Zurich agreement).\(^5\) This information may inform rehabilitation providers to improve treatment outcomes for people with hip-related pain.

Hip movement and dynamic joint stability might reflect the complex interaction between superficial and deep hip muscles,\(^16\) however this interaction is poorly understood. Superficial muscles with large physiological cross-sectional areas and long lever arms can generate high forces,\(^17\) while deeper hip muscles are more suited to stability due to their morphology and proximity to the joint.\(^16,18,19\) Gluteus maximus (GMAX) and glutus medius (GMED) are important prime movers of the hip,\(^17\) and commonly targeted in hip rehabilitation programs. GMED muscle size is impaired in people with advanced hip OA,\(^5,7,8,10,20\) however, beyond this, little is known about muscle size or structural changes within the muscle that may indicate reduced performance (i.e., fatty infiltrate that is lipid accumulation within the muscle belly) in people with non-OA hip-related pain.

Hip muscle function, particularly of the deeper hip muscles, is difficult to measure accurately. Segmenting specific muscle bellies and creating a three-dimensional likeness from magnetic resonance (MR) images is a reliable, non-invasive and valid method\(^21,22\) used to determine muscle volume. In addition, muscle volume may be used as a “proxy” for force generating capacity. There is some evidence that altered hip muscle volume is associated with hip-related musculoskeletal disease. For example, hip muscle volume is lower in those with high OA severity, but not in people with less severe OA.\(^5,7\) In women with chronic hip-related pain (including chondrolabral pathology and FAIS) and no hip OA, hip abductor muscle volume (determined by pooling GMIN, GMED, TFL and part of GMAX volumes) is larger than in asymptomatic controls, despite lower hip abductor strength.\(^23\)

MR imaging also allows for the grading of fatty infiltrate within the muscle, which may be associated with disuse and influence muscle strength.\(^24\) Patients with hip OA have greater fatty infiltrate in GMIN and GMAX than healthy controls.\(^8\) Greater fatty infiltrate has been observed in people with knee OA,\(^25\) post whiplash disorder\(^26\) and cervicogenic headaches,\(^27\) compared to controls. Greater fatty infiltrate within lumbar multifidus in young athletes with lower-back pain is associated with less future sporting participation.\(^28\)

Therefore, the purpose of this study was to (i) compare the volumes and fatty infiltrate of hip muscles (GMAX, GMED, GMIN, TFL, QF) between symptomatic and less-symptomatic sides of participants with hip-related pain; (ii) compare the volumes and fatty infiltrate of hip muscles between healthy controls and symptomatic participants; and (iii) explore the relationship of hip muscle volumes to muscle strength and patient-reported outcome measures (including pain, function and QOL) in individuals with hip-related pain.

STUDY DESIGN

This cross-sectional study was conducted the Laboratory for Movement Control and Pain Research at the University of Queensland and compared hip muscle volumes between individuals with hip pain and healthy controls. Ethics approval for the study was obtained from the University of Queensland (#2013001448). All participants provided a priori written consent.

PARTICIPANTS

Participants with hip-related pain were recruited from patients scheduled to undergo hip arthroscopic surgery for intra-articular hip lesions performed by a single surgeon (PW). All participants had engaged in non-surgical management (including hip muscle strengthening) prior to being assessed, in order to be eligible for surgical management. Participants were invited to participate via mail prior to the planned hip arthroscopic procedure. Healthy control participants were recruited from the Brisbane community via advertisements in the media and posters. To be eligible, participants with hip-related pain and healthy controls were required to be aged between 18 to 60 years and be able to walk and ascend/descend stairs without aid. Participants with hip-related pain were included if they had: (i) persis-
tent hip/groin pain (>5 months) reproduced by physical activities (e.g., walking, stair climbing), and positive physical examination findings in hip joint provocation testing (combined hip movements; Flexion-Adduction-Internal Rotation test and Flexion-Internal Rotation); (ii) the treating surgeon determined that they did not have FAIS based on imaging findings, clinical signs and symptoms. Where participants had bilateral hip-related pain, the hip scheduled for arthroscopic surgery was deemed the study hip. Control participants were included if they: (i) had no current lower limb or low back pain; (ii) no history of hip/groin pain in the prior 12 months or previous hip surgery. The exclusion criteria for all participants included the following: (i) contraindications for MR images and (ii) inability to understand written and spoken English. The control participants were age, gender and body mass index (BMI) matched, as closely as possible, to the hip pain participants.

PROCEDURE
A single investigator (TR) not blinded to group but blinded to the side of hip pathology in hip pain participants, performed all physical measures.

PARTICIPANT CHARACTERISTICS
Age, gender, leg dominance, height, and weight data were collected, and BMI was calculated. All participants provided a written informed consent prior to data collection.

HIP MUSCLE STRENGTH TESTING
All participants underwent hip muscle strength testing on both limbs. Isometric hip abduction, adduction, internal rotation, external rotation and extension strength were measured (in that order) using a Commander Power track II handheld dynamometer (JTECH Medical Industries, Midvale, UT, USA). The investigator resisted the movement in the contraction direction and provided feedback to the participant to increase their force over ~2 seconds to their maximum, and then hold for ~3 seconds before returning to rest. Each direction was assessed three times, with 10 seconds rest between each test. This method has been previously proven to be reliable.29–31 Maximum strength data (single maximum trial) were converted to torque values using the lever arm measurement (N.m).31

MAGNETIC RESONANCE IMAGING ACQUISITION
Hip MR images were taken at a private radiology clinic (Queensland X-Ray, Coorparoo, Queensland) with a standardized protocol, optimized for visualization of cartilage and muscle morphology on a 3T Siemens Medical MRI scanner (Siemens Healthcare, Erlangen, Germany) and read by a single radiologist. Dedicated hip flex coils and sequences are designed to provide very high-resolution imaging with the ability to detect early chondral loss and optimize viewing of muscle volumes. A large field of view axial T1 weighted sequence was performed to permit muscle segmentation. Sequences obtained included coronal proton density with and without fat saturation; axial and axial oblique proton density fat saturated sequences and sagittal proton density fat saturated sequence.

**Table 1. Goutallier Classification System**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Amount of Fat in Muscle</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Normal muscle</td>
</tr>
<tr>
<td>1</td>
<td>Muscle contains some fatty streaks</td>
</tr>
<tr>
<td>2</td>
<td>Fatty infiltration, but still more muscle than fat</td>
</tr>
<tr>
<td>3</td>
<td>Equal amounts of fat and muscle</td>
</tr>
<tr>
<td>4</td>
<td>More fat than muscle is present</td>
</tr>
</tbody>
</table>

MEASUREMENT OF HIP MUSCLE VOLUMES
The volumes of the GMAX, GMED, TFL and QF were measured on axial MR images by manually segmenting muscle boundaries using commercially available software (Amira 6.3.0 FEI, part of Thermo Fisher Scientific, Hillsboro, Oregon, USA). GMIN volume was not included in the analysis of this study as the quality of the images (fascial borders) did not easily allow for measurement along the entirety of the muscle. For each muscle, the cross-sectional areas were summed, and the total sum was multiplied by the slice thickness to obtain the muscle volume. A trained investigator (HH), who remained blinded to the study groups, performed all segmentations. The research team determined the intra-rater reliability of the muscle volume measurement technique to be excellent (ICC 0.995–0.997) by completing segmentation of five MR images twice, consistent with previously established inter-rater reliability (ICC 0.87–0.99).6,7

RATING OF FATTY INFILTRATION
A single assessor (AS) graded the degree of fatty infiltration using the Goutallier classification system.32 This system has good inter-rater (ICC=0.9) and intra-rater reliability (weighted kappa 0.72–0.81)8,33 for hip muscles. This system rates each muscle from 0 (normal muscle) to 4 (more fat than muscle) (Table 1). These values were then dichotomized to indicate no fatty infiltration (score of 0 and 1), or fatty infiltration (2 or more). The landmarks used for grading each muscle have been reported previously.24 Briefly, GMIN, GMED and upper GMAX were each assessed on axial images at the level of the greater sciatic foramen, and 2/3 the distance from the top of the iliac crest to the proximal tip of the greater trochanter. They were further divided into two equal segments consistent with previous studies.34–36 The average of the Goutallier scores across the three sections of GMIN, GMED and upper GMAX indicated the level of fatty infiltrate for each muscle. TFL was assessed at the level of the fovea capitis, and QF was graded at the level of the largest cross-sectional area.

PATIENT-REPORTED OUTCOMES
Participants in the hip pain group were administered several questionnaires including the International Hip Outcome Tool (iHOT-33),36 the Hip Dysfunction and Osteoarthritis Outcome Score (HOOS),37 the Arthritis Self
Efficacy (ASE), the Tampa Scale for Kinesiophobia (Tampa), the Hospital Anxiety and Depression Scale (HADS), the Tegner Activity Level Scale (TAS), the Visual Analogue Scale (VAS), the Pain Catastrophizing Scale (PCS) and The Photograph Series of Daily Activity (PHODA). The questionnaires were either filled in electronically or via paper-based forms, depending upon preference.

The HOOS and iHOT-33 were used to assess health-related symptoms and function. The HOOS consists of five subscales on pain, symptoms, function in activities of daily living (ADL), sport and recreation function (Sport/rec) and hip-related QOL. A normalized score is calculated for each subscale (0 to 100), where 100 indicates no hip-related limitations, and zero indicates maximum hip-related limitations. The iHOT-33 measures symptoms and functional limitations, sports and recreational physical activities, job-related concerns and social, emotional, and lifestyle concerns on a scale from 0-100, with 0 indicating maximum hip-related limitations. The ASE was used to assess perceived confidence in ability to perform behaviours that would modify joint pain on a scale from 1-10. A score of 10 on ASE indicates the optimal score. The Tampa scale quantifies fear of movement and re-injury due to movement and physical activity. It consists of 17 statements of subjective experience of injury and activity on a scale from 0 to 68, where a score of 68 indicates greater fear of re-injury due to movement. The PCS, a 12-item instrument, was used as a measure of perception of pain on a scale between 0-52 for the total score. The PCS sub scales of Rumination (0-16), Magnification (0-12) and Hopelessness were also used. For all the PCS items, 0 is the optimal score. Physical activity level was assessed using the TAS with a scale from 0-10, where a score of 0 is where a participant is on sick leave or disability pension because of their hip problems and 10 is a participant performing as a nationally elite sportsperson. Participants were also asked to rate their average daily pain over the last week and the worst pain they experienced in the last week on separate 10cm VAS. The scale was anchored by "no pain" (score of 0) and "worst pain" (score of 10). Anxiety and depression were assessed using the HADS. The Anxiety and Depression sub scales are both scored by "no pain" (score of 0) and "worst pain" (score of 10).

RESULTS

PARTICIPANTS' CHARACTERISTICS

Between April 17, 2014 and April 14, 2015, 16 participants with hip-related pain (eight with greater pain on the dominant limb) and 15 healthy controls were invited to participate in this study. All participants were part of a larger cohort study. There were no statistically significant differences in participant characteristics between the hip-related pain and control groups (Table 2). In the hip-related pain group, 11 participants (69%) underwent arthroscopic surgery in the year after testing – of these, 100% had chondralabral pathology at hip arthroscopy. Participants with hip-related pain had moderate to severe limitations due to hip-related pain (Table 3).

COMPARISONS OF HIP MUSCLE VOLUMES AND FATTY INFILTRATE

There were no statistically significant differences in GMAX, GMED, TFL and QF muscle volumes nor fatty infiltration between symptomatic and less-symptomatic limbs in individuals with hip-related pain (Table 2 and Figure 1a), or between hip-related pain and control participants (Table 2 and Figure 1b).

HIP MUSCLE VOLUMES AND PATIENT-REPORTED HIP-RELATED LIMITATIONS

There were moderate to good associations between GMED muscle volumes and hip-related patient-reported outcomes in individuals with hip pain (Table 3). Those with greater GMED muscle volumes had less symptoms (HOOS-symptoms: \( \rho = -0.566, p=0.04 \), i-HOT-33 symptoms: \( \rho = -0.591, p=0.05 \)) and greater function (HOOS-ADL: \( \rho = -0.522, p=0.03 \)).
p=0.05, HOOS-Sport/rec: $\rho = -0.552$, p=0.04), social health status (i-HOT-33: $\rho = -0.579$, p=0.04) and QOL (HOOS-QOL: $\rho = -0.617$, p=0.02). There were no significant associations between GMAX, TFL and QF muscle volumes, and patient-reported outcome measures.

**HIP MUSCLE VOLUMES AND MUSCLE STRENGTH**

There were several significant associations between hip muscle volumes and strength in individuals with hip-related pain (Table 3). Greater GMAX volumes correlated with greater hip abduction ($\rho_{ho}=0.624$, p=0.01) and internal rotation ($\rho_{ho}=0.507$, p=0.045) strength. Those with greater hip GMED volumes had greater hip extension strength ($\rho_{ho}=0.547$, p=0.03) and those with greater QF volumes had greater hip abduction strength ($\rho_{ho}=0.658$, p=0.008).

**DISCUSSION**

The results of this study determined that people with hip-related pain and no clinical signs of FAIS, who were scheduled for hip arthroscopy, had no difference in volume for the muscles measured in the study on the symptomatic limb when compared to their less-symptomatic limb or matched healthy controls. There were also no differences in hip muscle fatty infiltrate between symptomatic and less-symptomatic hips or when compared to healthy controls. In the hip-related pain group, reduced GMED muscle volume correlated with poorer function (HOOS-ADL and HOOS-Sport/rec), symptoms (HOOS-symptoms and i-HOT-33 symptoms) and QOL (HOOS-QOL). Smaller muscle volume of GMAX was associated with lower abduction and internal rotation strength, smaller QF volume with lower hip abduction strength and smaller GMED volume with lower hip extension muscle strength.

**HIP MUSCLE VOLUME**

Lack of muscle volume differences (both between groups and between limbs in the hip-related pain group) is unexpected given the known hip muscle strength deficits in this population,31 and in people with FAIS.12 This finding was consistent with findings of no differences in muscle volumes in people with mild OA,6,7 and women with hip-related pain,23 with only one prior study reporting smaller muscle volumes in 50 people with unilateral FAIS.47 It is possible that muscle volume differences only become evident in those with moderate to severe hip OA.

Direct comparisons with prior studies are hampered by key differences in methodology, for example normalizing muscle volume for weight and pooling of muscle groups.23 The current results strengthen the notion of a continuum of hip pathology where younger people with less severe symptoms and/or less marked joint changes have hip muscle weakness but no change in muscle size. As the symptoms and joint degeneration progress, measurable muscle volume changes may occur.

Hip muscle volume in participants with hip-related pain cannot fully explain the observed hip muscle weakness. Pain inhibition might explain the strength deficit, but a prior report by this group found no association between muscle strength and patient reported pain.31 Changes in the motor control of the hip muscles may provide an alternative explanation. Although no studies to the authors’ knowledge have investigated changes in motor control in...
people with hip-related pain with no FAIS, there is a growing body of research investigating motor control changes in people with hip-related pain with FAIS.48–50 Results from these studies report changes in the timing and activation of the deep hip muscles with functional movements such as squatting and walking. It is unclear whether these other findings could be interpreted as a strategy to reduce hip impingement or another mechanism.48–50 Studies of other peripheral and axial joints in patients have demonstrated selective changes in muscle function associated with joint pain; including timing of onset and cortical representation of these muscles.51–55 Specific strategies for hip rehabilitation could be explored in future studies.

### FATTY INFILTRATE

Muscle fatty infiltrate appears to be rarely evident in people with hip-related pain. Similar to hip muscle volume, muscle fatty infiltrate may be a sign of disuse accompanying advanced joint disease, greater BMI or aging.24 While the current findings indicated no difference in fatty infiltrate between limbs or between groups, further studies of fatty infiltrate in different groups with varying disease severity are warranted.

### MUSCLE STRENGTH

Greater hip muscle volumes were moderately associated with higher muscle strength, especially hip abduction strength. Hip abductor strength will be influenced by the

<table>
<thead>
<tr>
<th>i) Patient reported Outcomes</th>
<th>Gluteus Maximus</th>
<th>Gluteus Medius</th>
<th>Tensor Fasciae Latae</th>
<th>Quadratus Femoris</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip Dysfunction and Osteoarthritis Outcome Score (0-100)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symptoms</td>
<td>59±16</td>
<td>-0.173</td>
<td>0.55</td>
<td>-0.566</td>
</tr>
<tr>
<td>Pain</td>
<td>63±15</td>
<td>-0.283</td>
<td>0.33</td>
<td>-0.525</td>
</tr>
<tr>
<td>Activities of daily living</td>
<td>71±12</td>
<td>-0.403</td>
<td>0.15</td>
<td>-0.522</td>
</tr>
<tr>
<td>Sport and recreation</td>
<td>52±19</td>
<td>-0.461</td>
<td>0.10</td>
<td>-0.552</td>
</tr>
<tr>
<td>Quality of life</td>
<td>42±19</td>
<td>-0.345</td>
<td>0.23</td>
<td>-0.617</td>
</tr>
<tr>
<td>Visual Analogue Scale for Pain in the last week (0-10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average daily pain</td>
<td>4±2</td>
<td>0.331</td>
<td>0.25</td>
<td>0.531</td>
</tr>
<tr>
<td>Worst pain</td>
<td>6±3</td>
<td>0.059</td>
<td>0.84</td>
<td>0.448</td>
</tr>
<tr>
<td>International Hip Outcome Tool-33 (0-100)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symptoms</td>
<td>53±26</td>
<td>-0.517</td>
<td>0.07</td>
<td>-0.591</td>
</tr>
<tr>
<td>Sport</td>
<td>32±30</td>
<td>-0.264</td>
<td>0.38</td>
<td>-0.306</td>
</tr>
<tr>
<td>Job</td>
<td>50±29</td>
<td>-0.092</td>
<td>0.77</td>
<td>-0.432</td>
</tr>
<tr>
<td>Social</td>
<td>34±33</td>
<td>-0.416</td>
<td>0.16</td>
<td>-0.579</td>
</tr>
<tr>
<td>Hospital Anxiety and Depression Scale (0-21)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anxiety</td>
<td>8±4</td>
<td>-0.22</td>
<td>0.45</td>
<td>0.038</td>
</tr>
<tr>
<td>Depression</td>
<td>7±2</td>
<td>0.215</td>
<td>0.46</td>
<td>0.252</td>
</tr>
<tr>
<td>Tampa (17-68)</td>
<td>41±6</td>
<td>0.189</td>
<td>0.52</td>
<td>0.228</td>
</tr>
<tr>
<td>Arthritis SE (0-10)</td>
<td>6±2</td>
<td>0.229</td>
<td>0.43</td>
<td>0.011</td>
</tr>
<tr>
<td>Pain Catastroph (0-52)</td>
<td>14±13</td>
<td>-0.062</td>
<td>0.83</td>
<td>0.422</td>
</tr>
<tr>
<td>PHODA (0-100)</td>
<td>33±15</td>
<td>0.019</td>
<td>0.95</td>
<td>0.224</td>
</tr>
<tr>
<td>Tegner (0-10)</td>
<td>4±2</td>
<td>0.336</td>
<td>0.52</td>
<td>0.272</td>
</tr>
<tr>
<td>ii) Hip muscle strength (N.m/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abduction</td>
<td>0.624</td>
<td>0.01</td>
<td>0.48</td>
<td>0.06</td>
</tr>
<tr>
<td>Adduction</td>
<td>0.468</td>
<td>0.07</td>
<td>0.399</td>
<td>0.13</td>
</tr>
<tr>
<td>Internal Rotation</td>
<td>0.507</td>
<td>0.05</td>
<td>0.484</td>
<td>0.06</td>
</tr>
<tr>
<td>External Rotation</td>
<td>0.279</td>
<td>0.30</td>
<td>0.268</td>
<td>0.32</td>
</tr>
<tr>
<td>Extension</td>
<td>0.42</td>
<td>0.11</td>
<td>0.547</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Data are presented as mean±standard deviation. Abbreviations: Tampa: Tampa Scale for Kinesiophobia; Pain Catastrophising; Arthritis SE: Self Efficacy; PHODA: The Photograph Series of Daily Activity; Tegner: Tegner Activity Scale. Bold font denotes significant correlation.
primary synergists, the upper portion of GMAX, GMED, GMIN, and TFL. Furthermore, the deep hip external rotators (including QF) have been shown to be active during hip abduction,\textsuperscript{18,56} potentially contributing to efficient force transfer from the more superficial lateral muscles. Strengthening programs that target all synergistic hip abductors and hip stabilizer muscles may be important for the restoration of normal muscle function at the hip joint.

PATIENT REPORTED OUTCOMES

Lower GMED volume was associated with greater symptoms, poorer function in sport and activities of daily living (HOOS, i-HOT-33) and lower QOL. The mechanism explaining how smaller muscle volume might affect patient-reported outcomes is unclear, and it is possible that greater symptom severity is the driver of disuse and smaller muscle volume. Rehabilitation strategies targeting hip muscle size and strength deficits are certainly justifiable in this population. But, the moderate levels of symptoms, patient-related disability, kinesiophobia and lower than normal QOL may indicate that a more holistic approach is required. This may include patient information and advice, aerobic exercise and for some with fear avoidance and unhelpful beliefs about pain, more specific cognitive training.\textsuperscript{57} Patient information and advice needs to be tailored to the patient, with recent qualitative research indicating that patient expectations, active coping strategies, information about structure and pain, and appropriate guidance on returning to physical activity may be important.\textsuperscript{57–59}

LIMITATIONS

The study had several limitations in addition to the relatively small sample size. Although the hip group had clinical and radiographic evidence of hip pathology, it is difficult to be absolutely certain that the participants in the hip-related pain group had pain coming from the hip joint. A limitation of the within-subject comparisons was that one participant in the hip-related pain group had bilateral
symptoms. In this case, the comparison was most symptomatic to less symptomatic, not symptomatic to asymptomatic. In addition, the recruitment of the participants with hip-related pain from only one surgeon may have led to selection bias. The cross-sectional study design means temporal and causative relationships cannot be established. Further, although there were not statistically significant differences between the groups, the healthy control group was on average six years younger than the hip-related pain group. This age difference may reduce the strength of the conclusions that can be made about hip strength and hip muscle volume. Some, but not all, of the superficial and deeper hip muscles were examined. The study may have been strengthened by including superficial muscles such as the hip adductors and flexors which have been shown to be weak in people with hip-related pain and other deeper hip muscles such as iliocapsularis which may have an important stability role in movement and gait. Lastly, while all of the participants had engaged in non-surgical management, there were no records of program duration, or how much hip-muscle strengthening was performed, therefore the authors cannot be certain whether the pre-operative management may have had an influence on the study findings.

CONCLUSION

Individuals with hip-related pain and no clinical FAIS have hip muscle volumes and hip muscle fatty infiltration that are not significantly different to matched healthy controls or to their less-symptomatic limb. Smaller muscle volume of GMAX was associated with lower abduction and internal rotation strength, smaller QF volume with lower hip abduction strength and smaller GMED volume with lower hip extension muscle strength. Smaller hip muscle volume, particularly of GMED, was associated with poorer hip function, greater symptoms, and lower QOL. This information may inform rehabilitation professionals programs to improve treatment outcomes for people with hip-related pain.

CONFLICTS OF INTEREST

The authors report no conflicts.

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No Difference in Hip Muscle Volumes and Fatty Infiltration in Those With Hip-Related Pain Compared to Controls


Bilateral Comparison of Anterior Shoulder Position in Elite Tennis Players

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Keywords: scapula, pectoral musculature, tennis, shoulder

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Background
In elite tennis players, musculoskeletal adaptations in the dominant upper extremity have been reported for range of motion, strength, and scapular biomechanics. In addition to scapular dysfunction, tightness and inflexibility of the pectoral musculature have been identified as risk factors for the development of overuse shoulder injury in overhead athletes.

Hypothesis
Differences in anterior shoulder position will be identified between the dominant and non-dominant extremity in elite tennis players. The purpose of this study was to examine bilateral differences in anterior shoulder posture measured using a double square in elite tennis players without shoulder injury.

Study Design
Descriptive Laboratory Study

Methods
Three hundred and six uninjured elite tennis players were measured in the supine position using a double square method to measure anterior shoulder position. The distance from the surface of the table to the anterior most position of the shoulder (in millimeters) was measured bilaterally and compared. A dependent t-test was used to test for significant differences in anterior shoulder position between the dominant and non-dominant extremity.

Results
One hundred thirty-three males and 173 females were included in this study with a mean age of 16.58 years. The mean difference between extremities indicates increased anterior shoulder positioning on the dominant shoulder of 7.65 mm in females, and 8.72 in males. Significantly greater (p<.001) anterior shoulder position measures were documented on the dominant shoulder as compared to the non-dominant shoulder.

Conclusions
The results of this study showed significantly (p<.001) greater anterior shoulder position on the dominant extremity of elite male and female tennis players. The differences of
INTRODUCTION

The unilaterally dominant muscular activation inherent in tennis groundstrokes and in the serve specifically target the internal rotators during the acceleration phase and may lead to asymmetrical scapular postures. Prior authors have shown bilateral asymmetries in glenohumeral joint rotational range of motion and shoulder postures, respectively in elite level tennis players. Clinical assessment of the shoulder and scapular positioning for unilateral overhead athletes often reveals asymmetry between the dominant and non-dominant sides. It has been well established that overhead athletes regularly have increased external rotation and corresponding decreases in internal rotation range of motion of the dominant shoulder compared to their non-dominant shoulder. In addition, when both internal rotation and the total arc of rotation between shoulders is asymmetrical, it has been associated with an increased risk of injuries in overhead athletes.

Injuries to the shoulder in elite level tennis players can occur from repetitive overuse required for elite skill development and competition. The repetitive demands of the game of tennis inherently produce selective strength development of the internal rotators on the dominant shoulder without concomitant increases in posterior strength development of the rotator cuff and scapular stabilizers. Pectoralis minor length and associated tightness have been measured using differing techniques in several studies. These descriptive studies aid clinicians in the design of preventative treatment as well as in the rehabilitation of sports-specific injuries.

Various methods to quantify scapular position asymmetries in athletes have been published, Kibler has highlighted the association between scapular dyskinesis and overuse injury in tennis players and in overhead athletes in general. Kibler has developed a method for evaluating and classifying scapular pathology using visual observation during movement and static positioning. One of the challenges encountered by clinicians is the accurate identification of scapular dysfunction and general scapulo-thoracic positioning in the clinical environment. Kibler developed and reported on the "Lateral Scapular Slide Test" using a tape measure to measure bilateral scapular positioning and established a criterion by which patients and athletes could be classified "at risk" by using a bilateral difference of 1 to 1.5 cm as a baseline criterion measure. Further studies assessing the reliability of these measurement techniques have been conducted and report acceptable reliability metrics for clinical usage.

The double square method has been used to measure the distance (in millimeters) between the most anterior aspect of the acromion and a supportive surface. This measurement provides a clinically applicable measure of the anterior positioning of the shoulder and can be performed in either supine or standing position.

Shoulder posture has been objectively studied in athletes who participate in several overhead sports in order to help describe and understand posture among these athletes. Kleumper et al. analyzed whether a stretching program would effectively reduce the forward shoulder posture in competitive swimmers. The study utilized the double square method in a standing position in a population of competitive swimmers. The authors' postulated that the repetitive propulsive training inherent in the concentric internal rotation dominant phases of the primary swimming mechanics used in training and competition led to adaptive changes producing an anterior shoulder posture in these elite athletes. A pilot study concluded that the double square method was highly reliable with an intraclass correlation coefficient (ICC) of 0.99 and SEM of 0.1 mm. Following a six-week anterior shoulder stretching program, there was a 9mm decrease bilaterally in forward shoulder posture.

A clinical study by Borstad validated methods of measuring pectoralis minor length using Vernier calipers as well as a tape measure. These two measurement techniques have been shown to have good intratester reliability with ICCs of 0.85 and 0.84, respectively. Lewis et al. utilized a rigid transparent right angle to measure the distance between the table and the posterior aspect of the acromion to assess pectoralis minor length in subjects with and without shoulder symptoms. This method demonstrated excellent intra-rater reliability with ICC ranging from 0.92 to 0.97.

Despite the evidence presented on the asymmetries of the resting scapular posture for overhead athletes, little has been reported in regards to normative values for the asymmetric anterior shoulder position, and no prior information reported in tennis players. The purpose of this study was to examine bilateral differences in anterior shoulder posture measured using a double square method in elite tennis players without shoulder injury. It was hypothesized that increased anterior shoulder positioning would be present on the dominant extremity in elite level tennis players due to the unilateral upper extremity demands inherent in the sport. This information will allow clinicians and sport scientists to use this measure to identify abnormal scapular and shoulder positioning from potential normal sport specific adaptations using a readily available device and methodology.

METHODS

Three-hundred and six uninjured elite level tennis players (133 Males, 173 Females) between the ages of 10 and 24 were recruited to participate in this study. The definition of elite for this study is: competitive junior players involved in year-round training and participating in regional and/or national level tournaments as well as NCAA collegiate tennis players. Subjects signed an informed consent prior to measurement and participation in this research. The IRB of

Level of Evidence

3

7-8mm between extremities has clinical application for interpreting anterior shoulder position test results in this population.

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Physiotherapy Associates reviewed and approved this study. All subjects were free from shoulder injury in the year prior to testing and had no prior surgical procedures performed to either shoulder in their medical history. Subjects with significant observable scoliotic curves were excluded from the study due to the unknown association of significant spinal scoliosis on scapular positioning using visual examination by the primary author, a physical therapist with 37 years of clinical experience.

PROCEDURES

Subjects were positioned in a supine position on a plinth with a firm supportive surface. They were positioned with their knees bent 90 degrees and hips flexed 45 degrees. This position was meant to promote relaxation in the supine position. The upper extremities were positioned at the side of the subject with the forearms pronated such that the hands were resting comfortably on the supportive surface. Males were tested with their shirts removed, and females were either a sports bra or tank top such that the entire anterior surface of the shoulder was exposed.

A double square (Model #420EM, Johnson Level and Tool Manufacturing, Inc, Mequon, Wisconsin) was used to measure the distance from the supportive surface to the anterior most aspect of the skin overlying the humeral head of the shoulder. No overpressure was used and the force of gravity was used to consistently rest the upper arm of the double square against the anterior shoulder. The double square has levels on each end to ensure that the perpendicular distance from the supportive surface to the anterior most aspect of the shoulder is measured bilaterally. The examiner slid one double square up or down to accurately position the square against the anterior most aspect of the shoulder and recorded the distance on the 30 cm ruler to the nearest millimeter. This number was entered on the data collection sheet along with tennis specific demographic data on each subject (including years of competitive tennis play, use of a one-handed or two-handed backhand). One trial was used bilaterally with a random determination of first measured extremity. The dominant shoulder was operationally defined as the shoulder the player served with and used during their forehand groundstroke. Figure 1 shows the experimental set-up with subject positioning and use of the double square for measurement of anterior shoulder position.

DATA ANALYSIS

SPSS (version 23.0) was used to generate descriptive data as well as compare means from the dominant and non-dominant extremity of the elite tennis players measured in this study. A dependent t-test was used to test for differences between extremities. Significance was set at the p< 0.05 level.

RESULTS

Three hundred and six elite junior tennis players (mean age 16.58 years) were measured in this study. Subject demographics are presented in Table 1. Players had 6.99 to 7.82 mean years of competitive tennis experience and nearly all (88-99%) used a two-handed backhand groundstroke. For males, the mean anterior most aspect of the dominant shoulder was positioned 125.1 ± 17.87 mm from the table with the non-dominant arm positioned 116.38 ± 17.11 mm. For females the mean positioning was 121.95 ± 12.42 mm for the dominant arm and 114.50 ± 12.34 for the non-dominant arm. The mean difference in anterior shoulder positioning between extremities was 7.65 mm for females, and 8.72 for males, indicating greater anterior shoulder positioning on the dominant shoulder. Significantly greater (p< 0.001) anterior shoulder position measures were documented on the dominant shoulder as compared to the non-dominant shoulder (Table 2).

DISCUSSION

In the modern game of tennis, a great majority of tennis strokes include the serve and forehand. Both of these strokes are characterized by strong concentric muscular contractions during the acceleration phase by the pectoralis major during internal rotation of the shoulder. Musculoskeletal profiling studies of elite tennis players have identified significantly greater internal rotation strength development on the dominant arm likely as a result of this repetitive concentric internal rotation.

The results of the present study show significantly greater anterior shoulder position on the dominant arm compared to the non-dominant arm using this simple, clinically applicable technique with a double square. Reeser et al. used a standard carpenter’s level placed across the shoulders in the supine position in elite level volleyball players and reported that 63% of the players in their sample had anterior shoulder positioning which they attributed to pectoral tightness/shortening. Additionally, in a previous investigation, players with pectoral tightness identified using this supine carpenter level technique had a significant association with shoulder pain. In the current sample of athletes, 64% of males and females had greater than 5 mm of increased anterior shoulder position with a mean dominant / non-dominant difference of 7-8 mm.
Table 1. Participant demographics a

<table>
<thead>
<tr>
<th></th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>17.08 ± 3.45</td>
<td>15.83 ± 3.77</td>
</tr>
<tr>
<td>Height (in)</td>
<td>66.22 ± 3.86</td>
<td>67.99 ± 5.51</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>60.09 ± 10.53</td>
<td>61.61 ± 16.81</td>
</tr>
<tr>
<td>Years of Competitive Tennis Play</td>
<td>7.92 ± 3.89</td>
<td>6.99 ± 4.23</td>
</tr>
<tr>
<td># of Tournaments/Year</td>
<td>14.78 ± 8.14</td>
<td>17.05 ± 6.50</td>
</tr>
<tr>
<td>2-handed Backhand (%)</td>
<td>99.4</td>
<td>88.5</td>
</tr>
</tbody>
</table>

a Data presented as mean ± SD unless otherwise indicated

Table 2. Anterior shoulder measurement a

<table>
<thead>
<tr>
<th></th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dominant</td>
<td>Non-Dominant</td>
</tr>
<tr>
<td>Anterior Shoulder Position</td>
<td>121.95 ± 12.42</td>
<td>114.30 ± 12.34</td>
</tr>
</tbody>
</table>

a Data presented as mean ± SD (mm) unless otherwise indicated
b Indicates significant association, p ≤ 0.05

Kluemper et al.27 did not report bilateral difference data in their study using the double square method in elite level swimmers, but used this technique to show improvements (decreases) in anterior shoulder position with the use of two stretches and multiple elastic resistance exercises for the posterior rotator cuff and scapular musculature. Peterson et al.37 tested the reliability of the double square technique alongside three other measurement techniques to quantify shoulder and scapular positioning. Similar to Kluemper et al.,37 Peterson et al.7 found this technique had high levels of intratester reliability (ICC=0.89).

The use of the double square technique in this investigation to measure anterior shoulder position has significant clinical application. Due to the role scapular dysfunction plays in the overhead athlete, this test can accompany other scapular evaluation techniques to objectively identify the anterior shoulder position caused by tightness of the pectoralis musculature or other factors.5 The descriptive data presented in this study may help to identify thresholds for intervention whereby anterior shoulder position differences between dominant and non-dominant side may be greater than the apparent musculoskeletal side to side adaptations reported in this descriptive investigation. The results of this study indicate that increases in dominant arm anterior shoulder positioning by more than 7-8 mm compared to the contralateral side in elite tennis players could indicate a need for the utilization of interventions to address pectoralis muscle tightness/shortening specifically. This test can provide objective measurements whereby prescription of specific stretches to address pectoral muscle tightness may be considered and changes in side-to-side anterior shoulder positioning could be monitored.

To address pectoralis tightness in the shoulder with an increase in anterior shoulder position several studies provide objective guidance.38–40 Borstad et al.38 compared the efficacy of a unilateral self-stretch, a manual sitting stretch and a manual supine stretch of pectoralis minor. They found that the most effective stretch of the three to be the self-stretch. The unilateral self-stretch was described as stabilizing the subject’s forearm in a vertical plane and then rotating the trunk in an opposite position. However, when performed as part of a six-week home stretching program, there was no increase in pectoralis minor length in both healthy and symptomatic subjects.1 Conversely, pectoralis minor stretching done in conjunction with a shoulder strengthening routine have led to improvements in posterior scapular tilting and forward shoulder position.21,41

Care must be taken when selecting stretches for the pectoralis musculature to protect the anterior capsule in the overhead athlete.28 The supine foam roll stretch used by Kluemper et al.27 places the shoulders in a neutral rotated position with low levels of abduction while a partner or clinician presses the shoulder girdle posteriorly. This technique does not compromise the anterior capsule through the excessive use of horizontal abduction and external rotation positions inherent in other pectoralis muscle stretches.38 Research studies demonstrating the efficacy of pectoralis stretches as well as anatomic and biomechanical analysis of the glenohumeral joint position used during stretching of the pectoralis musculature ultimately should guide the clinician in the optimal selection to address anterior shoulder tightness in the overhead athlete.

Limitations in the present study include the use of only uninjured elite level tennis players in the current sample. This does not allow the present study to identify a critical dominant / nondominant side to side difference where symptoms or pathology may be present. Additional studies including population specific injured athletes could provide insight into identifying this critical level. The physical therapist performing all measurements was not blinded to arm...
dominance of the subjects being tested in this study. Further study comparing pre-post stretching regimens in players with symptoms and excessive anterior shoulder position profiles should be conducted to provide additional insight into the optimal evaluation and subsequent management of anterior shoulder position.

CONCLUSION

The results of this study showed significantly (p< 0.001) greater anterior shoulder position on the dominant extremity of elite male and female tennis players. The use of elite level uninjured tennis players and the identification of mean differences of 7-8mm between extremities has clinical application for the interpretation of anterior shoulder position test results in this population. The characteristic anterior shoulder muscle activation required in high level tennis play may produce anatomic musculoskeletal adaptations such as an increase in anterior shoulder position which can be measured and monitored using the double square technique in a supine position.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

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REFERENCES


Original Research

A Comparison of Pitching Biomechanics and Sport Specialization in High School Pitchers

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Background

The prevalence of sport specialization in high school athletes continues to rise, particularly among baseball players. Previous research has focused on the incidence of injury among specialized and non-specialized athletes but has yet to examine the level of sport specialization and pitching biomechanics.

Hypotheses/Purpose

The purpose of this study was to investigate differences in pitching volume and biomechanics between low-, moderate-, and high-level specialized baseball pitchers. It was hypothesized that high-level specialized pitchers would have the most pitching volume within the current and previous years while low-level specialized pitchers would exhibit the least amount. The second hypothesis states that kinematics and kinetics commonly associated with performance and injury risk would differ between low-, moderate-, and high-level specialized pitchers.

Study Design

Case-Control Study

Methods

Thirty-six high school baseball pitchers completed a custom sport specialization questionnaire before participating in a three-dimensional pitching motion analysis. Sport specialization was based off current guidelines and categorized as low-, moderate-, and high-level specialized based upon self-reported outcomes. Pitchers then threw ≈10 fastballs from a mound engineered to professional specifications. Data averaged across fastballs was used for biomechanics variables. Key pitching biomechanical and pitching volume variables were compared between low-, moderate-, and high-level specialized pitchers.

Results

High-level specialized pitchers were older (p = 0.005), had larger body mass (p = 0.05) and BMI (p = 0.045), and threw faster (p = 0.01) compared to low-level specialized pitchers. Pitching volume and pitching biomechanics were similar across groups.

Conclusions

Pitching biomechanics were similar across groups, although high-level specialized pitchers threw with significantly higher throwing velocity compared to low-level pitchers. The low amount of pitching volume throughout the season may be responsible for the lack of additional observed differences. Further research should examine the relationship between pitching biomechanics, upper extremity strength and flexibility, and sport specialization.
INTRODUCTION

Organized youth sports within the United States involve over 60 million youth athletes per year. Participation across all age groups from six to eighteen years old has increased over the past two decades, resulting in a concomitant increase in sport specialization. Sport specialization is defined as intentional and focused participation in a single sport for the majority of the year that restricts opportunities for engagement in other sports and activities. Additionally, single and multisport athletes may be considered specialized if they meet some or all of the following criteria: a) participation in a single sport for greater than eight months of the year that includes regular organized practices, competitions, or other structured training, b) the athlete may have limited or ended involvement in other sports to enable focused participation in a single sport or have only ever been involved in one sport, c) focused participation in a single sport limits the opportunities or time available for other activities, such as involvement in other sports, academics, extracurricular activities, time with friends, and community engagement. Furthermore, sport specialization can be categorized as high-, moderate-, and low-level specialized based on responses to “Can you pick a main sport?”, “Did you quit other sports to focus on a main sport?”, and “Do you train >8 months in a year?” High-level specialists, those answering “yes” to at least two of the aforementioned questions, were previously shown to be more likely to experience an overuse injury compared to moderate- (answering “yes” to two questions) and low-level specialists (answering “yes” to ≤ 1 questions). Sport specialization is associated with performing the same mechanical motions repeatedly and often focusing on certain musculoskeletal areas while neglecting others in order to attempt to perform optimally in a sport. Despite increasing evidence suggesting that sport specialization may contribute to overuse injuries in youth athletes, specialization prevalence continues to rise in the United States, particularly among baseball players.

Specialization prevalence of multiple sports revealed that baseball athletes are more likely to specialize as well as endure the highest prevalence of overuse injuries. Coinciding with recent trends, elbow injuries within youth baseball players significantly increased from 2006 to 2016, and 57% of all ulnar collateral ligament reconstructions now performed in youth pitchers. Injury risk is increased when compounding repetition from practice and competition as repeated sport-specific mechanical motions can lead to traumatic injury or overuse injury, both of which are negative consequences of sport specialization. While specialization is thought to enhance skills and abilities needed to achieve elite status, there is a consensus that participating in multiple sports throughout the year and unstructured play is important for developing a well-rounded athlete to mitigate the chronic stresses of pitching.

Pitching volume has been shown to be a risk factor for upper extremity injury in youth baseball pitchers, as increased pitches per game, innings pitched per season, months pitched per year, and pitching for multiple teams are all associated with increased injury risk. Repetitive stress on the musculoskeletal system can result in overuse injuries, to which youth athletes are considered highly susceptible due to musculoskeletal and physiological immaturity. Pitchers between 9–14 years old who pitched more than eight months per year were shown to be five times more likely to undergo surgery compared to those pitching less than eight months. Additionally, youth pitchers who regularly throw with arm fatigue are 56 times more at risk to require surgery or end their baseball career due to injury. Even with youth pitchers learning proper techniques, fatigue from competition can impair pitching biomechanics.

Biomechanical assessments have been gaining popularity in order to assess performance and potential injury risk through analysis of kinematics (i.e., motions) and kinetics (i.e., forces and torques) within the pitching motion. These assessments suggest a balance between increased performance brought on by increased throwing velocity and increased injury risk, as injuries are most likely to occur when high forces and torques are repeatedly applied to vulnerable tissue. The large amount of kinetic forces produced throughout the body during the pitching motion cause the throwing arm to sustain a substantial amount of kinetic energy. Understanding and implementing efficient pitching biomechanics can help to safely facilitate kinetic energy propagation from stride-foot contact (SFC) to ball release (BR), timepoints commonly used to denote the arm cocking, acceleration, and deceleration actions exhibited in the pitching motion. Less-skilled pitchers demonstrate a decreased ability to safely propagate kinetic energy through to the baseball, leading to increased injury risk. Pitching biomechanics that allow for fluid kinetic energy propagation may help mitigate the effects of increased pitching volume observed in specialized baseball pitchers.

Previous research has yet to examine the relationship between the level of sport specialization and pitching biomechanics. Therefore, the purpose of this study was to investigate differences in pitching volume and biomechanics between low-, moderate-, and high-level specialized baseball pitchers. It was hypothesized that high-level specialized pitchers would have the largest volume of pitching within the current and previous years with low-level specialized pitchers exhibiting the least amount of pitching volume. The second hypothesis states that pitching biomechanics variables commonly associated with performance and injury risk would differ between low-, moderate-, and high-level specialized pitchers.

MATERIALS AND METHODS

Data were retrospectively gathered from pitching biomechanics evaluations at the Wake Forest Pitching Lab, available as an open service to all interested pitchers. Pitching
evaluations were specifically advertised to regional baseball teams. An evaluation included completion of several questionnaires, including the sport specialization questionnaire, and three-dimensional pitching motion analysis. Study inclusion criteria included high school pitchers between the ages of 13 – 18 for whom pitcher is their primary or secondary position. Participants were excluded from the study if pitching was not their primary or secondary position or if they presented with an injury at the time of the pitching assessment. This study was approved by Wake Forest University’s Institutional Review Board.

Pitchers were first given a questionnaire to complete upon arriving at the lab. The questionnaire was adopted by the research team from a cricket health and well-being study and was piloted and refined for use on baseball personnel including a group of current and former baseball players (n = 121), collegiate and professional baseball coaches (n = 5), and medical professionals (sport physician, physical therapists, and athletic trainers; n = 4) who specialize in treating baseball players. The degree to which an athlete was specialized was defined in conjunction with current published guidelines and categorized as low-, moderate-, or high-level specialization based upon the athlete’s answer to three survey questions (Figure 1).

The first question required pitchers to answer ”Are you active in other sports besides baseball“ (i.e., exclusion of other sports) by listing all sports they’re actively participating in. Pitchers were then asked, ”How many times per week do you participate in another sport“ (i.e., duration of training) and prompted to answer with 1 Day, 2 Days, 3 Days, 4 Days, or 5+ Days. Lastly, pitchers were asked ”How do you assess your current exercise volume“ (i.e., focused participation) on a seven-point scale, with 1 corresponding to Extremely Low and 7 being Extremely High. A point was given if athletes were only active in baseball, participated in another sport less than four times per week, and if perceived exercise volume was below four on a seven-point scale.

The sum of these three questions was used to assign the degree of specialization with a score of “3” categorized as high-level specialization, “2” as moderate-level specialization, and “1” as low-level specialization. The questionnaire also required each pitcher to self-report workload variables including, the number of games played in the current year, games pitched in the current year, innings pitched in the current year, and innings pitched in the previous year.

Biomechanical pitching data included kinematic and kinetic data examined from 3D motion capture reports generated as part of a pitching evaluation at the Wake Forest Pitching Lab dating from July 2019 to January 2020. Biomechanical data were collected using the full-body marker set required for PitchTrak (Motion Analysis Corporation, Santa Rosa, CA), consisting of forty-one retro-reflective markers in conjunction with a twelve-camera motion analysis system (Qualysis AB, Göteborg, Sweden) sampling at 400 Hz. Each pitcher was given as much time as needed to complete their self-determined, regular pre-throwing warmup routine before stating their readiness to start throwing from the force-plate instrumented (AMTI, Watertown, MA) pitching mound (Porta-Pro Mounds Inc, Sauget, Illinois) sampling at 1,200 Hz. The pitching mound was engineered to meet major league specifications and was situated at a standard distance of 18.4 meters from the target. Pitchers threw roughly ten fastballs to which only fastball data were analyzed for this study. Ball velocity was recorded using a military-grade Doppler radar device (Trackman, Scottsdale, AZ).

Pitching biomechanics variables were taken from results averaged across all pitches. Kinematic outcomes included shoulder horizontal abduction angle at SFC, shoulder rotation angle at maximum shoulder external rotation (MER), lateral trunk tilt angle at MER, lead knee flexion angle at BR, forward trunk tilt angle at BR, and lateral trunk tilt angle at BR. Kinetic variables included maximum shoulder distraction force and maximum elbow valgus torque. Shoulder distraction force and elbow valgus torque were normalized by body weight (N) and body weight multiplied by height (Nm), respectively. Biomechanical variables were chosen due to their direct implications to injury risk or increased throwing velocity. All variables were calculated with Visual3D (C-Motion, Inc. Germantown, MD).

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS Statistics v26; IBM Corp, Armonk, NY) at an a priori significance level of 0.05. Data were assessed with Shapiro-Wilk normality tests. An initial analysis of variance (ANOVA) was used to compare differences in age, height, mass, BMI, and throwing velocity between high-, moderate-, and low-level specialized pitchers. However, due to non-normal distributions, a Kruskal-Wallis test was used to assess differences in workload variables and biomechanics variables between the high-, moderate- and low-level groups. Variables that did not violate the assumption of normality were described as means.
and standard deviations while non-normal variables were described as medians and interquartile range (IQR) values. To account for inflated Type I error rates incurred by performing multiple Kruskal-Wallis tests, Bonferroni corrections were applied to each H-test. Following the correction, pairwise comparisons with Bonferroni corrections were completed for H-tests that demonstrated significance following correction. Eta-squared effect sizes were calculated and interpreted as small = 0.01-0.06, moderate = 0.06-0.14, and large effects ≥ 0.14.30

RESULTS

Thirty-six male high school pitchers (Age: 15.28 ± 1.32 years) were included in this study. Of the 36 pitchers, 11 (30.5%) were classified as low-level specialization, 14 (39%) as moderate-level, and 11 (30.5%) as high-level. Pitchers were 1.83 ± 0.08 meters in height and 75.98 ± 12.74 kilograms in weight, with a body mass index (BMI) of 22.67 ± 3.01 kg/m². Twenty-three pitchers were currently playing other sports, six pitchers noted spending four or more days per week participating in other sports, and 26 pitchers assessed their current exercise volume as five or more.

High-level specialized pitchers were significantly older ($p = 0.005$), had larger body mass ($p = 0.05$) and BMI ($p = 0.045$), and threw faster ($p = 0.01$) compared to low-level specialized pitchers (Table 1). No significant differences in pitcher demographics were observed between high- and moderate-level specialized pitchers as well as between moderate- and low-level specialized pitchers. No significant differences were found in games played in the current year, games pitched in the current year, innings pitched in the current year, or innings pitched in the previous year across groups (Table 2). Additionally, no significant differences were observed in pitching biomechanics variables across groups (Table 3).

DISCUSSION

The purpose of this study was to investigate differences in pitching volume and pitching biomechanics between low-, moderate-, and high-level specialized pitchers. Results from this study found that high-level specialized pitchers were significantly older and had significantly more weight and BMI as well as throw with significantly greater ball velocity compared to low-level specialized pitchers. All groups spent similar amounts of time participating in baseball-related activities as well as generated similar movements and torques throughout the pitching motion. Due to pitchers across groups generating similar movements and torques throughout the pitching motion, negative outcomes associated with sport specialization may not be a direct result of pitching biomechanics.

The lack of significant differences in pitching volume between groups may suggest that low-, moderate- and high-level specialized pitchers are spending the same amount of time participating in baseball per week, but low- and moderate-level pitchers spend additional time within other sports. Low-level specialized pitchers were the only group to note their weekly participation in other sports to be three days or more, with only six of fourteen moderate-level pitchers noting two days per week of non-baseball participation. The observed similar games and innings pitched suggest athletes across groups had seasons of similar length to which the number of innings pitched may further expose why no significant differences in pitching biomechanics were also observed. One study following youth pitchers over ten years found that athletes who pitched more than 100 innings in a year were 3.5 times more likely to sustain a serious injury.31 Low-, moderate-, and high-level specialized pitchers within this study reported throwing an average of 34, 32, and 40 innings in the current year, respectively, as well as 48, 46, and 45 innings in the previous year, respectively. As muscle fatigue increases throughout the season, elbow joint stiffness decreases, leading to additional stress on the ulnar collateral ligament and a higher prevalence of injury.32

Changes in pitching performance have shown to decrease at a slower rate than changes in pitching biomechanics, suggesting kinematic compensations are made to limit fatigue.33 Pelvic orientation, elbow height, and shoulder external rotation were the most sensitive kinematic parameters to inning, game, and season fatigue.19 These biomechanical outcomes all have the possibility of producing greater torque at the shoulder and valgus stress at the elbow in fatigued pitchers.34,35 Therefore, the amount of pitching volume exhibited within this study may suggest that differences in pitching biomechanics are further identified by pitchers with increased games played, games pitched, and innings pitched within a calendar year.

Pitching biomechanics were similar across groups and resembled pitching biomechanics typically seen in high school pitchers,36–38 although high-level specialized pitch-

### Table 1: Mean ± Standard deviation and inferential statistics of pitcher demographics

<table>
<thead>
<tr>
<th>Group</th>
<th>Low (n = 11)</th>
<th>Moderate (n = 14)</th>
<th>High (n = 11)</th>
<th>95% CI</th>
<th>F</th>
<th>P-value</th>
<th>$\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>14.36 ± 0.92</td>
<td>15.21 ± 1.25</td>
<td>16.27 ± 1.1</td>
<td>14.83, 15.73</td>
<td>6.9</td>
<td>0.003*</td>
<td>0.29</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.82 ± 0.08</td>
<td>1.82 ± 0.1</td>
<td>1.85 ± 0.08</td>
<td>1.8, 1.86</td>
<td>0.21</td>
<td>0.735-0.04</td>
<td></td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>70.49 ± 7.93</td>
<td>75.4 ± 16.38</td>
<td>82.2 ± 8.98</td>
<td>71.67, 80.29</td>
<td>2.3</td>
<td>0.050*</td>
<td>0.12</td>
</tr>
<tr>
<td>BMI</td>
<td>21.29 ± 1.87</td>
<td>22.57 ± 3.52</td>
<td>24.18 ± 2.74</td>
<td>21.65, 23.69</td>
<td>2.92</td>
<td>0.045*</td>
<td>0.13</td>
</tr>
<tr>
<td>Velocity (m/s)</td>
<td>32.05 ± 1.92</td>
<td>34.4 ± 4.06</td>
<td>36.4 ± 2.26</td>
<td>33.14, 35.45</td>
<td>3.97</td>
<td>0.01*</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Low = Low-level specialized, Moderate = Moderate-level specialized, High = High-level specialized, CI = Confidence interval, BMI = Body mass index

*Indicates Significant Difference ($p < 0.05$)
ers threw with significantly higher throwing velocity compared to low-level specialized pitchers. Differences in weight and BMI may explain why high-level specialized pitchers within this study threw faster than low-level specialized pitchers. Due to the high-level group also being significantly older than the low-level group, it is possible that the observed difference in body mass may be attributed to maturation. Pitchers with more body mass are commonly shown to demonstrate higher throwing velocities than those who weighed less. This is due to the ability of larger athletes to generate more strength and create larger forces. However, high- and moderate-level specialized pitchers did not experience greater loading within the shoulder and elbow, suggesting differences may be attributed to other potential factors. Throwing velocity has correlated with pitcher mass, throwing arm range of motion, upper extremity isometric strength, and upper extremity concentric strength. In collegiate pitchers, isometric internal rotation, isometric external rotation, and concentric external rotation at 90°/s⁻¹ and 180°/s⁻¹ of the throwing arm showed a strong positive correlation to throwing velocity. Additionally, high school pitchers within a weighted baseball throwing program significantly increased their shoulder external rotation range of motion and throw-
ing velocity compared to baseline observations.42 Therefore, the difference found in throwing velocity between high- and low-level specialized pitchers may be further explained when examining strength and flexibility of the throwing arm.

This study acknowledges multiple limitations. First, sport specialization within this study was not determined in total congruence with the commonly referenced Jayanthi scale.6 Until recently, the definition and categorization of sport specialization was not widely agreed upon. However, these results are the first to compare pitching biomechanics on any measure of specialization. Second, this study involved a wide range of when subjects reported for their pitching evaluation. Subjects reporting in the late summer months could potentially have more pitching volume throughout the year, especially in the specialized group. Third, data could have been skewed due to the subject’s recall bias, specifically their ability to accurately recall the number of games played, games pitched, and innings pitched within both the current year and the previous year. Subjects were unlikely to precisely recall this data and instead provided an estimated recount to their best ability. Lastly, pitching biomechanics data collected within the lab setting decreases generalizability to the pitching biomechanics athletes might demonstrate during competition.

CONCLUSION

Low-, moderate-, and high-level specialized high school pitchers demonstrated similar pitching biomechanics across groups. The significant difference in throwing velocity between low-level and high-level specialized pitchers may be further explained by other components (such as upper extremity strength and range of motion) which were not measured as part of this study. Furthermore, the low amount of pitching volume throughout the season may be responsible for the lack of additional observed differences. Additional research efforts should examine the effect of a baseball pitcher’s exposure to increased competitive workloads in a given year on pitching biomechanics as well as the relationship between upper extremity strength and range of motion and pitching biomechanics in specialized pitchers.

ACKNOWLEDGEMENTS

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CONFLICTS OF INTEREST

The authors have no conflicts of interest to report.
REFERENCES


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Original Research

The Kerlan-Jobe Orthopaedic Clinic Shoulder & Elbow Score used as a Patient-Reported Outcome Measure for the Youth and High School Aged Baseball Athlete

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1 Physical Therapy, Walsh University, 2 Physical Therapy, Nova Southeastern University
Keywords: baseball, outcome measure, upper extremity, youth athletics

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Background
The Kerlan-Jobe Orthopaedic Clinic Shoulder & Elbow Score (KJOC) provides questions for the overhead athlete that can aid with determining if someone is throwing with or without pain. However, this scale was initially created for the adult baseball athlete and has not been validated for younger male demographics.

Hypothesis/Purpose
To (1) determine if the scores on the KJOC are different between those throwing with and without pain in male youth and high school-aged baseball athletes, and (2) establish a prediction score for whether a young baseball athlete is throwing with symptoms.

Methods
The KJOC questionnaire was used to compare scores in male baseball players between the ages of 10 through 18. This questionnaire consists of 10 questions that each contain a 10-point visual analogue scale (VAS). When all questions are added together the highest possible score is 100 points, with a higher score equating to a better outcome of throwing without symptoms. Retrospective data from 28 subjects with throwing arm pain were compared to 28 prospective subjects actively participating in baseball with no pain. A Mann Whitney-U test was used to compare the mean scores, and regression analysis was used to establish a threshold score between those throwing with and without pain.

Results
Significant differences were found between the groups (U = 698.5, p < .001) with capability to discriminate those throwing with pain versus those throwing without pain (Area Under Curve (AUC) .891). Results indicate this discriminating threshold score to be at 68.6 points, which signifies anyone scoring above this threshold would be throwing with no pain and a score below this number indicating throwing with pain.

Conclusion
The KJOC can differentiate between younger baseball athletes throwing with and without pain. The predictive threshold score can be used in a clinical setting to aid with determining if a youth or high school-aged athlete is suffering from pain while participating in overhead throwing, and to guide rehabilitation management.

Level of Evidence
Level III
INTRODUCTION

Participation in overhead athletics occurs across a wide variety of age groups. Many sports, such as baseball, have become part of numerous youth communities. Previous reports have estimated that 4.8 million children between the ages of four through fifteen participate in some form of recreational baseball. This competitive atmosphere continues into higher levels of play, with 11.5 million athletes participating in high school or club baseball. Due to the repetitive demands of overhead throwing, injuries occur from participation in baseball. Between the years 1994 to 2006, it is believed that approximately 1,596,000 children under the age of eighteen were treated for baseball-related injuries in emergency departments in the United States. Specifically related to throwing, approximately 30% to 70% of youth throwers report having experienced throwing arm pain. More than 60% of these injuries can be found in the shoulder or elbow throughout a pitcher’s career. Contributing factors that have increased the risk of injury development for the young baseball athlete include several possibilities for over exposure to throwing. These comprise pitch counts, yearly participation, early sport specialization, playing on multiple teams, and altered throwing biomechanics.

Due to the high occurrence of injury in the young baseball population, it is imperative to provide injury assessment to manage athletes for participation screening, and to measure response to treatment in rehabilitation settings. Patient-reported outcome (PRO) measures are often used to provide a reported assessment from the athlete on how they are performing specific tasks. This assessment quantifies response through item scoring, which in turn gives a finalized number that can guide clinical decision-making if the athlete is experiencing symptoms. These scales aid with providing assessment regarding the physical, psychological, and social domains and their influence on patient beliefs, experiences, and perceptions. Many region-specific PRO measures have been developed and validated through past literature. Concerning the upper extremity, many of these measures focus on the arm with lack of specificity for the shoulder and/or the elbow, and have been studied in a wide range of populations. Many of these scales are utilized for a general population, and were not created to address the high physical demands of throwing. For this reason, some researchers have attempted utilizing a combination of PRO measures, however this poses a dilemma to the patient with completing multiple scales, which can be a daunting process. Additionally, those PRO scales that focus on the upper extremity and are created for the general populace, have ceiling effects, lack specificity for asking baseball-related questions, or do not differentiate between body regions.

More recent research has suggested the use of visual analog scales (VAS) to capture specific questions that address the physical demands of overhead athletes. The Kerlan-Jobe Orthopaedic Clinic Shoulder & Elbow Score (KJOC) includes 10 questions specific to the overhead athlete, each scored on a 10-point VAS, which can aid with determining if someone is throwing with or without pain. When all questions are added together the highest possible score is 100 points, with a higher score equating to a better outcome of throwing without symptoms. Items in the KJOC scale include questions on areas like presence of pain, weakness, fatigue, instability, or difficulty initiating activity; as well as impact of pain on throwing motion, velocity, power, endurance, control, and competition level. The scale also asks about effect of symptoms on sports relationships with others. However, this tool was created for the adult baseball athlete and was not originally validated for younger demographics. In its original validation, the KJOC was found to be more sensitive to detecting performance changes while participating in amateur and professional sports. The KJOC has now been studied in the adult throwing athlete and younger female softball players, and researchers have established a single score to separate groups between those that are throwing with pain to those that are throwing without pain. A “cut-score” has not yet been established for the male youth and high-school aged baseball athlete. Therefore, the purpose of this study was to determine if the scores on the KJOC are different between those throwing with and without pain in male youth and high school-aged baseball athletes. Additionally, this study aimed to establish a prediction score for whether a young baseball athlete is throwing with symptoms. The hypothesis was that the scores on the KJOC would be statistically different between groups in the young baseball athlete, and that there would be a predictive score that could determine if a younger athlete is throwing with or without symptoms.

METHODS

STUDY DESIGN

This was a quasi-experimental study of youth and high school-aged male baseball athletes. There were two groups of participants. The first group was allocated through retrospective design and had been in physical therapy previously due to complaints of pain with throwing during participation in baseball; data for this group was collected as part of usual clinical care procedures. The subjects recruited in the retrospective group had already completed the KJOC during the initial physical therapy evaluation prior to initiation of physical therapy treatment. The second group were prospective subjects who were currently participating in baseball and had no symptoms with throwing. All subjects filled out the KJOC questionnaire. The KJOC is a one-hundred millimeter VAS consisting of ten questions that postulate athletic performance, symptoms, and interpersonal relationships related to overhead sports. Additional questions were asked such as highest level of baseball participation, throwing arm dominance, positions played, and if the athlete was currently throwing with or without pain or could not participate due to arm pain.

STUDY PARTICIPANTS

Youth and high-school aged baseball players between the ages of 10 to 18 years were recruited through purposive sampling and were located in the Northeast Ohio area. Inclusion criteria for the retrospective group entailed prior attendance at a local physical therapy clinic and had attended physical therapy due to elbow or shoulder pain in
their throwing arm, filled out the KJOC at the onset of care, and were active participants in competitive levels of play for baseball. Concerning the prospective group, subject recruitment focused on baseball athletes in the above age range, participating in competitive levels of play for baseball, and who were throwing with no complaints of pain. Exclusion from the study entailed subjects that did not meet the above criteria regarding age range and/or did not participate in baseball at a competitive league level of play. Institutional Review Board approval was obtained from Nova Southeastern University prior to subject allocation. Written informed consent was gained from all participants with parental consent and utilization of an adolescent assent form for both retrospective and prospective groups. An a priori analysis was run to determine the appropriate sample size to accurately detect differences between groups. A medium to high effect size of 0.7 was utilized based on prior literature.\(^5,19–21\) Previous research on different demographics using the KJOC has found statistically significant differences between those throwing with and without arm pain.\(^5,19–21\) The statistical analysis chosen for this study included a Mann-Whitney U and logistic regression. Statistical power analysis software, G*Power, was used to ensure satisfactory statistical power.\(^22,23\) Additionally, for a logistic regression analysis previous research has recommended 10 to 20 subjects per outcome variable.\(^24–26\) For the purpose of this research there are two outcomes, throwing with pain and throwing without pain. Therefore, a sample size of 56 subjects, 28 in each group, was found to provide the intended power, which was set at 0.8, for this study.

**STUDY PROCEDURE**

A letter was sent out to all retrospective group participants and their parents outlining the intent of the study, which included the informed consent and assent forms. These forms were then completed in person or sent back to the lead author via mail. A research flyer was created for the prospective group. Local youth, high school, and travel baseball coaches were contacted by the lead investigator to pass this flyer out to all potential participants to contact the lead author. Once contact was established with subjects, each participant with a parent then met with the lead investigator at a local physical therapy outpatient clinic. Once informed consent was obtained, each participant filled out the KJOC, which took approximately 10 minutes to finish. All subjects in both groups were given standardized instructions to fill out the KJOC independently without parental or legal guardian influence.

**STATISTICAL ANALYSIS**

The study analysis was performed using SPSS software version 27 (Armonk, NY: IBM Corp). A Mann Whitney-U Test was used to compare the mean scores of the KJOC between the retrospective and prospective groups. A logistic regression was performed to aid with establishing a predictive score that would determine if subjects were throwing with or without pain. The predictive variable was the subject’s KJOC score, and a dichotomous outcome variable was created for those throwing with pain and those throwing without pain. A receiver operating characteristic curve (ROC) was created to graphically illustrate the diagnostic capability of the dichotomous outcome variable and aid with determining a threshold. The Youden’s J Statistic \((J = \text{sensitivity} + \text{specificity} - 1)\) was then utilized to aid with diagnostic capability and decide on the exact threshold or “cut-score” for the KJOC. The significance level for all statistical tests was set at 0.05.

**RESULTS**

A total of 56 participants were recruited with 28 subjects in the retrospective group and 28 participants in the prospective group. The characteristics of the participants studied can be found in Table 1. Most recruited subjects were right-handed dominant and participated in sport as a pitcher and additionally played other positions in the field. The retrospective throwing with pain group have been further classified in Table 1 as shoulder pain, elbow pain, or shoulder and elbow pain with throwing. The mean score on the KJOC in those throwing with pain was 61.9 points (+/- 19.7), while the mean for those throwing without pain was determined to be 88.7 points (+/- 9.2); as seen in Table 2. Figure 1 represents the KJOC scores found throughout each group.

The results of the Mann Whitney U indicated that the groups were significantly different from one another \((U = 698.5, p < 0.001)\). The results of the logistic regression with creation of an ROC curve revealed that the KJOC was able to discriminate between those throwing with pain and those throwing without pain \((\text{Area Under Curve (AUC) } .891)\), as represented in Figure 2. Youden’s J statistic was then utilized to establish a predictive threshold score for identifying young baseball athletes who are throwing with and without pain. The results indicate this threshold score to be at 68.6 points, which signifies anyone scoring above this threshold would be throwing with no pain and a score below this number indicating throwing with pain.

In considering that the age range of the subjects encompasses a variety of stages of growth and musculoskeletal development, the authors have also provided a breakdown of the data in Tables 1 and 2 into younger (10-13 years old) vs older ages (14-18 years old). The age demographic was split to display different levels of participation: ages prior to high school and the high school-aged athlete. As can be observed in Table 2, the scores for pain and no pain were very comparable when age was taken into consideration. According to Mann-Whitney-U tests, the distribution of KJOC scores was not significantly different across age categories for both the no pain \((p = 0.286)\) and the pain \((p = 0.853)\) groups, indicating that age subgroup was not a major factor impacting the KJOC threshold determination.

**DISCUSSION**

Injury assessment can entail various objective and subjective measures. A patient-reported assessment tool can aid with participation screening and guide clinical decision-making in physical therapy. PRO measures provide a quantified score to determine if an athlete is experiencing pain with participation. The intent of this study was to deter-
Table 1. Participant Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Throwing with pain</th>
<th>Throwing without pain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Subjects (n)</td>
<td>n = 28</td>
<td>n = 28</td>
</tr>
<tr>
<td>Age (years) reported as mean (SD)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age Group Totals (n)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-13 years of age</td>
<td>13.8 (2.5)</td>
<td>14.1 (2.1)</td>
</tr>
<tr>
<td>14-18 years of age</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>Throwing Arm dominance (n)</td>
<td>LHD 2</td>
<td>LHD 1</td>
</tr>
<tr>
<td></td>
<td>RHD 26</td>
<td>RHD 27</td>
</tr>
<tr>
<td>Positions Played (n)</td>
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<td></td>
</tr>
<tr>
<td>Catcher Only</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Pitcher Only</td>
<td>1</td>
<td>0</td>
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<tr>
<td>Position Player Only</td>
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<td>7</td>
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<td>Pitchers &amp; Position Player</td>
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<td>15</td>
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<tr>
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<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Pitcher &amp; Catcher</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Injured Body Part (n)</td>
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<td></td>
</tr>
<tr>
<td>Elbow</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Shoulder</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Shoulder &amp; Elbow</td>
<td>3</td>
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</tr>
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</table>

Abbreviations: LHD, left-hand dominant; RHD, right-hand dominant

Table 2. Descriptive Statistics

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
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<tbody>
<tr>
<td>Entire Age Range: 10-18</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>KJOC No Pain</td>
<td>28</td>
<td>69.7</td>
<td>99.7</td>
<td>88.7</td>
<td>9.2</td>
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<tr>
<td>KJOC Pain</td>
<td>28</td>
<td>23.0</td>
<td>95.0</td>
<td>61.9</td>
<td>19.7</td>
</tr>
<tr>
<td>Age Group: 10-13</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KJOC No Pain</td>
<td>10</td>
<td>76.2</td>
<td>99.7</td>
<td>90.8</td>
<td>8.8</td>
</tr>
<tr>
<td>KJOC Pain</td>
<td>11</td>
<td>26.9</td>
<td>88.6</td>
<td>63.0</td>
<td>20.3</td>
</tr>
<tr>
<td>Age Group: 14-18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KJOC No Pain</td>
<td>18</td>
<td>69.7</td>
<td>99.2</td>
<td>87.6</td>
<td>9.5</td>
</tr>
<tr>
<td>KJOC Pain</td>
<td>17</td>
<td>23.0</td>
<td>95.0</td>
<td>61.2</td>
<td>19.9</td>
</tr>
</tbody>
</table>

mune if utilization of the KJOC in youth baseball players can differentiate and predict those throwing with and without symptoms. The validation of such a number could further communication if a youth baseball athlete is throwing with pain, and provide guidance with management, as well as being useful in monitoring treatment success or supporting return to sport decisions. This is the first study to utilize the KJOC with male baseball athletes between the ages of 10 through 18 and compare groups between those with and without upper extremity symptoms. Prior literature has validated the KJOC’s use in the professional adult baseball athlete. During the original research, a score of a 81.3 was found to be 95% accurate with separating groups of pain and no pain in adult baseball athletes.\(^5\)\(^,\)\(^18\) Beyond its original validation, a respondent score of 90 on the KJOC determined asymptomatic throwing in the adult baseball thrower.\(^27\) Concerning the younger softball pitcher, research on female athletes in Canada has indicated that those with KJOC scores lower than 90 in the preseason had significantly greater risk of reporting an in-season injury.\(^19\) Additionally, Wei et al studied a small sample (n=9) of younger throwing athletes with clinical symptoms of little league elbow utilizing MRI, and recorded their KJOC scores.\(^28\) The authors reported that an average score of 60.5 on the KJOC indicated that subjects reported trouble with play or were no longer throwing due to pain.\(^28\) Thus, the literature utilizing the KJOC in youth baseball players is scarce and shows considerable variability in what scores are considered predictive or how they can assist decision-making; and does not include comparisons between those throwing with pain and those who are pain-free. The current study specifically looks at this comparison and shows that there is a statistical difference in KJOC scores between those throwing with and without symptoms. The between-groups analysis provides a way to identify a predictive threshold score for symptoms with throwing, with a cutoff score of 68.6 being the most appropriate threshold score to distinguish between these two groups.

The use of the KJOC in the youth baseball athlete population is clinically relevant and provides an important tool to guide decision-making. Choosing the right PRO measure for a patient may pose a challenge to many clinicians. To identify which PRO measures are better suited to the assessment of young baseball throwers, it is important to un-
understand the intent of each PRO measure, interpretability, validation, reliability for testing, responsiveness to change, and response scaling. Other PRO scales that focus on the upper extremity, such as the Disability of Arm, Shoulder and Hand (DASH) and the Pennsylvania Shoulder Score (PSS) have ceiling effects, lack specificity for asking baseball-related questions, or do not differentiate between body regions.\textsuperscript{6,29} Previous research has challenged the KJOC and its use with the younger thrower regarding interpretability and the use of a VAS due to the younger reader simply choosing extreme end points for each question.\textsuperscript{7} In response to this, the development of the Youth Throwing Score (YTS) was created, which uses a Flesch-Kincaid reading level for the younger demographic and uses a Likert
scale for response. However, further research has concluded the use of either a VAS or Likert scale can still provide dichotomous extremes for answers in a young population.

The application of a PRO measure, such as the KJOC, can provide valuable and clinically relevant information for the healthcare provider concerning many International Classification of Functional, Disability, and Health (ICF) enablement model constructs. Specifically, the KJOC provides information regarding body function and structure, activity and participation, and environmental factors that are associated with participation in baseball. Critics of the KJOC assert that this scale focuses only on impairments and activity limitations and does not address other domains of emotional or social factors. However, children may have a difficult time answering questions within the emotional or social domain. Additionally, the KJOC scale does ask how much the athlete’s arm problems have affected their relationships, which does provide an environmental/contextual factor construct of the ICF model.

The use of a PRO measure can also help enhance communication between the provider and the patient so that the clinician further explores subjective information on the patient’s throwing pain patterns. The establishment of a cut-score offers a predictive number that guides the likelihood that throwing is reproducing the athlete’s upper extremity symptoms. This information can help the clinician initiate a more detailed conversation with the subject regarding their pain patterns and activity/participation limitations. It can also further guide clinical decision-making to continue with a current plan of care, such as a throwing progression program, or to modify the program based on the response to this questionnaire.

The results of this study support the use of the KJOC in the young baseball athlete, and its usefulness in predicting the presence of symptoms with throwing via a threshold score. However, there are some limitations to be considered. Further research should address the interpretability of this scale compared to other published PRO measures, such as the YTS. The demographic studied includes a large range from 10 to 18 years of age, which could provide a limitation regarding the wide range of interpretability of questions across levels of education. Finally, lack of random sampling in this study reduces generalizability, however, the samples chosen include real-life representations of youth athlete demographics with and without pain that are readily available, and which provide important information with clinical applicability. A randomized prospective study would be limited by the lack of control over the occurrence of symptoms and other considerations such as natural history. Additional research could employ the KJOC throughout this populations’ participation in sport that could include the beginning, during, and end of their baseball season and retesting at the initial complaint of arm pain with throwing. Finally, in this study there is a wider range of variability in KJOC scores for those throwing with pain (Interquartile Range (IQR) = 35.50) versus those throwing without pain (IQR = 15.48), which results in an overlap of scores and complicates group separation. Future research could address scores on the KJOC at different age ranges or levels of play for the youth baseball athlete, in an attempt to obtain narrower variability and enhance predictive ability for those throwing with symptoms.

CONCLUSION

The results of this study reflect that the KJOC can differentiate between younger baseball athletes throwing with and without pain. The predictive threshold score of 68.6 points can be used in a clinical setting to aid in determining if a youth or high school-aged athlete is suffering from pain while participating in overhead throwing. Lack of subjective communication given by patients of a younger age can pose a challenge to assess response to treatment. The results of this research can aid with improving communication between a younger demographic reporting pain and assessing subjective levels of function. Additionally, the KJOC can be utilized with the youth baseball athlete population to monitor progression of treatment and aid with documentation.

CONFLICT OF INTEREST

There are no conflicts of interest to disclose.

Submitted: August 30, 2021 CDT, Accepted: April 26, 2022 CDT
REFERENCES


Background
Percussive therapy is hypothesized to speed recovery by delivering gentle, rhythmic pulses to soft tissue. However, patients often present with a differential soreness response after percussive therapy, which may lead to altered clinical outcomes.

Purpose
To compare the acute effects of percussion therapy on passive range of motion (ROM) and tissue-specific ultrasound measures (pennation angle [PA] and muscle thickness [MT]) between healthy individuals responding positively vs. negatively to percussive therapy performed on the dominant arm posterior rotator cuff.

Study Design
Cross-sectional laboratory study

Methods
Fifty-five healthy individuals were assessed on a subjective soreness scale before and after a five-minute percussive therapy session on the dominant arm posterior rotator cuff muscles. Participants with no change or a decrease in muscle soreness were assigned to the positive response group and participants who reported an increase in muscle soreness were assigned to the negative response group. Passive internal rotation (IR) and external rotation (ER) ROM and strength, and muscle architecture of the infraspinatus and teres minor were measured via ultrasound on the dominant shoulder. All dependent variables were collected before percussive therapy, and 20 minutes following percussive therapy.

Results
The positive response group had greater improvements than the negative response group in dominant arm IR ROM (2.3° positive vs. -1.3° negative, p=0.021) and IR strength (1.1 lbs vs. -1.2 lbs, p=0.011) after percussive therapy. No differences in ER strength or ROM were observed between groups. Regarding muscle architecture, the positive group had a lesser change in teres minor MT (0.00 mm vs. 0.11 mm, p=0.019) after percussive therapy. All other muscle architecture changes were not statistically different between groups.

Conclusion
Participants with a positive response to percussive therapy had increased dominant arm IR ROM and IR strength, and decreased teres minor MT, after percussive therapy compared to the negative response participants.

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Level of Evidence

INTRODUCTION

Exercise often leads to clinical symptoms of pain, soreness, or tightness. Adequate recovery of the involved soft tissues is required in order for increases in exercise capacity and strength to occur with repeated bouts of exercise. This clinical manifestation and progression of exercise-induced muscle damage (also known as delayed onset muscle soreness [DOMS]) commonly begins 6–12 hours after exercise, increases progressively until peak soreness occurs around 48–72 hours, and finally decreases until soreness is completely imperceptible 5–7 days after exercise.1–3 DOMS is often accompanied by impaired muscle contraction and reduced force capacity,2,4,5 while a local or even global area of increased muscle tone is commonly observed.5–9 DOMS is also associated with reduced range of motion (ROM) and altered biomechanical function of the adjacent joints.2,4,5,10,11 It is commonly accepted that the main mechanisms of DOMS are related to ultrastructural damage of skeletal muscle, sarcomelial disruption, and Z-Band streaming, caused by intense and exhausting exercise and/or unfamiliar sporting activity.7,12,13

An important determinant of muscle function is musculotendinous architecture, which is the arrangement of contractile and connective tissue elements within a muscle.14 Pennation angle (PA), defined as the angle between the muscle fiber and the intramuscular tendon, is an important architectural and functional factor of a pennate muscle.15 Additionally, muscle thickness (MT), the distance between the superficial and deep tendon aponeurosis,14,16 can be considered an indirect measure of strength and can also be an important factor influencing a muscle’s function.4,14,16–19 Passive muscle-tendon lengthening has been shown to decrease PA and decrease muscle width and depth in the medial gastrocnemius.20 These architectural changes are associated with increased ROM. Therefore, changes in muscle architecture can serve as an indicator of individual muscle tightness, which are consequences of DOMS.8

Low intensity training has been suggested after eccentric or high-intensity training sessions with the thought of reducing DOMS.7 It has been proposed that the short-term alleviation of pain during exercise is due to the breakup of adhesions in the sore muscles, an increased removal of noxious waste products via an increased blood flow, or an increased endorphin release.21 Due to this theory, research has become focused on creating similar effects with passive modalities. Percussive therapy is a recent therapy that delivers gentle, rhythmic pulses to soft tissue with the use of a handheld device or therapeutic massager. These commercially available devices fall under classification as a therapeutic massager which is defined by the FDA as “an electrically powered device intended for medical purposes, such as to relieve minor muscle aches and pains.” It is suggested that these devices are able to “soften” muscle tissue, alleviate pain, and improve blood flow, which is similar to the suggested effects of instrument assisted soft tissue mobilization (IASTM) when used to reduce DOMS. However, some individuals have increased soreness or a negative response following an acute bout of percussive therapy.

Percussive therapy has only been scientifically investigated in one recent study, and no studies were identified that examine the varying soreness response of participants.22 Also, no study has evaluated the effects of percussive therapy at the shoulder. Evaluating the varying soreness response of participants can help clarify why some participants experience worsened muscle soreness after percussive therapy. Additionally, it is unknown if there is any effect of percussive therapy on shoulder ROM, strength, and muscular architecture, which is an important determinant of muscle function and underlying mechanisms for tissue ROM and strength.14 Researching the effects of percussive therapy on healthy controls is a valuable assessment for understanding basic mechanistic changes at the shoulder, which can lead to future research in injured and athletic populations.

Therefore, the primary purpose of this study is to compare the acute effects of percussion therapy on passive range of motion (ROM) and tissue-specific ultrasound measures (pennation angle [PA] and muscle thickness [MT]) between healthy individuals responding positively vs. negatively to percussive therapy performed on the dominant arm posterior rotator cuff.

MATERIALS AND METHODS

This study used a cross-sectional laboratory study. A convenience sample of healthy and active individuals were recruited through advertisement at a local university. No study participants were competitive collegiate athletes. Only participants 18–40 years of age with no upper extremity injuries/surgeries within the prior year were included.

Study approval was received by the Temple University Institutional Review Board (IRB). Participants read and signed an IRB-approved consent form and completed a health history questionnaire. A previously developed Likert Scale of Muscle Soreness was used to determine the participants’ level of soreness specific to their shoulder prior to and following treatment (Figure 1).23 The original scale was adapted to focus on pain throughout the shoulder ROM instead of during walking. A change in score was then calculated as the difference in Likert score from pre- to post-treatment to determine if the participant experienced a change in muscle soreness as a result of percussive therapy. Participants with no change or a decrease in muscle soreness were assigned to the "positive" response group and participants who reported an increase in muscle soreness were assigned to the "negative" response group. Clinical measures and muscle architecture (via ultrasound) were evaluated before percussive therapy, and then 20 minutes after percussive therapy intervention.
Figure 1. The Likert Scale of Muscle Soreness is a 0-6 scale used to determine the soreness level of the participant prior to and following percussive therapy intervention.

GLENOHUMERAL RANGE OF MOTION

For ROM, participants were asked to lie supine on a treatment table with their dominant shoulder abducted to 90 degrees and elbow flexed to 90 degrees. One tester (S.J.T.) used one hand to stabilize the scapula over the anterior shoulder and the other hand to rotate the participant’s shoulder into IR until scapular motion was detected. A second tester (M.P.) placed a digital inclinometer (Saunders Group Inc, Chaska, MN) along the lateral forearm and recorded the amount of glenohumeral rotation (degrees). Three measurements were obtained and the average was calculated. The same procedures were completed for external rotation. Reliability for the testing investigator was previously established and published.

GLENOHUMERAL STRENGTH

For isometric strength, participants were asked to lie supine on a treatment table with their dominant shoulder abducted to 90 degrees in neutral rotation and elbow flexed to 90 degrees. A tester (S.J.T.) then placed a digital hand-held-dynamometer (Hoggan Health Industries, Draper, Utah) at the distal wrist on the dorsal (posterior) side and instructed the participant to maximally contract in the direction of ER for five seconds. The same procedures were completed for IR, except for the digital hand-held-dynamometer being placed on the ventral (anterior) side of the distal wrist. This was repeated three times and the mean recordings were utilized for data analysis.

MUSCLE ARCHITECTURE

All ultrasound imaging was performed by one investigator (S.J.T.) using a 15-MHz linear-array transducer (Fujifilm Sonosite Inc. Bothel, WA, USA) using previously-published ultrasound techniques to measure muscle architecture. The superficial PA was quantified by measuring the angle between the deep aponeurosis and the muscle fascicles superficial to the deep aponeurosis, while the deep PA was quantified by measuring the angle between the deep muscle fascicles and the deep aponeurosis. This definition of superficial and deep PA was used for both the infraspinatus and teres minor. In contrast, MT quantification varied between the infraspinatus and the teres minor due to differences in measurement location. Infraspinatus MT was measured at the location of the suprascapular notch for consistency, while
Mainly, the positive and negative groups had similar spectively) after percussive therapy (p=0.021) and IR strength (-1.2 lbs vs. 1.1 lbs, p=0.011, reative) as compared to the positive group (2.3° positive, tive group (Figure 5). All other muscle architecture changes were similar between groups.

DISCUSSION

The results of this current study found that participants with a self-reported negative response to percussive therapy had worsened dominant arm IR ROM and IR strength, and increased teres minor MT, after percussive therapy compared to the positive response participants. Meanwhile, both groups had similar changes in ER ROM and ER strength due to percussive therapy. Regarding muscle architecture, the negative group had a greater change in teres minor thickness (0.11 mm vs. 0.00 mm, p=0.019) after percussive therapy (Figure 6). The blocking of these nociceptive impulses is thought to result in a relaxation effect that inhibits muscle guarding when there is sensory input related to pain or soreness. However, the negative group may have highly sensitive nociceptive fibers that become activated during percussion therapy, resulting in increased soreness and muscle guarding after percussive therapy. This potential response following percussion therapy should be considered by clinicians prior to implementation into a warm-up, injury prevention, or rehabilitation protocol.

The current study found that the positive group had increased IR ROM by almost 4 degrees compared to the negative group following percussion therapy. Conversely, the posterior shoulder muscles in the positive group may have exhibited an increased mechanical softening effect as shown by an IR ROM increase of about 2 degrees. However, the clinical significance of either of these changes is unclear due to the numerical values not exceeding measurement error. Mechanical softening of the tissue is the result of various mechanical forces including compression, tension, torsion, or shear on the tissues, which can lead to the tissue becoming more pliable. The softening could have allowed more elasticity in the passive elements of the muscle and allowed a greater degree of stretch. Treatment was only applied to the external rotator muscles which would allow greater stretch into IR. Since treatment was isolated to the ER muscles, it is not surprising that there were differences in IR ROM but no changes in ER ROM. The observed differences may be explained by the muscle soreness after percussive therapy causing an increased nociceptive response, and also a slight increased teres minor MT, which was likely a result of increased blood flow. Increased fluid volume either in a muscle or joint has the potential to limit joint ROM as seen in acute muscle and joint injuries that result.

RESULTS

Fifty-five recreationally active participants (29 male, 26 female) were included with a mean age of 23.7 ± 3.4 years. Eighteen participants (32.7%) reported a decreased Likert score (Negative response group; i.e. worse subjective shoulder soreness) after percussive therapy, while 37 (67.3%) reported either the same Likert score or an increased Likert score (Positive response group; i.e. similar or improved subjective shoulder soreness) after percussive therapy. There were no significant demographic differences between the positive and negative groups (Table 1).

The negative group had decreases in IR ROM (-1.3° negative) as compared to the positive group (2.3° positive, p=0.021) and IR strength (-1.2 lbs vs. 1.1 lbs, p=0.011, respectively) after percussive therapy (Table 2) (Figure 5). Meanwhile, the positive and negative groups had similar

![Figure 2. Percussive therapy being used on the posterior rotator cuff muscles while the participant lays in a prone position.](image)
Table 1. Demographic comparison between the positive response and negative response groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Positive (n=37)</th>
<th>Negative (n=18)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>23.4 ± 3.2</td>
<td>24.3 ± 3.7</td>
<td>0.359</td>
</tr>
<tr>
<td>Female Sex</td>
<td>14 (37.8%)</td>
<td>12 (66.7%)</td>
<td>0.083</td>
</tr>
<tr>
<td>Height (inches)</td>
<td>68.5 ± 3.8</td>
<td>66.2 ± 4.1</td>
<td>0.061</td>
</tr>
<tr>
<td>Weight (pounds)</td>
<td>166.7 ± 28.0</td>
<td>163.6 ± 48.0</td>
<td>0.802</td>
</tr>
<tr>
<td>Current Sport Participation</td>
<td>34 (91.9%)</td>
<td>16 (88.9%)</td>
<td>0.716</td>
</tr>
<tr>
<td>Days Per Week of Exercise</td>
<td>4.3 ± 1.2</td>
<td>3.9 ± 1.6</td>
<td>0.342</td>
</tr>
</tbody>
</table>

Continuous data is presented as mean ± standard deviation, and categorical data is presented as n (%).

Figure 3. Ultrasound image of the infraspinatus muscle.
PD = posterior deltoid and ISP = infraspinatus. Green Line = muscle thickness, orange line = deep aponeurosis, blue line = muscle fascicle, and red curve = pennation angle.

Figure 4. Ultrasound image of the teres minor.
PD = posterior deltoid and TM = teres minor. Green line = muscle thickness, orange line = deep aponeurosis, blue line = muscle fascicle, and red curve = pennation angle.

in swelling. Previous research has shown that blood volume can have an effect on passively stretched and actively contracted muscles. For example, a previously published theoretical model, small increases in intramuscular volume can lead to a 50% increase in passive stretch tension.31 Another study found that increasing the fluid volume of the muscle in a bullfrog by 40% resulted in a 69% increase in tension produced during passive stretch.32 However, since the increased MT was very minimal, the clinical significance is questionable.

Interestingly, the authors did not find any group differences in muscle PA. Previous research has found that the PA of muscles is adaptable and can change due to alterations in the passive components of muscle or the neuromuscular activation of a muscle.33 Due to the acute increase in soreness in the negative group, the authors expected there would be more involuntary activation to the muscle at rest in these patients, resulting in an increased PA. However, PA changes were similar to the positive group, suggesting that a single bout of percussion therapy does not affect the involuntary activation of the posterior rotator cuff muscles. Future research examining a longitudinal, repetitive application of percussion therapy may clarify this relationship.

Unlike traditional warm-up programs with static stretching pre- or post-competition, which often results in a loss of strength, percussive therapy appears to elicit the benefits of static stretching without a reduction in strength for individuals who respond positively to the treatment. In a clinical setting, increasing ROM while maintaining strength is crucial to performance and the reduction of injury risk. For example, overhead athletes tend to lose IR ROM and strength as the competitive season progresses, resulting in decreased performance and/or increased injury risk.34–38 However, individuals interested in using percussive therapy may be tested to determine their soreness response.30,39–41 Those who respond positively to percussive therapy may benefit from the implementation of percussive therapy into their injury prevention and/or rehabilitation programs.

There are several limitations to this study. First, muscle soreness was quantified using a self-reported Likert scale which is subject to reporter bias. Also, only healthy volunteers were included in this study, so findings may not be generalizable to injured or athletic populations. Finally, while statistically significant differences were observed, the clinical relevance of the study findings could not be clarified. Future research that includes injured and/or athletic populations can help clarify the clinical applicability of percussive therapy and identify patient populations that benefit significantly from the treatment.

CONCLUSION

The results of the current study indicate that participants with a positive response to percussive therapy had increased dominant arm IR ROM and IR strength, and de-
Table 2. Comparison of the changes in clinical measures and muscle architecture due to percussive therapy, between the positive response and negative response groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Positive (n=37)</th>
<th>Negative (n=18)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Clinical Measures</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔER ROM (°)</td>
<td>1.2 ± 8.8</td>
<td>-0.7 ± 9.7</td>
<td>0.619</td>
</tr>
<tr>
<td>ΔER Strength (pounds)</td>
<td>0.4 ± 2.9</td>
<td>-0.6 ± 3.6</td>
<td>0.283</td>
</tr>
<tr>
<td>ΔIR ROM (°)</td>
<td>2.3 ± 6.3</td>
<td>-1.3 ± 7.2</td>
<td>0.021</td>
</tr>
<tr>
<td>ΔIR Strength (pounds)</td>
<td>1.1 ± 2.8</td>
<td>-1.2 ± 3.3</td>
<td>0.011</td>
</tr>
<tr>
<td><strong>Muscle Architecture</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔSuperficial Infra PA (°)</td>
<td>0.2 ± 1.7</td>
<td>0.2 ± 2.1</td>
<td>0.805</td>
</tr>
<tr>
<td>ΔDeep Infra PA (°)</td>
<td>-0.4 ± 1.9</td>
<td>-0.9 ± 1.8</td>
<td>0.375</td>
</tr>
<tr>
<td>ΔInfra Thickness (mm)</td>
<td>0.07 ± 0.15</td>
<td>0.04 ± 0.08</td>
<td>0.424</td>
</tr>
<tr>
<td>ΔSuperficial TM PA (°)</td>
<td>0.5 ± 2.7</td>
<td>0.0 ± 2.9</td>
<td>0.560</td>
</tr>
<tr>
<td>ΔDeep TM PA (°)</td>
<td>0.0 ± 3.2</td>
<td>0.3 ± 1.9</td>
<td>0.722</td>
</tr>
<tr>
<td>ΔTM Thickness (mm)</td>
<td>0.00 ± 0.17</td>
<td>0.11 ± 0.13</td>
<td>0.019</td>
</tr>
</tbody>
</table>

Δ=change in, ER=external rotation, IR=internal rotation, ROM=range of motion, PA=pennation angle, infra=infraspinatus, TM=teres minor. Statistically significant differences are in bold. Data is presented as mean ± standard deviation.

Figure 5. Comparison of the changes in internal rotation (IR) range of motion (ROM) and strength between positive response and negative response groups due to percussive therapy.

ACKNOWLEDGEMENTS

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DISCLOSURES

Jack Trainer: Received percussion therapy device from TT Therapeutics to perform the study. Was hired and shortly worked for TT Therapeutics after completion of the study. TT Therapeutics was not involved in the data collection, analysis, interpretation, writing, or approval of the study.

Matthew Pascarella: None
Ryan Paul: None
Stephen Thomas: None

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Figure 6. Comparison of the change in teres minor (TM) muscle thickness between positive response and negative response groups due to percussive therapy.
REFERENCES


Correlations Between Preseason Functional Test Scores and Game Performance in Female Collegiate Volleyball Players

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Keywords: y-balance test, single-leg hop, standing long jump, lower extremity functional test

Background

Functional tests (FT) are assessment tools that attempt to evaluate balance, flexibility, strength, power, speed, or agility through performance of gross motor skills. FT are frequently administered by coaches or sports medicine professionals to evaluate athletic ability, to predict performance, to identify athletes at risk for injury, or to evaluate an athlete's ability to return to sport after injury. Functional tests which can provide accurate or predictive information regarding athletic ability would be advantageous to coaching staffs or medical professionals.

Purpose

The primary purpose of this study was to identify correlations between preseason FT scores and in-season game statistics in a cohort of female collegiate level volleyball (VB) players. A secondary purpose was to present FT descriptive data for this cohort based on level of competition, player position, and starter status.

Study Design

prospective cohort; correlational

Methods

One hundred and thirty-one female collegiate VB players representing three levels of competition completed four FT [standing long jump (SLJ), single-leg hop (SLH), lower extremity functional test (LEFT), and the Y-Balance Test - Lower Quarter (YBT-LQ)] at the start of the preseason. Player statistics were collected from team records at the completion of the season.

Results

Starters performed significantly better on all tests. There were moderate negative correlations between LEFT scores and game statistics for liberos, defensive specialists, and outside hitters. There were moderate positive correlations between YBT-LQ composite scores and game statistics for liberos, defensive specialists, hitters, and middle blockers. There were also low to moderate level positive correlations between SLJ and SLH scores and game performance for outside hitters. There were low to moderate level positive correlations between SLH scores and game performance for middle blockers and opposite side hitters.
Conclusions

The results of this study indicate that there are low to moderate correlations between some preseason functional test scores and some game statistics. The SLJ, SLH, LEFT, and YBT-LQ tests may help coaches with talent identification and/or may influence training strategies.

Level of Evidence

INTRODUCTION

Functional tests (FT) are assessment tools that attempt to evaluate measures of balance, flexibility, strength, power, speed, or agility through performance of gross motor skills.1,2 FT are inexpensive alternatives to laboratory based measures and are frequently administered by strength coaches or sports medicine professionals to evaluate athletic ability, to predict performance, to identify athletes at risk for injury, or to evaluate an athlete’s ability to return to sport after injury.3–10 These tests are performed during the off-season or at the start of the preseason to identify deficits that may be addressed by training programs.

There are numerous examples in the literature that illustrate correlations between test scores and game performance.11–16 Coaches may use this information when evaluating talent and/or it may influence training strategies. However, some of the aforementioned studies utilized tests that may not be available in all collegiate settings. The advantage of utilizing FT, instead of high-tech options like a motion capture lab or isokinetic machines, are that they are quick to perform, require minimal equipment, are less expensive than other tests, and that they can be administered and interpreted by all professionals.1,2

Correlations between FT scores and player demographics or game performance has been reported in collegiate and professional volleyball (VB) players.1,11,12,14–16 Sattler et al. evaluated performance of the squat jump (SJ), counter-movement jump (CMJ), block jump (BJ), and the attack jump (AJ) in a cohort of high-level adult male and female volleyball players from Slovenia.14,15 They reported male outside hitters had significantly greater SJ and CMJ than male setters and significantly greater AJ performance than male liberos.14,15 However, there was no difference in test performance between female VB players.15 Boldt et al. reported significant correlations between body fat and t-test agility drill performance \( r = 0.544 \) and fat free mass and standing long jump performance \( r = 0.538 \) in National Collegiate Athletic Association (NCAA) Division III (D III) female VB players.11 Bunn et al. reported significant positive correlations between 1) broad jump (aka standing long jump) scores and block assists/set for setters and kills/set, errors/set, block assists/set, and block solos/set for middle blockers and 2) T-drill test scores with digs/set for setters in NCAA Division I female VB players.12

There have been only a few studies reporting correlations between preseason FT scores and performance measures in female collegiate level VB players.11,12 Evaluating potential relationships between FT scores and game performance in female collegiate VB players may help coaches with talent identification and/or may influence training strategies per player position. The primary purpose of this study was to identify correlations between preseason FT scores and in-season game statistics in a cohort of female collegiate level VB players. It was hypothesized that there would be positive correlations between preseason test performance and game statistics per each test. A secondary purpose was to present FT descriptive data for this cohort based on level of competition, player position, and starter status.

METHODS

PARTICIPANTS

Female collegiate level VB players were recruited from nine teams over a three-year period (2015-2017). A total of 151 VB players, representing three levels of competition, completed all tests: NCAA D II (n = 32), NCAA D III (n = 74), NAIA (n = 25). Each athlete completed the informed consent document prior to testing. This study was approved by George Fox University’s (Newberg, OR) and Azusa Pacific University’s (Azusa, CA) Institutional Review Boards.

PROCEDURES

Female collegiate level VB players were recruited from university or college programs from the Portland, OR and Azusa, CA regions. This study was part of a larger prospective cohort study. Athletes were tested at the start of the preseason with an athlete completing each test during one testing session. Each athlete completed the Y-Balance Test – Lower Quarter (YBT-LQ), the standing long jump (SLJ), the single-leg hop (SLH; performed bilaterally), and the lower extremity functional test (LEFT) in that order. The testing sequence was designed to have athletes perform the dynamic balance test first, followed by the lower extremity tests for lower body power (i.e., SLJ and SLH), and finally the most fatiguing test, the LEFT, was performed last.1,2,7

Age and anthropometric data were collected from each athlete prior to performing the FT. Height was collected using a cloth measuring tape affixed to a wall. Body mass was measured when the athlete stood on a force plate (model BP 600600; AMTI, Watertown, MA). Specific athletic information (e.g., player position and starter status) and game statistics were collected from team records at the completion of the season. Next, each athlete completed a five-minute dynamic warm-up.4 Athletes performed the following movements in a hallway adjacent to the lab: forward walking, backward walking, heel walking, tip toe walking, marching, and hip flexion with opposite arm reach.4 Each athlete also performed three submaximal effort SLJ as part of the dynamic warm-up.4
Y-BALANCE TEST - LOWER QUARTER PROTOCOL

The YBT-LQ test was performed by each athlete first. Each athlete received test instruction and performed six warm-up trials per lower extremity. After the warm-up trials each athlete performed the test in the anterior direction completing three trials on the right (i.e., right LE weight-bearing) followed by performing three trials on the left. After the anterior trials were completed athletes performed three trials per lower extremity (right side followed by the left side) in the postero-medial direction followed by the posterolateral direction. A trial was repeated if the athlete performed the test with a technique error. The mean score for the three trials in each reach direction was used for subsequent statistical analyses. YBT-LQ reach measures were normalized to the athlete’s limb length. After completing the YBT-LQ test an investigator measured limb length bilaterally from the anterior superior iliac spine to the distal aspect of the medial malleolus. The formula to normalize reach distance is: \((\text{reach distance} / \text{limb length}) \times 100\). A composite reach score, which is a measure representing reach scores into each direction of the “Y” was also calculated: \((\text{mean anterior reach} + \text{mean posteromedial reach} + \text{mean posterolateral reach}) / (\text{limb length x 3})\) \times 100. Group mean individual and composite scores were used for data analysis. The YBT-LQ has excellent intrarater reliability (0.85-0.91) and interrater reliability (0.99-1.00).

STANDING LONG JUMP

An athlete stood with her feet approximately shoulder width apart behind a line of tape affixed to the floor. A cloth measuring tape, oriented perpendicular to the line of tape (i.e., the starting point), was used for measuring the distance jumped and hopped. Each athlete performed three maximal effort SLJ with hands clasped behind the back during testing. Jump distance was measured from the starting line to the rearmost heel. A 30 second rest break was provided to each athlete between trials. If the athlete used her arms during the SLJ or if she failed to stick the landing a trial was repeated. The mean of three SLJ was used for data analyses. Mean scores were normalized as a percentage of the athlete’s height (% ht.). The test-retest reliability for the SLJ is excellent ranging from 0.95 to 0.96.

LOWER EXTREMITY FUNCTIONAL TEST (LEFT)

The final test performed by each athlete was the LEFT. The LEFT, an agility drill, is performed over a diamond shape course. The dimensions of the LEFT is 9.14 meters (m) [30 feet] in the north-south direction and 3.05 m [10 feet] in the west-east direction. Strips of tape in the shape of equilateral triangles (0.305 m) were affixed to the floor at the end of each axis. Prior to starting the test, the athlete stood at the southern triangle and received test instruction. Athletes were instructed to run to the northern triangle and back followed by running backwards from the southern triangle to the northern triangle and back. As the athlete neared completion of the backwards run, the tester provided verbal instructions as to the subsequent agility drill and the direction of movement through the course. The LEFT consists of the following drills, performed counter-clockwise and clockwise (except for the forward and backwards runs) in this order: forward run, backward run, side shuffles, cariocas, Figure 8s, 45° cuts (plant outside foot), 90° cuts (plant outside foot), crossover 90° cuts (plant inside foot), forward run, and the backward run. The tester used a stopwatch to record the time (seconds) it took the athlete to complete the test. Each athlete only performed the LEFT once. The ICCs for the LEFT is 0.95-0.97.

STATISTICAL ANALYSIS

Shapiro-Wilk test was performed to assess normality of data. Each functional test demonstrated a normal distribution (SLJ p = 0.153, R SLH p = 0.446, L SLH p = 0.958, LEFT p = 0.458, R YBT-LQ composite p = 0.159, L YBT-LQ composite p = 0.750). Descriptive statistics (mean ± SD) were calculated for age, anthropometric measures, and FT measures (note: descriptive data for the YBT-LQ has been previously reported and is therefore not reported in this study). Independent t-tests were used to compare mean functional test scores per player movement categorization (i.e., based on player positions) and starter status. Player movement categorization was based on positional requirements related to the frequency of vertical jumping during sport. One group (n = 80) consisted of athletes who frequently perform vertical jumps during a game: outside hitters, middle blockers, and opposite side hitters. The other group (n = 51) consisted of liberos, defensive specialists, and setters. One-way analysis of variance (ANOVA) was performed to assess mean differences for age, anthropometric, and FT measures between athletes per level of competition. ANOVA was also performed to compare FT measures between athletes based on player position. A post-hoc Bonferroni test was performed after ANOVA to identify significant differences between subcategories within a group. Pearson product moment correlations were calculated to identify correlations between functional test scores and in-season game statistics (kills/set, assists/set, service ace/set, digs/set, blocks/set, points/set). A sample size of 26 per group analysis (i.e., correlations between player position and preseason test scores) was calculated using G*Power.
Correlations Between Preseason Functional Test Scores and Game Performance in Female Collegiate Volleyball Players

Table 1. Demographic Information and Functional Performance Test Scores (Mean ± SD) Per Level of Competition

<table>
<thead>
<tr>
<th>Variable</th>
<th>Totals (n = 131)</th>
<th>NCAA D II (n = 32)</th>
<th>NCAA D III (n = 74)</th>
<th>NAIA (n = 25)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>19.3 ± 1.1</td>
<td>19.3 ± 0.9</td>
<td>19.1 ± 1.1</td>
<td>19.8 ± 1.2</td>
<td>0.032a</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.74 ± 0.08</td>
<td>1.76 ± 0.07</td>
<td>1.73 ± 0.08</td>
<td>1.75± 0.09</td>
<td>0.200</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>70.84 ± 9.69</td>
<td>71.15 ± 9.12</td>
<td>70.46 ± 9.41</td>
<td>71.58 ± 11.44</td>
<td>0.866</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>23.4 ± 3.0</td>
<td>23.0 ± 2.5</td>
<td>23.6 ± 3.2</td>
<td>23.4 ± 2.8</td>
<td>0.595</td>
</tr>
<tr>
<td>SLJ (% ht.)</td>
<td>0.81 ± 0.1</td>
<td>0.84 ± 0.1</td>
<td>0.81 ± 0.1</td>
<td>0.79 ± 0.1</td>
<td>0.228</td>
</tr>
<tr>
<td>(R) SLH (% ht.)</td>
<td>0.65 ± 0.1</td>
<td>0.66 ± 0.1</td>
<td>0.64 ± 0.1</td>
<td>0.65 ± 0.1</td>
<td>0.740</td>
</tr>
<tr>
<td>(L) SLH (% ht.)</td>
<td>0.63 ± 0.1</td>
<td>0.67 ± 0.1</td>
<td>0.61 ± 0.1</td>
<td>0.64 ± 0.1</td>
<td>0.127</td>
</tr>
<tr>
<td>LEFT (sec)</td>
<td>111.5 ± 11.8</td>
<td>105.8 ± 17.4</td>
<td>112.6 ± 8.9</td>
<td>115.3 ± 7.7</td>
<td>0.004b,c</td>
</tr>
</tbody>
</table>

NCAA = National Collegiate Athletic Association; D II = Division II; D III = Division III; NAIA = National Athletic Intercollegiate Association; SLJ = standing long jump; SLH = single leg hop; LEFT = lower extremity functional test; % ht. = refers to jump or hop distances normalized as a percentage of one’s height.

aSignificant difference between NAIA and D III; p-value = 0.026
bSignificant difference between D II and D III; p-value = 0.017
cSignificant difference between D II and NAIA; p-value = 0.007

with alpha set at 0.05, power at 0.8, and an effect size of 0.5. Correlation (r) scores were stratified by magnitude: low (≤ 0.35); moderate (0.36 -0.67); strong (0.68-1.0).29,30 Statistical analysis was performed using SPSS Statistics 25.0 (IBM, Chicago, IL, USA) with alpha level set at 0.05.

RESULTS

Mean age, anthropometric measures, and FT scores for the entire sample and per level of competition are presented in Table 1. The mean age was 19.3 ± 1.1 years; mean height was 1.74 ± 0.08 m; mean weight was 70.84 ± 9.69 kg; mean body mass index was 23.4 ± 3.0 kg/m² (Table 1). There were no significant differences in demographic information between groups except for age; NAIA athletes were significantly older than D III athletes. Mean scores for the FT were: SLJ (% ht.) 0.81 ± 0.1; (R) SLH (% ht.) 0.65 ± 0.1; (L) SLH (% ht.) 0.63 ± 0.1; and LEFT 111.5 ± 11.8 sec (note: mean YBT-LQ for this population was previously reported28). There was only one difference in FT performance based on level of competition; D II VB players completed the LEFT significantly faster than D III and NAIA athletes.

Table 2 presents correlation statistics between preseason FT scores and in-season game statistics for all participants. There was a low statistically significant positive correlation between SLJ performance and digs/set (r = 0.225; p = 0.01). Right SLH performance had low statistically significant positive correlations with kills/set (r = 0.205; p = 0.019) and points/set (r = 0.187; p = 0.032). Left SLH performance had low statistically significant positive correlations with kills/set (r = 0.272; p = 0.002), digs/set (r = 0.209; p = 0.017), and points/set (r = 0.266; p = 0.002). There were low statistically significant negative correlations between LEFT scores and kills/set (r = -0.191; p = 0.029), digs/set (r = -0.249; p = 0.004), and points/set (r = -0.182; p = 0.037). Preseason YBT-LQ performance was positively correlated to some game statistics and negatively correlated with others. There were numerous low to moderate statistically significant positive correlations between individual and composite YBT-LQ scores and service ace/set and digs/set. There were numerous low to moderate significant negative correlations between YBT-LQ scores and kills/set, blocks/set, and points/set.

Table 3a presents correlation statistics between preseason SLJ, SLH, and LEFT measures and in-season game statistics per player positions. There were statistically significant moderate negative correlations between LEFT performance and assists/set (r = -0.469; p = 0.028) and digs/set (r = -0.449; p = 0.036) in liberos and defensive specialists. There were statistically significant moderate positive correlations between SLH performance and kills/set (R) r = 0.519; p = 0.008; [L] 0.410; p = 0.042) and points/set (R) r = 0.539; p = 0.005; [L] r = 0.400; p = 0.047) in setters. There were several low and moderate positive correlations between SLJ and SLH performance for kills/set, assist/set, digs/set, and points/set in outside hitters. Outside hitters also demonstrated several moderate negative correlations between performance and LEFT scores. SLH performance with the left lower extremity had low and moderate level correlations with kills/set (r = 0.508; p = 0.05), service ace/set (r = 0.558, p = 0.022) and points/set (r = 0.32; p = 0.04) in MB and OPP.

Table 3b presents correlation statistics between preseason YBT-LQ measures and in-season game statistics per player positions. There were some statistically significant negative correlations between YBT-LQ scores and game performance in liberos, defensive specialists, and setters. There was a moderate negative correlation between (L) posterolateral reach and assists per set (r = -0.433; p = 0.044) in liberos/defensive specialists. There were two moderate negative correlations between YBT-LQ scores and game statistics in setters: (L) posteromedial reach and assists per set (r = -0.433; p = 0.044) and (R) posterolateral and digs/set (r = -0.431; p = 0.032). There were however two significant moderate positive correlations observed in the libero/defensive specialist grouping. Composite score performance was moderately correlated with digs/set (IR) composite r = 0.506; p = 0.016; [L] composite r = 0.558; p = 0.010). There were several positive low and moderate correlations between individual reach measures and performance in out-

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side hitters. There were also numerous low to moderate statistically significant correlations between reach scores and performance in MB and OPP; however, of the 22 statistically significant correlations 12 of them were negative correlations.

The secondary purpose of this study was to present FT descriptive data for this cohort based on player position, starter status, and player movement categorization. There were no significant differences in functional test scores when comparing athletes per individual positions (Table 4). [Note: in Table 4 L and DS were combined into one category and MB and OPP were combined into one category. These combinations were performed for two reasons: some athletes were identified in team statistics as playing more than one position and combining similar positions helped to create larger sample sizes per group]. There was a significant difference for each functional test based on starter status (SLJ p = 0.000; [R] SLH p = 0.002; [L] p = 0.002; LEFT p = 0.018) (Table 4).

There were no significant differences in preseason FT scores when comparing athletes based on movement categorization (i.e., grouping athletes based on performing frequent vertical movements during sport versus lateral movements) (Table 5). One group consisted of athletes who frequently perform vertical movements during VB (e.g., hitting, blocking): outside hitters (OH), middle blockers (MB), opposite side hitters (OPP). The other group consisted of athletes who frequently perform horizontal movements during VB (e.g., digging, defense): libero (L), setter (S), defensive specialist (DS).

DISCUSSION

This is the first study to report mean scores for several frequently utilized FT for a cohort of female collegiate level VB players and correlations between preseason test scores and in-season game statistics. The data presented in this study has applications for head coaches, strength coaches, and sports medicine professionals.

JUMP AND HOP TESTS

There was no difference in SLJ or SLH scores between athletes based on level of competition. There was however a significant difference in SLJ and SLH measures based on starter status with starters jumping and hopping significantly farther than their nonstarter counterparts. This data has applications for head coaches and strength coaches. First, SLJ and SLH measures can be used by coaches to evaluate aspects of an athlete’s lower extremity power.1,2,31–36 Many smaller universities (i.e., non-Division I institutions) lack expensive equipment (e.g., isokinetic machines) to test their athletes; the SLJ and SLH tests may be used as clinical correlates for quantifying lower extremity power.1,2,31–36

There were several low to moderate level positive correlations between jump or hop performance and game statistics (Table 2). The jump and hop tests appear to have the greatest value when evaluating VB athletes per position (Table 5a). For example, there were several low to moderate correlations between game statistics and SLJ or SLH performance by outside hitters. Outside hitters are involved in the offensive attack and thus are frequently performing vertical jumps throughout the game. Having greater lower extremity power is advantageous for their position.33

There were also low and moderate level correlations between (L) SLH power and game performance in middle blockers and opposite side hitters. Middle blockers and opposite side hitters play in the front line and are responsible for blocking and attacking. The correlations between (L) SLH and game stats illustrates the importance of lower extremity power, especially in the left lower extremity which
Table 3a. Pearson Product Moment Correlations ($r$) between Preseason Functional Test [SLJ, SLH, LEFT] Scores and In-Season Game Statistics per Player Position

<table>
<thead>
<tr>
<th>Position and Statistics</th>
<th>SLJ</th>
<th>(R) SLH</th>
<th>(L) SLH</th>
<th>LEFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liberos and Defensive Specialists (n = 22)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kills/Set</td>
<td>-0.144</td>
<td>-0.142</td>
<td>-0.209</td>
<td>0.371</td>
</tr>
<tr>
<td>Assists/Set</td>
<td>0.407</td>
<td>0.122</td>
<td>0.051</td>
<td>-0.469$^+$</td>
</tr>
<tr>
<td>Service Ace/Set</td>
<td>0.255</td>
<td>0.015</td>
<td>0.080</td>
<td>-0.403</td>
</tr>
<tr>
<td>Digs/Set</td>
<td>0.301</td>
<td>0.096</td>
<td>0.184</td>
<td>-0.449$^+$</td>
</tr>
<tr>
<td>Blocks/Set</td>
<td>-0.135</td>
<td>-0.018</td>
<td>-0.083</td>
<td>0.329</td>
</tr>
<tr>
<td>Points/Set</td>
<td>-0.129</td>
<td>-0.120</td>
<td>-0.186</td>
<td>0.336</td>
</tr>
<tr>
<td>Setters (n = 25)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kills/Set</td>
<td>0.356</td>
<td>0.519$^+$</td>
<td>0.410$^+$</td>
<td>0.015</td>
</tr>
<tr>
<td>Assists/Set</td>
<td>-0.070</td>
<td>0.069</td>
<td>-0.004</td>
<td>-0.035</td>
</tr>
<tr>
<td>Service Ace/Set</td>
<td>0.101</td>
<td>0.228</td>
<td>0.038</td>
<td>0.235</td>
</tr>
<tr>
<td>Digs/Set</td>
<td>-0.113</td>
<td>-0.032</td>
<td>-0.077</td>
<td>0.138</td>
</tr>
<tr>
<td>Blocks/Set</td>
<td>0.023</td>
<td>0.152</td>
<td>0.140</td>
<td>0.080</td>
</tr>
<tr>
<td>Points/Set</td>
<td>0.313</td>
<td>0.539$^+$</td>
<td>0.400$^+$</td>
<td>0.135</td>
</tr>
<tr>
<td>Outside Hitters (n = 43)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kills/Set</td>
<td>0.260</td>
<td>0.353$^+$</td>
<td>0.416$^+$</td>
<td>-0.365$^+$</td>
</tr>
<tr>
<td>Assists/Set</td>
<td>0.261</td>
<td>0.323$^+$</td>
<td>0.363$^+$</td>
<td>-0.264</td>
</tr>
<tr>
<td>Service Ace/Set</td>
<td>0.047</td>
<td>0.253</td>
<td>0.238</td>
<td>-0.443$^+$</td>
</tr>
<tr>
<td>Digs/Set</td>
<td>0.373$^+$</td>
<td>0.467$^+$</td>
<td>0.459$^+$</td>
<td>-0.465$^+$</td>
</tr>
<tr>
<td>Blocks/Set</td>
<td>0.148</td>
<td>0.278</td>
<td>0.222</td>
<td>-0.177</td>
</tr>
<tr>
<td>Points/Set</td>
<td>0.202</td>
<td>0.297</td>
<td>0.381$^+$</td>
<td>-0.391$^+$</td>
</tr>
<tr>
<td>Middle Blockers and Opposite Side Hitters (n = 41)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kills/Set</td>
<td>0.122</td>
<td>0.075</td>
<td>0.308$^+$</td>
<td>-0.081</td>
</tr>
<tr>
<td>Assists/Set</td>
<td>0.011</td>
<td>-0.043</td>
<td>-0.014</td>
<td>-0.183</td>
</tr>
<tr>
<td>Service Ace/Set</td>
<td>0.276</td>
<td>0.144</td>
<td>0.358$^+$</td>
<td>-0.231</td>
</tr>
<tr>
<td>Digs/Set</td>
<td>0.144</td>
<td>0.085</td>
<td>0.129</td>
<td>-0.256</td>
</tr>
<tr>
<td>Blocks/Set</td>
<td>-0.133</td>
<td>-0.025</td>
<td>0.006</td>
<td>-0.022</td>
</tr>
<tr>
<td>Points/Set</td>
<td>0.127</td>
<td>0.089</td>
<td>0.322$^+$</td>
<td>-0.113</td>
</tr>
</tbody>
</table>

*p-value < 0.05; SLJ = standing long jump; SLH = single leg hop; (R) = right; (L) = left; LEFT = lower extremity functional test

is often used as the primary take-off leg during the vertical jump in athletes who are right-side dominant when hitting.

**LOWER EXTREMITY FUNCTIONAL TEST**

Starters were significantly faster at completing the LEFT course than their nonstarter counterparts. There was a negative correlation between many game statistics and LEFT performance (measured in seconds). In other words, completing the course faster (i.e., athletes with a lower LEFT score) correlated with better game performance. To complete the LEFT quickly one must be able to rapidly change direction in response to verbal cues. There were moderate negative correlations (i.e., faster performance of the LEFT correlated with better game performance) for liberos, defensive specialists, and outside hitters (Table 3a). These athletes must possess agility to respond to unpredictable ball play.

**Y BALANCE TEST – LOWER QUARTER**

There were both positive and negative correlations between preseason scores and game performance when evaluating the general population of athletes in this study (Table 2). Negative correlations represent opposite relationships between test performance and game statistics. It is not recommended to select athletes based on these negative correlations nor to “detrain” athletes. The YBT-LQ does not appear to be a useful test for measuring athletic ability for all VB athletes due to the low correlations with many per-
Table 3b. Pearson Product Moment Correlations between Lower Quarter Y-Balance Test (YBT-LQ) Scores and In-Season Game Statistics per Player Position

<table>
<thead>
<tr>
<th>Position(s) and YBT-LQ</th>
<th>Kills/ Set</th>
<th>Assists/ Set</th>
<th>Service Ace/ Set</th>
<th>Digs/ Set</th>
<th>Blocks/ Set</th>
<th>Points/ Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liberos and Defensive Specialists (n = 22)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(R) Anterior</td>
<td>-0.153</td>
<td>-0.347</td>
<td>-0.010</td>
<td>0.118</td>
<td>-0.087</td>
<td>-0.144</td>
</tr>
<tr>
<td>(R) Posteromedial</td>
<td>0.168</td>
<td>0.334</td>
<td>0.037</td>
<td>0.063</td>
<td>0.180</td>
<td>0.179</td>
</tr>
<tr>
<td>(R) Posterolateral</td>
<td>0.093</td>
<td>-0.305</td>
<td>-0.112</td>
<td>0.036</td>
<td>0.122</td>
<td>0.094</td>
</tr>
<tr>
<td>(L) Anterior</td>
<td>-0.188</td>
<td>-0.370</td>
<td>-0.043</td>
<td>0.035</td>
<td>-0.141</td>
<td>-0.191</td>
</tr>
<tr>
<td>(L) Posteromedial</td>
<td>-0.176</td>
<td>-0.433*</td>
<td>-0.100</td>
<td>0.066</td>
<td>0.288</td>
<td>0.203</td>
</tr>
<tr>
<td>(L) Posterolateral</td>
<td>-0.063</td>
<td>-0.295</td>
<td>-0.068</td>
<td>0.127</td>
<td>0.125</td>
<td>0.074</td>
</tr>
<tr>
<td>(R) Composite</td>
<td>-0.295</td>
<td>0.070</td>
<td>0.327</td>
<td>0.506*</td>
<td>-0.306</td>
<td>-0.277</td>
</tr>
<tr>
<td>(L) Composite</td>
<td>-0.339</td>
<td>0.018</td>
<td>0.343</td>
<td>0.538*</td>
<td>-0.315</td>
<td>-0.314</td>
</tr>
<tr>
<td>Setters (n = 25)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(R) Anterior</td>
<td>0.224</td>
<td>0.013</td>
<td>0.063</td>
<td>-0.140</td>
<td>-0.015</td>
<td>0.197</td>
</tr>
<tr>
<td>(R) Posteromedial</td>
<td>0.002</td>
<td>-0.345</td>
<td>0.127</td>
<td>-0.349</td>
<td>-0.201</td>
<td>0.058</td>
</tr>
<tr>
<td>(R) Posterolateral</td>
<td>-0.224</td>
<td>-0.391</td>
<td>-0.041</td>
<td>-0.431*</td>
<td>-0.389*</td>
<td>-0.217</td>
</tr>
<tr>
<td>(L) Anterior</td>
<td>0.354</td>
<td>-0.103</td>
<td>0.225</td>
<td>-0.100</td>
<td>0.101</td>
<td>0.383</td>
</tr>
<tr>
<td>(L) Posteromedial</td>
<td>-0.114</td>
<td>-0.335</td>
<td>0.176</td>
<td>-0.344</td>
<td>-0.241</td>
<td>-0.028</td>
</tr>
<tr>
<td>(L) Posterolateral</td>
<td>-0.157</td>
<td>-0.468*</td>
<td>0.062</td>
<td>-0.355</td>
<td>-0.313</td>
<td>-0.114</td>
</tr>
<tr>
<td>(R) Composite</td>
<td>-0.063</td>
<td>-0.122</td>
<td>0.054</td>
<td>-0.195</td>
<td>-0.326</td>
<td>-0.069</td>
</tr>
<tr>
<td>(L) Composite</td>
<td>-0.055</td>
<td>-0.180</td>
<td>0.165</td>
<td>-0.164</td>
<td>-0.300</td>
<td>-0.016</td>
</tr>
<tr>
<td>Outside Hitters (n = 43)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(R) Anterior</td>
<td>0.269</td>
<td>0.294</td>
<td>0.232</td>
<td>0.458*</td>
<td>0.008</td>
<td>0.256</td>
</tr>
<tr>
<td>(R) Posteromedial</td>
<td>0.275</td>
<td>0.343*</td>
<td>0.265</td>
<td>0.359*</td>
<td>0.174</td>
<td>0.256</td>
</tr>
<tr>
<td>(R) Posterolateral</td>
<td>0.217</td>
<td>0.338*</td>
<td>0.153</td>
<td>0.331*</td>
<td>0.137</td>
<td>0.206</td>
</tr>
<tr>
<td>(L) Anterior</td>
<td>0.425*</td>
<td>0.175</td>
<td>0.256</td>
<td>0.454*</td>
<td>0.226</td>
<td>0.421*</td>
</tr>
<tr>
<td>(L) Posteromedial</td>
<td>0.313*</td>
<td>0.290</td>
<td>0.249</td>
<td>0.418*</td>
<td>0.217</td>
<td>0.312*</td>
</tr>
<tr>
<td>(L) Posterolateral</td>
<td>0.279</td>
<td>0.324*</td>
<td>0.195</td>
<td>0.428*</td>
<td>0.209</td>
<td>0.248</td>
</tr>
<tr>
<td>(R) Composite</td>
<td>0.168</td>
<td>0.446*</td>
<td>0.270</td>
<td>0.469*</td>
<td>-0.052</td>
<td>0.188</td>
</tr>
<tr>
<td>(L) Composite</td>
<td>0.249</td>
<td>0.393*</td>
<td>0.301*</td>
<td>0.537*</td>
<td>0.038</td>
<td>0.273</td>
</tr>
<tr>
<td>Middle Blockers and Opposite Side Hitters (n = 41)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(R) Anterior</td>
<td>-0.261</td>
<td>0.119</td>
<td>0.154</td>
<td>0.107</td>
<td>-0.273</td>
<td>-0.248</td>
</tr>
<tr>
<td>(R) Posteromedial</td>
<td>-0.172</td>
<td>0.220</td>
<td>0.212</td>
<td>0.205</td>
<td>-0.439*</td>
<td>-0.183</td>
</tr>
<tr>
<td>(R) Posterolateral</td>
<td>-0.371*</td>
<td>0.331*</td>
<td>0.302</td>
<td>0.381*</td>
<td>-0.534*</td>
<td>-0.364*</td>
</tr>
<tr>
<td>(L) Anterior</td>
<td>-0.097</td>
<td>0.182</td>
<td>0.120</td>
<td>0.116</td>
<td>-0.099</td>
<td>-0.079</td>
</tr>
<tr>
<td>(L) Posteromedial</td>
<td>-0.042</td>
<td>0.247</td>
<td>0.231</td>
<td>0.237</td>
<td>-0.425*</td>
<td>-0.071</td>
</tr>
<tr>
<td>(L) Posterolateral</td>
<td>-0.156</td>
<td>0.374*</td>
<td>0.365*</td>
<td>0.362*</td>
<td>-0.368*</td>
<td>-0.143</td>
</tr>
<tr>
<td>(R) Composite</td>
<td>-0.435*</td>
<td>0.329*</td>
<td>0.294</td>
<td>0.422*</td>
<td>-0.673*</td>
<td>-0.443*</td>
</tr>
<tr>
<td>(L) Composite</td>
<td>-0.374*</td>
<td>0.398*</td>
<td>0.316*</td>
<td>0.465*</td>
<td>-0.636*</td>
<td>-0.384*</td>
</tr>
</tbody>
</table>

*p-value < 0.05; (R) = right; (L) = left
Table 4. Comparison of Functional Performance Test Scores (Mean ± SD) Per Player Position and Starter Status

<table>
<thead>
<tr>
<th>Category</th>
<th>(N)</th>
<th>Standing Long Jump (% ht.)</th>
<th>(R) Single-Leg Hop (% ht.)</th>
<th>(L) Single-Leg Hop (% ht.)</th>
<th>Lower Extremity Functional Test (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Player Position</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Libero and Defensive Specialist</td>
<td>22</td>
<td>0.83 (0.1)</td>
<td>0.65 (0.1)</td>
<td>0.67 (0.1)</td>
<td>111.7 (7.5)</td>
</tr>
<tr>
<td>Setter</td>
<td>25</td>
<td>0.80 (0.1)</td>
<td>0.64 (0.1)</td>
<td>0.59 (0.2)</td>
<td>113.0 (16.2)</td>
</tr>
<tr>
<td>Outside Hitter</td>
<td>43</td>
<td>0.83 (0.1)</td>
<td>0.68 (0.1)</td>
<td>0.64 (0.1)</td>
<td>108.3 (13.4)</td>
</tr>
<tr>
<td>Middle Blocker and Opposite Hitter</td>
<td>41</td>
<td>0.79 (0.1)</td>
<td>0.63 (0.1)</td>
<td>0.62 (0.1)</td>
<td>113.7 (7.7)</td>
</tr>
<tr>
<td>Totals</td>
<td>131</td>
<td>0.81 (0.1)</td>
<td>0.65 (0.1)</td>
<td>0.63 (0.1)</td>
<td>111.5 (11.8)</td>
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<tr>
<td><strong>p-value</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Libero and Defensive Specialist</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.142</td>
</tr>
<tr>
<td>Setter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.265</td>
</tr>
<tr>
<td>Outside Hitter</td>
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<td></td>
<td></td>
<td></td>
<td>0.174</td>
</tr>
<tr>
<td>Middle Blocker and Opposite Hitter</td>
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<td></td>
<td></td>
<td></td>
<td>0.165</td>
</tr>
</tbody>
</table>

**Starter**

<table>
<thead>
<tr>
<th></th>
<th>(N)</th>
<th>Standing Long Jump (% ht.)</th>
<th>(R) Single-Leg Hop (% ht.)</th>
<th>(L) Single-Leg Hop (% ht.)</th>
<th>Lower Extremity Functional Test (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>49</td>
<td>0.86 (0.1)</td>
<td>0.69 (0.1)</td>
<td>0.68 (0.1)</td>
<td>108.3 (12.4)</td>
</tr>
<tr>
<td>No</td>
<td>82</td>
<td>0.78 (0.1)</td>
<td>0.63 (0.1)</td>
<td>0.60 (0.1)</td>
<td>113.3 (11.0)</td>
</tr>
<tr>
<td><strong>p-value</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.000</td>
</tr>
</tbody>
</table>

Table 5. Functional Performance Test Scores (Mean ± SD) Per Player Movement Categorization

<table>
<thead>
<tr>
<th>Functional Test</th>
<th>L/DS/S (n = 51)</th>
<th>OH/MB/Opp (N = 80)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing Long Jump (% ht.)</td>
<td>0.81 (0.11)</td>
<td>0.81 (0.10)</td>
<td>0.817</td>
</tr>
<tr>
<td>(R) Single-Leg Hop (% ht.)</td>
<td>0.65 (0.12)</td>
<td>0.65 (0.12)</td>
<td>0.813</td>
</tr>
<tr>
<td>(L) Single-Leg Hop (% ht.)</td>
<td>0.62 (0.14)</td>
<td>0.63 (0.13)</td>
<td>0.588</td>
</tr>
<tr>
<td>LEFT (seconds)</td>
<td>111.5 (12.3)</td>
<td>111.4 (11.6)</td>
<td>0.968</td>
</tr>
</tbody>
</table>

LEFT = lower extremity functional test; L = libero; DS = defensive specialist; S = setter; OH = outside hitter; MB = middle blocker; Opp = opposite side hitter

Performance measures. Of interest though is the finding of a moderate positive correlation between digs/set and (R) or (L) composite scores in the entire population (Table 2). The composite score is often considered a measure of dynamic balance taking into account each of the three arms of the "Y". When evaluating correlations based on player position there was a moderate positive correlation between digs/set and composite scores in liberos/defensive specialists (Table 3b). These athletes frequently have to lunge in horizontal or diagonal positions to make a play on the ball. There were also low to moderate positive correlations between YBT-LQ reach measures and composite scores and digs/set in outside hitters (Table 3b). Many outside hitters are also required to play in the back row; and possessing greater dynamic balance as measured by the YBT-LQ may be advantageous for their defensive assignments. Administering the YBT-LQ may provide strength coaches with actionable information that could influence training programs for liberos, defensive specialists, and outside hitters. Other VB players, setters, middle blockers, and opposite side hitters, may not benefit from YBT-LQ testing. For example, there were many correlations, both positive and negative, between YBT-LQ scores and game performance in middle blockers and opposite side hitters (Table 3b). The inconsistency in correlations challenges a professional's ability to interpret the meaning of the scores for this group of athletes.

FUNCTIONAL TESTS MAY ALSO ALLOW COACHES TO SCREEN FOR ATHLETES AT-RISK FOR INJURY

Utilization of FT that can both discriminate injury risk and that can provide the coaching staff with information about one's athletic ability would be advantageous. The tests administered in this study, the standing long jump (SLJ), the single-leg hop (SLH), the lower extremity functional test (LEFT), and the Lower Quarter Y Balance Test (YBT-LQ), have shown promise as tests to identify female collegiate athletes who are at an increased risk for injury. Female Division III collegiate athletes, representing athletes from eight sports (including VB), were nine times more likely to experience a noncontact time-loss injury to the thigh or knee if they had lower standing long jump (SLJ ≤ 79% ht.), single-leg hop (SLH ≤ 64% each side), and slower extremity functional test (LEFT > 118 sec) scores. Female Division III collegiate level VB players with lower SLJ (< 80% height), lower bilateral SLH (< 70% height per side) and...
side-to-side asymmetry during SLH > 10% were four times more likely to experience a noncontact time-loss injury to the lower quadrant region (i.e., low back and lower extremities). In a separate cohort, female collegiate level VB players were three times more likely to experience a noncontact time-loss injury to the lower quadrant region if SLJ distance was < 80% height, both SLH scores were < 70% height, and the athlete had a prior history of injury. Asymmetrical YBT-LQ reach scores in the anterior direction was associated with a two times greater risk of a noncontact lower extremity injury in a sample of Division I athletes.

VALUE OF TESTS FOR REHABILITATION PROFESSIONALS

The descriptive data presented in this study, as well as previously reported LEFT and YBT-LQ data, may be of use to sports medicine professionals. Injury to the lower quadrant region (i.e., low back and lower extremities) is high with over 70 percent of all time-loss injuries occurring in this region. The most common lower quadrant injuries during volleyball games are ankle ligament sprains, internal derangement of the knee, and low back strains. The most common lower quadrant injuries sustained during volleyball practice are ankle ligament sprains, strains of the upper leg, and low back strains. The SLJ, SLH, LEFT, and YBT-LQ tests are frequently used to evaluate deficits due to injury and to track an athlete's recovery. The descriptive data from this study can provide scores specific to the female collegiate VB player population therefore improving a clinician's ability to make decisions about return to play.

For example, one return to sport testing algorithm recommends that most female athletes should complete the LEFT in 120 seconds or less prior to returning to sport. The results from this study (e.g., mean LEFT score of 111 sec) may influence sports medicine professionals to require collegiate level VB players to complete the LEFT faster than previously published data prior to resuming sport.

STRENGTHS AND LIMITATIONS

The strengths of this study include the large sample size recruited and the collection of FT data at the start of the athlete's season. A potential limitation of this study is that the researchers did not perform an a priori reliability study for leg length measurements. The leg length measurements are used to normalize reach measures during YBT-LQ testing. However, Plisky et al did report this procedure had an excellent reliability of 0.99. Another potential limitation for this study is the sample sizes recruited per level of competition. The highest percentage of athletes were recruited from Division III schools. Collecting data from additional athletes who compete for Division II or NAIA schools may have allowed for evaluating correlations based on level of competition. Also, this study did not recruit VB players from either Division I or community college levels. While there are likely similarities in test performance between the sample in this study and athletes from the Division I or community college levels, coaches and clinicians should use caution when applying normative data to those groups.

CONCLUSION

The results of this study indicate that there are low to moderate correlations between some preseason functional test scores and game statistics. Scores, particularly those that demonstrated moderate correlations, can be used by a coach/strength coach for talent identification and to inform training program design. The descriptive data presented in this study may help sports medicine professionals when evaluating measures of functional performance during a course of rehabilitation.

COI

The authors have no conflicts of interest to declare.

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REFERENCES


Normative Reference Values and Validity for the 30-Second Chair-Stand Test in Healthy Young Adults

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Keywords: Normal Values, Physical Performance Tests, Psychometric Testing, Sit-to-Stand Tests

Background
Clinicians often use physical performance tests (PPT) to measure performance measures in sports since they are easy to administer, portable, and cost-efficient. However, PPT often lack good or known psychometric properties. Perhaps, the 30-second chair-stand test (30CST) would be a good functional test in athletic populations as it has been shown to demonstrate good psychometric properties in older adults.

Hypothesis/Purpose
The purpose of this study was to determine normative values for and concurrent, convergent and discriminative validity of 30CST for healthy young adults aged 19-35 years.

Study Design
Cross-sectional

Methods
Eighty-one participants completed this study. All participants performed two trials of 30CST, 5-times sit-to-stand (5xSTS), and lateral step-up test (LSUT). Investigators used the International Physical Activity Questionnaire Leisure Domain (LD-IPAQ) to divide participants into insufficiently or sufficiently active groups based on the weekly metabolic equivalent of task per the Physical Activity Guidelines for Americans.

Results
Participants (Mean ± SD age, 25.1 ± 3.4 years; body height, 1.71 ± 0.09 m; body mass, 72.6 ± 16.1 kg; females 47) performed an average of 33.0±5.4 30CST repetitions. The 30CST performance was negatively associated with 5xSTS (r=-0.79 p=0.01) and positively associated with LSUT performances (r=0.51, p=0.01) when using Pearson correlations. In addition, the sufficiently active group performed significantly greater 30CST repetitions than the insufficiently active group (mean difference = 2.5; p=0.04).

Conclusions
In addition to finding a reference value for 30CST performance in young adults, investigators found that the 30CST displayed concurrent and convergent validity in assessing functional lower extremity (LE) muscle strength and discriminated between those with sufficient and insufficient physical activity levels. Training and rehabilitation professionals could use the 30CST for testing functional LE muscle strength for athletes.

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in pre-season or during rehabilitation. Future investigators should perform studies to determine if 30CST predicts sport performance.

**Level of Evidence**
Level 2

**INTRODUCTION**

Greater lower extremity (LE) muscle strength associates highly with athletic performance skills such as jumping and changing directions. Clinicians often use physical performance tests (PPT) to measure functional LE muscle strength, performance, during pre-season screenings, and for prediction of injury recovery or return to sport. Clinicians use PPT because they are inexpensive, portable, and easy to administer. However, all PPT measurement properties have not been studied extensively and their results should be interpreted with caution. One functional test that has received little attention by researchers in young adults and particularly in those involved in sports is the 30-second chair-stand test (30CST). During the 30CST, the individual performs the sit-to-stand-to-sit maneuver without using their arms as many times as possible from a standardized height chair in 30 seconds. The investigators believe this test may be useful in assessing functional LE strength and performance in young adults since 30CST has good psychometric properties to measure functional LE strength in older adults, and other sit-to-stand-tests (i.e., 5 Times Sit-to-Stand) has shown early promise as a lower extremity measure in young adults. Specifically, the 30CST has good test-retest reliability and criterion validity in older adults. In addition, 30CST could discriminate older individuals of varying age groups based on physical activity levels. Additionally, the importance of 30CST is evidenced by its inclusion in function and balance assessments in two well accepted balance evaluation programs designed for older adults: Stopping Elderly Accidents, Deaths & Injuries (STEADI) Algorithm by Center for Disease Control and Prevention (CDC) and Otago programs championed by the CDC.

In adults aged 20-59 years, McKay et al. demonstrated that the 30CST possesses criterion validity for LE muscle strength. However, there is no data concerning the validity of the 30CST in young adults (18 to 35 years). The existing data may not be valid since muscle strength declines after the third to fourth decade of life. Validity is important since this psychometric property assures a test can discriminate between individuals with and without certain characteristics, evaluate change across times, and predict future functional performances. The investigators found nothing in the literature that examined whether the 30CST test could discriminate between younger adults who are physically fit from those who are not physically fit as has been shown previously in older adults. In addition, a popular clinical test for assessing LE muscle strength is the Five Times Sit-to-Stand Test (5XSTS). Thus, the examination of 30CST with 5XSTS could inform the literature regarding concurrent and convergent validity of 30CST. Further credence that 30CST has good convergent validity would be if it can be correlated with LE functional muscle strength tests such as the lateral step-up test (LSUT), since both of these tests use similar motor action. Thus, there is a critical need for establishing the validity of 30CST in young adults before using it in clinical populations such as those involved in sports and physical activity.

Another important aspect of any clinical test is the presence of normative data because normative data helps clinicians establish performance benchmarks, which allows them to track patient progress, determine prognosis, and set rehabilitation or training goals. Interestingly, normative data for 30CST among different age groups exist. However, the investigators found several limitations such as a wide age ranges and the potential influence of physical fatigue within the existing normative value data that might necessitate establishing young adults performance in 30CST. Thus, examination of the 30CST in young adults is warranted because it can provide reference data, which can be used to assess and compare functional LE strength and understand muscle performance in young adults involved in sports or physical activity.

Therefore, the primary aim of this study was to determine reference values of 30CST performance in young adults aged 18 to 35 years. Second, the investigators evaluated the concurrent and convergent validity of 30 CST by examining its relationship with the LSUT and 5XSTS in young adults. Finally, the investigators assessed the discriminant validity of the 30CST by comparing young adults who meet versus those who did not meet the Physical Activity Guidelines for Americans recommendations for physical activity.

**MATERIALS AND METHODS**

**PARTICIPANTS**

The investigators recruited 81 healthy young adults for this cross-sectional study. The investigators found participants by posting fliers and word-of-mouth at a college campus. Participants were included in this study if they were between the ages of 18-35 years and ambulated independently. The investigators excluded potential participants from this study if they reported orthopedic, neurological, or cardiorespiratory conditions that affect exercise performance. During the consenting process, the investigators informed participants the benefits and risks of this study before individuals signed the consent form for this study. The University of Alabama at Birmingham Institutional Review Board approved this research protocol.

**PROCEDURES**

The data reported in this study are part of a larger study that investigated the interrelationships between PPT and neuromuscular performance (data not published). First, the investigators measured anthropometric measurements...
(body height, body mass, and body composition) and then participants performed balance tasks. Next, participants performed either jump task (outside the scope of aims of this study) or LE PPT randomly. Investigators randomized the order of the LE PPT: 30CST, 5-times sit-to-stand test (5xSTS), and lateral step-up test (LSUT). Participants performed two trials per test with a 60-second rest period between trials. For the LSUT, participants performed one trial of the standard test where they touch the ground with their full foot (standard LSUT), and another trial where they touched the ground with only their heel (modified LSUT). Participants completed the International Physical Activity Questionnaire-Long Format (IPAQ-LF). The investigators asked participants to complete this questionnaire during a 10-minute rest period between the LE PPT and balance tasks. Prior to collecting data, investigators practiced all tests and protocol prior to implementing the study. In addition to the pre-study training, one investigator, who was responsible for counting or timing all PPT in this study, has used these PPT in the clinic for over 50 years in his physical therapy practice.

ANTHROPOMETRIC MEASUREMENTS

The investigators measured body height (m) using a stadiometer (Charter HM200P Stadiometer, Taichung City, Taiwan) and body mass (kg) and body composition using a bioelectrical impedance analysis (BIA) machine (Tanita Body Composition Analyzer; TBF-300, Arlington Heights, Illinois, USA). The investigators derived body mass index (BMI) by dividing body mass (kg) by squared body height (m²). Participants wore light clothes and removed their shoes and socks for all the anthropometric measurements.

THIRTY SECONDS CHAIR–TO-STAND TEST (30CST)

The investigators provided instructions, demonstration, and a 10-second practice for each participant prior to testing. The investigators instructed the participants to stand up and sit down fully, using both lower extremities, after an investigator said, "go" and to perform as many cycles of sit-to-stand–to-sit as possible in 30 seconds. The investigators instructed participants to exert their maximum performance during the test. Participants started this test sitting in the middle of the chair, feet positioned on the floor, and arms crossed on an armless chair with a seat height of 45-cm positioned against a wall. One investigator blocked the chair from moving by placing one foot in front of the chair leg and guarding the participant. Participants started in the same 30CST position on the chair. In addition, the investigators instructed participants to fully stand up and sit down five times as fast as they could. Time started when the same investigator, who monitored the time and counted the 30CST cycles started the stopwatch and said, "Go." This investigator stopped the stopwatch when the participant’s buttock touched the chair for the fifth time. Participants rested for 60 seconds between the chair for two data collection trials. Participants also rested for 20-30 seconds between the practice and first data collection trial. Investigators have reported that this test to be reliable⁷ and valid.⁷

FIVE TIMES SIT-TO-STAND TEST (5XSTS)

The 5xSTS test is another PPT that examines functional LE strength.⁷ Like the 30CST, participants performed sit-to-stand–to-sit (using bilateral lower extremities) from the same chair positioned against the wall, with the same investigator blocking the front of the chair leg and guarding the participant. Participants started in the same 30CST position on the chair. In addition, the investigators instructed participants to fully stand up and sit down five times as fast as they could. Time started when the same investigator, who monitored the time and counted the 30CST cycles started the stopwatch and said, "Go." This investigator stopped the stopwatch when the participant’s buttock touched the chair for the fifth time. Participants rested for 60 seconds between the chair for two data collection trials. Participants also rested for 20-30 seconds between the practice and first data collection trial. Investigators have reported that this test to be reliable⁷ and valid.⁷

LATERAL STEP-UP TEST (STANDARD AND MODIFIED LSUT)

The LSUT also assesses the functional LE strength of the single leg that remains on the step throughout the 15-second test period. Prior to instruction and demonstration of this test, the investigators determined the participant’s dominant leg by asking the individual, "If I rolled a ball in front of you, which leg would you kick it with?" The investigators selected the non-dominant leg as the limb to be studied limb. Thus, the non-dominated leg remained on the 20-cm height step in this study. The investigators instructed the participant to fully touch the floor with their dominant foot but not bear weight and then return the same foot to the top of the step (standard LSUT). One repetition equaled one cycle of step-to-floor-to-step. Participants performed this test again after a 60-second rest but instead of touching the floor fully with their dominant foot, they touched the floor only with their heel (modified LSUT). Like the LSUT the modified LSUT tests unilaterally; the leg that remains on the step receives the score for the test. The investigators choose to perform this modification to determine if the inability to use the plantarflexors affect performance and association between this test and the other functional strength test assessed in this study. Participants performed several familiarization cycles of both the standard and modified LSUT with a 30-second rest break before the data collection trials. The same investigator kept time with a stopwatch and guarded the participant during this test. The other investigator counted the number of complete cycles while holding on the step for participant safety. The same investigator measured and recorded the outcomes for each test in this study. Investigators have also reported this test to be reliable¹⁹ and valid²⁰ to assess motor function.
INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE—LONG FORMAT (IPAQ–LF)

This questionnaire measures six different domains but for this part of the study, the investigators only used the leisure domain, as researchers have suggested the use of this domain in public health intervention and surveillance. The investigators followed the IPAQ scoring guidelines and calculated MET-minute/week. Participants completed the paper/pencil survey between the balance measurements and PPT, which allowed participants to rest for 10 minutes. The investigators helped provide clarification of items if individuals inquired. The IPAQ is a reliable and valid questionnaire to assess physical activity levels over the past week. For IPAQ-LF, the investigators chose 1000 MET-minutes/week as the cut-off score to categorize participants into two groups of sufficiently active and insufficiently active based on leisure time score of IPAQ-LF. The investigators selected this value since it is a number at the higher end of physical activity level recommendation by the Physical Activity Guidelines for Americans. The investigators chose this value since the variability of this data was wide in this study and previous researchers found that self-report for physical activity is inconsistent.

DATA AND STATISTICAL ANALYSIS

Statistical Package for the Social Sciences software (SPSS; IBM Corp., Armonk, NY) v27.0 was used for statistical analyses. Means and standard deviations were calculated to describe all data from this sample except for race and sex where frequencies and percentages were determined. All PPT displayed normal distributions when tested for skewness and kurtosis. Pearson correlations analyses were used to determine the associations between 30CST and the other three PPT: 5xSTS, standard LSUT, and modified LSUT. Correlation coefficients were interpreted as follows: weak (0.1 – 0.3), moderate (>0.3 to 0.5), or a strong correlation (>0.5). Independent t-tests were used to determine if 30CST could discriminate those individuals who met physical activity guideline recommendations from those who did not meet these guidelines. Pearson correlations were also used to determine discriminant validity of 30CST and IPAQ-LF leisure's domain score. Intraclass coefficients were determined between PPT performance trials to ensure adequate rest was provided between repetitions of each PPT. Alpha levels less than 0.05 were used to determine statistical differences.

RESULTS

Eighty-one participants completed this study, with the majority of the sample being female (58.0%) and Caucasian (66.7%) (Table 1). Approximately 62% of the participants met the upper limit of the physical activity guidelines for physical activity. Participants’ age ranged from 18 to 35 years (x̄ ± SD = 25.1 ± 3.4 years) with an average normal BMI (x̄ ± SD = 24.8 ± 4.6). However, those who were classified as insufficiently active (n = 51; men = 18; women = 13) in this study would be considered overweight (BMI, x̄ ± SD = 25.9 ± 4.9). The sufficiently active groups’ average body mass was significantly lower while the IPAQ-LF leisure domain score and 30CST were significantly greater than the insufficiently active groups (p < 0.05).

On average, participants performed 33.0 ± 5.4 repetitions of 30CST. There was a significant negative and strong association between 30 CST and 5xSTS (r = –0.78, p = 0.01) indicating that those who scored greater scores of 30CST took less time to complete five repetitions of sit-to-stand-to-sit (Table 2). The 30CST showed significant positive and strong correlations with the standard LSUT (r = 0.51, p = 0.01) and a positive and moderate modified LSUT (r = 0.47, p = 0.01). In addition, the sufficiently active group performed significantly greater repetitions of 30CST than those in the insufficiently active group: t (2,79) = 2.09 (p = 0.04). There was no significant association between the 30CST and IPAQ-LF leisure time score (p > 0.05). Finally, good to excellent intraclass coefficients found between PPT trials: 0.95 (95%CI = 0.89 – 0.94) for 30CST trials, 0.94 (95%CI = 0.90 – 0.96) for 5xSTS, and 0.79 (95%CI = 0.69 – 0.86) for LSUT.

DISCUSSION

The study findings provide reference values for 30CST with good concurrent, convergent and discriminate validity for healthy young adults aged 18 to 35 years and not formally participating in athletics. Specifically, the investigators found that young adults aged 18 to 35 years performed on average 33.0 repetitions (SD = 5.4 repetitions). Based on these results, the 30CST may be a good test to use in healthy adults especially since it could discriminate between those young adults sufficiently active and insufficiently active. This study results are different from those previously reported mainly because the previous investigators reported normative data across a wide age range including a mix of young and middle-aged adults or a mix of pediatric and young adults.

A possible reason why 30CST repetitions were better in these subjects than the previously reported normative values, is that the current investigators studied a well-defined age range (18-35 years) while the previous researchers studied different age groups, including individuals aged 20-59 years and 10-19 years. These previously selected age ranges likely contained individuals at either end of young adult age ranges who may possess large differences in muscle strength due to growing and aging processes that occur across the human lifespan. Muscle strength continuously increases through the first few decades of life with peak muscle strength occurring in the second or third decade of life. Muscle strength starts to decrease in the fourth decade of life in both sexes and could have metabolic implications. Lower extremity strength is directly associated with 30CST in older adults. Thus, we selected to study a group of individuals at a similar stage of muscle strength development which may explain the difference between the 30CST performances in this study compared to the reported by McKay and colleagues.

The investigators minimized risk of fatigue by allowing the participants to rest between all study activities, which may be another factor explaining greater 30CST performance in this study. The previous normative study did not report a provision of rest interval between research activi-
Table 1. Clinical and Demographics Descriptive Statistics.

<table>
<thead>
<tr>
<th></th>
<th>Sufficiently Active (n = 50)</th>
<th>Insufficiently Active (n = 31)</th>
<th>p-values</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>25.1 ± 3.3</td>
<td>24.8 ± 3.6</td>
<td>0.720</td>
<td>25.1 ± 3.4</td>
</tr>
<tr>
<td>Race, N (percent)</td>
<td>White 39 (78.0) Others 11 (22.0)</td>
<td>White 20 (64.5) Others 11 (35.5)</td>
<td>0.185</td>
<td>White 54 (66.7) Others 27 (33.3)</td>
</tr>
<tr>
<td>Sex, N (percent)</td>
<td>Males 16 (32.0) Females 34 (68.0)</td>
<td>Males 18 (58.1) Females 13 (41.9)</td>
<td>NA</td>
<td>Males 34 (42.0) Females 27 (58.0)</td>
</tr>
<tr>
<td>Body Mass (kg)</td>
<td>69.3 ± 14.6</td>
<td>77.7 ± 17.3</td>
<td>0.021</td>
<td>72.6 ± 16.1</td>
</tr>
<tr>
<td>Body Height (m)</td>
<td>1.7 ± 0.1</td>
<td>1.7 ± 0.9</td>
<td>0.122</td>
<td>1.7 ± 0.1</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.1 ± 4.3</td>
<td>25.9 ± 4.9</td>
<td>0.086</td>
<td>24.8 ± 4.6</td>
</tr>
<tr>
<td>IPAQ Leisure Domain</td>
<td>2297.7 ± 1265.6</td>
<td>444.2 ± 325.1</td>
<td>&lt;0.001</td>
<td>1588.3 ± 1357.4</td>
</tr>
<tr>
<td>30-CST (Repetitions)</td>
<td>34.0 ± 5.2</td>
<td>31.5 ± 5.5</td>
<td>0.040</td>
<td>33.0 ± 5.4</td>
</tr>
<tr>
<td>Five times sit-to-stand</td>
<td>4.3 ± 0.6</td>
<td>4.5 ± 0.8</td>
<td>0.223</td>
<td>4.4 ± 0.7</td>
</tr>
<tr>
<td>Lateral Step-Down</td>
<td>18.0 ± 2.1</td>
<td>18.1 ± 2.6</td>
<td>0.760</td>
<td>18.1 ± 2.3</td>
</tr>
<tr>
<td>Modified Lateral Step-Down</td>
<td>15.2 ± 2.4</td>
<td>15.1 ± 3.1</td>
<td>0.881</td>
<td>15.2 ± 2.6</td>
</tr>
</tbody>
</table>

BMI: Body Mass Index; IPAQ: International Physical Activity Questionnaire; MET: Metabolic Equivalent of Tasks; 30-CST: 30-Second Chair-Stand Test.
Values are represented as means ± SD.

Table 2. Pearson Correlation Coefficients Among the Variables of Interest.

<table>
<thead>
<tr>
<th></th>
<th>30-Second Chair-Stand (Repetitions) Pearson Correlation/Partial Pearson Correlations*</th>
<th>IPAQ Leisure (MET-minute/week)</th>
<th>Body Mass (kg)</th>
<th>Body Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-Second Chair-Stand (Repetitions)</td>
<td>-</td>
<td>0.110</td>
<td>0.086</td>
<td>-0.261*</td>
</tr>
<tr>
<td>Five times sit-to-stand (Seconds)</td>
<td>-0.778**/-0.762**</td>
<td>-0.129</td>
<td>0.039</td>
<td>0.255*</td>
</tr>
<tr>
<td>Lateral Step-Down (Repetitions)</td>
<td>0.512**/.596**</td>
<td>0.039</td>
<td>0.032</td>
<td>0.200</td>
</tr>
<tr>
<td>Modified Lateral Step-Down (Repetitions)</td>
<td>0.465**/.560**</td>
<td>0.164</td>
<td>-0.054</td>
<td>0.234*</td>
</tr>
</tbody>
</table>

IPAQ: International Physical Activity Questionnaire
* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

In addition, they did not mention if they randomized the order of the PPT. A previous systematic review has reported that fatigue, induced by LE exercise, affected PPT and balance performances including the speed and power of sit-to-stand-to-sit repetitions in older adults. Furthermore, investigators reported that the quadriceps femoris muscle fatigue increased in young adult who performed greater repetitions of 30CST, emphasizing the importance of rest interval between trials. Thus, the biasing effect of fatigue could have adversely affected the outcome measures based on the PPT order performed in the previously published normative values for individuals aged 10 to 19 years and 20 to 59 years. Specifically, the researchers of previously published normative values of 30CST for adults used a comprehensive test battery of physical function such as the six minutes walking test, which may pose a fatiguing effect on 30CST if it followed multiple functional tests without rest breaks between tests. The investigators of the current study feel confident that they provided enough rest in this study due to the good to excellent intraclass coefficients found between PPT trials. Thus, one could infer that enough rest was allowed between and within PPT in this study. LSUT intraclass coefficient was not as strong as the sit-to-stand-to-sit but still good considering the modification the second trial of the LSUT.
The 30CST showed moderate to strong concurrent/convergent validity to assess LE muscle strength due to the moderate correlations found between the 5xSTS and LSUT tests. The 5xSTS\(^7\) and LSUT\(^20\) have previously been validated with LE resistive strength tests and functional tests in older adults. Jones et al\(^6\) showed that 30CST had a strong correlation ($r = 0.77$) with 1-repetition maximum (1RM) of a leg press. McCarthy\(^8\) and colleagues found moderate association between 30CST and hip ($r = 0.33$) and knee ($r = 0.44$) extensor leg strength measured by a Cybex isokinetic dynamometer. In addition, McKay showed a moderate association between knee extensor strength and 30CST ($r = 0.42$) in adults 60 years and older.\(^{13}\) Interestingly, the modified LSUT association with 30CST ($r = 0.47$), while significant, was less than the correlation between the standard LSUT and 30CST ($r = 0.51$). Previous authors reported that individuals use their plantarflexors during sit-to-stand activities,\(^8\) which is also common during LSUT performance. However, the activation of the plantarflexors during the modified LSUT was minimized in the “moving leg” during the step down and up phases of this test. Thus, bilateral plantarflexors where being used in both phases of the LSUT but not the modified LSUT which would potentially be the reason why the LSUT association magnitude was greater than the modified LSUT association with 30CST.

The 30CST was also found to discriminate between those individuals that did not meet 1000 MET-minutes week and those who did, measured by leisure domain of IPAQ-LF. Previous researchers found that 30CST had good discriminant validity in distinguishing between older adults who exercised regularly from those who did not.\(^6\) Thus, the 30CST may be a good test to discriminate between young adult athletes who are aerobically fit and those who are not, but further research needs to be done with athletes.

Several limitations existed in this study. First, the investigators did not have enough participants to determine if the 30CST test would be able to discriminate exercise level within males and females. Second, the investigators did not adjust the seat height of the chair dependent on body height or leg length despite previous researchers finding that seat height affects 30CST performance in older adults.\(^{51}\) However, partial correlations to control body height showed significant moderate correlations between 30CST and the other PPT (Table 2). Third, concurrent and convergent validity were determined using functional strength test scores rather than a gold standard strength score as measured by an isokinetic dynamometer which may raise concerns. However, all three tests used in this study are reliable and valid to measure functional lower extremity strength, commonly used clinically, and showed moderate to strong correlation coefficients which should increase trust in these findings. Furthermore, McKay et al. showed that lower extremity muscle strength was associated with 30CST using a handheld dynamometer.\(^{13}\) Finally, these results may not generalize well to athletes and other populations especially since most of the study participants were Caucasian, healthy, and young adults. Thus, this study should be repeated with athletes and different populations to ascertain that these findings are similar or different in these populations.

**CONCLUSION**

PPT’s are often used in the evaluation of LE strength and performance in young adults\(^7,\)\(^32\) and athletes\(^2,\)\(^5\) due to the ease of administration, cost and portability.\(^2,\)\(^4\) The results of this study indicate that the 30CST has concurrent and convergent validity in assessing LE muscle strength and discriminate between sufficient and insufficient physical activity levels in young healthy adults. The 30CST could be a useful test to assess functional LE strength in young adults since this test is inexpensive, portable and easy to administer. Thus 30CST may be a good PPT to measure LE strength in athletes since it meets many of the measurement properties sought when selecting field-based strength tests.\(^4\) However, this study should be replicated with athletes to ascertain that the findings of this study are found in athletes.

**CONFLICTS OF INTEREST**

The authors have no conflicts of interest to declare.

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Introduction
Opioid prescription to treat pain among orthopedic surgery patients remains common practice in the United States but overprescribing opioids can lead to abuse. The purpose of this study was to determine the effect of a multimodal non-pharmacological ‘pain relief kit’ on pain, function, and opioid consumption in individuals recovering from orthopedic surgery.

Hypothesis
Patients provided with the pain relief kit would consume less opioid medication, report lower pain levels, and have better functional outcome scores than the control group.

Level of Evidence
2b

Methods
Fifty-three subjects (18 women, 35 men) having orthopedic surgery were randomly assigned to either receive the Pain Relief Kit (treatment) or control group. At the first postoperative physical therapy visit (within 1 week of surgery) the treatment group was provided elastic resistance bands, kinesiology tape, Biofreeze, and a hot/cold pack as part of the Pain Relief Kit. Patients completed the SF-36 and either the DASH or LEFS questionnaires consistent with their surgery at baseline and four weeks post-op. Both groups reported daily pain (Visual Analogue Scale), opioid use, and over the counter medication use. The treatment group also recorded daily kit modality use.

Results
There was no significant difference in total opioid use between the treatment (108±252 milligram morphine equivalents) and control groups (132±158 MME; p=0.696). Opioid use and pain declined from week one to four with no difference between groups (p<0.001). Outcome scores and SF-36 scores improved from week one to four with no difference between groups (p<0.001).

Conclusion
A non-pharmacological pain relief kit did not have an effect on opioid use in this patient population nor did it improve pain relief or function compared to controls.
INTRODUCTION

Orthopedic surgeons are the third highest opioid prescribers among all physicians. Opioids are routinely prescribed for pain relief during the postoperative recovery process after orthopedic surgery. In recent years, regulatory agencies, including state governments, have enacted initiatives to decrease the use of opioids in the perioperative setting. These include legislative reforms, institutional reforms such as educational programs and prescribing guidelines, and physician-led practice-based reforms. Recent evidence suggests that state-level legislation is effective in decreasing opioid use in the postoperative period for patients undergoing orthopedic procedures. Orthopedic patients traditionally have the most in-person ‘face time’ with their clinicians. Therefore, orthopedic surgeons can have a direct role in not only patient education, but also in improving pain management strategies and decreasing the opioid burden on society.

The use of opioids for pain management after major surgery has been linked to subsequent prolonged opioid dependence. As a result, the growing concern for opioid misuse and abuse has increased in the general public. Reducing postoperative pain by other means could decrease opioid consumption. Apart from counselling patients and establishing reasonable expectations for pain control as part of the treatment plan, several non-opioid alternative strategies exist for pain management. Physical therapy may be used to increase exposure to nonpharmacological treatments for people with musculoskeletal pain conditions. In recent practice guidelines, nonpharmacological treatments have been emphasized for initial pain management of musculoskeletal pain, and physical therapists are providers who routinely deliver nonpharmacological treatments such as ice, heat, tape and therapeutic exercise. Additionally, same day physical therapy following orthopedic surgery leads to decreased inpatient opioid consumption. Therefore, it may be possible that, if implemented in addition to regularly scheduled physical therapy, these non-pharmacologic interventions can provide sufficient postoperative pain relief to reduce opioid use.

Cryotherapy, a common recovery modality easily used at home, has consistently been shown to alleviate pain. Cryotherapy works to reduce pain by reducing skin surface temperature, which can promote a reduction in nerve conduction velocity. A popular, and sometimes more user-friendly, substitute to cryotherapy is Biofreeze. Biofreeze is a menthol-based superficial cooling product which has previously been shown to effectively reduce pain in a variety of musculoskeletal conditions. Although the active ingredient in Biofreeze, menthol, does not lower tissue temperature, it stimulates cold thermoreceptors through a chemical reaction resulting in pain relief. Heat packs are also commonly utilized at home when individuals seek comfort and pain relief. Ultimately both cold and hot modalities provide an analgesic effects and successfully, albeit temporarily, reduce pain.

Other alternative recovery modalities capable of indirectly reducing pain include elastic adhesive tape and elastic resistance exercises. Elastic adhesive tape, commonly known as kinesiology tape, is superior to minimal intervention for pain relief, but this effect does not hold true when compared to other treatment approaches in individuals with chronic musculoskeletal pain. Conversely, elastic resistance exercises involve the participation of the patient, and are commonly used to build strength, increase range of motion, and reduce pain in the physical therapy setting. Although potentially counterintuitive to individuals experiencing symptoms of pain, elastic band exercises can be low-impact and when dosed appropriately will not exacerbate pain. Elastic resistance exercises have been shown to reduce pain and improve range of motion in knee arthroplasty patients. In general, exercise programs that improve one’s strength not only lessen pain but also improve functional ability.

Nonpharmacologic therapies might be of greater interest to the patient concerned with, or opposed to taking opioid medication, and could potentially provide a comparable analgesic effect, particularly if used in a multimodal pain management strategy. Therefore, the purpose of this study was to determine the effect of a multimodal non-pharmacological ‘pain relief kit’ on pain, function and opioid medication consumption in individuals recovering from orthopedic surgery. It was hypothesized that patients who were provided with the pain relief kit would consume less opioid medication, report lower pain levels, and have better functional outcome scores than the control group.

METHODS

Patients were included in the study if they underwent an orthopedic surgery that included bone drilling as part of the procedure. Exclusion criteria for this study included any patient who was currently already taking opioids or had a history of alcohol or substance abuse. Based on the variability between patients in opioid use after total knee arthroplasty and ACL reconstruction, it was estimated that with 25 patients per group there would be 80% power to detect a 60% lower use of opioids in the pain relief kit group at p<0.05.

Patients were randomized to receive either standard care (control) or with the addition of the pain-relief kit (treatment). The treatment duration was four weeks, beginning on the first postoperative physical therapy visit which took place within one week post-op. Patients in the control group received usual care in the clinic but did not receive any components of the pain relief kit as part of their home program. The treatment group received standard care in addition to the pain relief kit. Treatment group patients were shown how to properly use each item in the kit at the first physical therapy visit. All patients were prescribed physical therapy two to three days per week. Patients kept a daily log of the volume and rate of opioid and non-opioid pain medication consumption, VAS pain score, and a log of compliance with each of the items in the pain relief kit (if in the treatment group). All patients completed the Short Form 36 Health Survey Questionnaire (SF-36) questionnaire in addition to DASH (Disabilities of the Arm Shoulder and Hand) scores for upper extremity procedures, or the LEFS (Lower Extremity Functional Scale) scores for lower extremity pro-
procedures at baseline or the first post-op physical therapy visit and at four weeks post-op.

**NON-OPIOID INTERVENTION - PAIN RELIEF KIT**

Each item in the pain relief kit was recommended to be utilized up to three times daily or every 6-8 hours. Joint specific exercises were initially performed against gravity and progressed to elastic resistance using yellow and then red TheraBands (TheraBand Akron, OH, USA).

BioFreeze Roll-On 4% menthol (BioFreeze Warrenville, IL, USA) was recommended to be applied during the morning hygiene routine or up to 3 times throughout the day in response to pain. Additionally, it was recommended to be applied five minutes prior to and following exercise or any other moderate intensity activity. Kinesiology tape was recommended to be applied to the affected area at 25% elongation and reapplied every three days or as needed when tape failed to adhere. Upper extremity patients were instructed to apply the tape across the trapezius in accordance with tightness or pain and lower extremity patients instructed to apply the tape along the quadriceps. Thermal Therapy [warm or cool was delivered using the TheraPearl (Bausch & Lomb Inc., New York, USA)], was recommended to be applied during the morning hygiene routine and as needed throughout the day in response to pain. Application of heat was recommended for 30 minutes prior to engaging in exercise and application of cold was recommended for 20 minutes following exercise.

**DAILY MEDICATION LOG**

Most patients were prescribed oxycodone/acetaminophen (5 mg/325 mg) to be taken every six hours as needed. Six patients were not prescribed oxycodone, instead four were prescribed hydrocodone/acetaminophen, and two Tramadol. Patients were asked to keep a daily log of prescription and non-prescription analgesics taken. Opioid use is reported in this research as Milligram Morphine Equivalent (MME) or the amount of morphine in milligrams equivalent to the strength of the opioid dose prescribed.

**DAILY PAIN LOG - VISUAL ANALOG SCALE (VAS)**

Perceived pain was recorded daily using a 10 cm VAS with anchor statements on the left (no pain) and on the right (extreme pain). The VAS is widely accepted as a reliable standard for self-reporting of pain post operatively for a wide range of surgical and orthopedic procedures in a clinical setting. The patient was asked to mark their average pain over the previous 24 hours on the line at the same time each day.

**OUTCOME SCORES**

**LOWER EXTREMITY FUNCTIONAL SCALE (LEFS)**

Lower extremity outcomes were evaluated using the LEFS. The LEFS is a self-report questionnaire that asks patients to answer the question “Today, do you or would you have any difficulty at all with:” in regard to twenty different everyday activities. The LEFS has shown sufficient reliability to administer and is applicable for research purposes and clinical decision making for individual patients.

**DISABILITIES OF THE ARM, SHOULDER AND HAND (DASH)**

Upper extremity outcomes were evaluated using the DASH. The DASH outcome measure is a 30-item, self-report questionnaire designed to assess the patient's health status. The DASH questionnaire is used as an indicator of the impact of an impairment on the level and type of disability. It assesses the whole person’s ability to function, even if the person is compensating with the other limb. Beaton et al. has shown strong validity, test-retest reliability, and responsiveness of the DASH questionnaire in both proximal and distal disorders of the upper extremity, confirming its usefulness for assessing disability in the upper extremity.

**SHORT FORM 36 HEALTH SURVEY QUESTIONNAIRE (SF-36)**

Patients’ global rating of health status and quality of life was assessed using the SF-36. The SF-36 is a self-reported questionnaire evaluating eight aspects of the patient’s perception of health: physical functioning, bodily pain, role limitations due to physical health problems, role limitations due to personal or emotional problems, emotional well-being, social functioning, energy/fatigue, and general health perceptions. The SF-36 has been widely validated and has been shown to have high reliability for measuring health perception in a general population.

**STATISTICAL ANALYSIS**

The effects of the pain relief kit on opioid use, over the counter pain medication, VAS pain scores, functional outcome scores, and SF-36 scores were assessed using mixed model analysis of variance with repeated measures for time (weeks 1-4) and treatment as a between-subjects factor (pain-relief kit versus control). Within the treatment group the relationship between use of the pain relief kit and opioid and non-opioid medication use was assessed using the Pearson correlation coefficient. Difference in opioid use between patients having arthroplasty versus other procedures was tested using an independent t test.

**RESULTS**

There were 28 patients in the pain-relief kit group (9 women, 19 men) and 25 in the control group (9 women, 16 men). Twelve patients had total joint arthroplasty (4 pain-relief kit, 8 control) and the remaining 41 patients (24 pain-relief kit, 17 control) had various procedures requiring bone drilling (23 ACL reconstructions, 12 shoulder arthroscopies, two other knee procedures, three elbow procedures and one ankle procedure). Procedures performed on the patients in the pain relief kit group included 15 ACL reconstructions, four arthroplasties, seven shoulder arthro-
Use of a Non-Pharmacological Pain Relief Kit to Reduce Opioid Use Following Orthopedic Surgery: A Prospective Randomized...
Figure 1. Opioid use in morphine equivalents for patients using pain-relief kit versus controls over the four weeks of the intervention (data for 38 patients who did not have total joint arthroplasty are shown). Time effect p<0.001, Treatment effect p=0.352, Treatment by Time p=0.653.

Figure 2. Visual analog scale pain scores for the pain-relief kit group and the control group over the four-week study period. Time effect p<0.001, Treatment effect p=0.205, Treatment by Time p=0.942.

could help reduce use of non-opioid pain medication where opioids are not being prescribed.

There is evidence to support the use of cryotherapy to reduce pain following orthopedic surgery. Ice or cold-water recirculation is a mainstay of outpatient care after knee arthroscopic surgery and can effectively reduce reported pain without increased risk of adverse events.
However, neither were shown to be effective after elective total knee arthroplasty.\textsuperscript{57,58}

Conversely, there is a paucity of evidence on the use of heat packs on pain control or opioid consumption following orthopedic procedures. Nevertheless, the participants in the treatment group of the present study utilized the heat pack at a greater rate per week compared with the topical analgesic (3.0±2.6 vs. 2.0±1.7 days per week). There still was no difference in the pain management whether they used heat or cold.

The elastic bands were the most frequently used tool in the pain kit (3.8±2.5 days/week). Elastic resistance exercises are very commonly integrated into the physical therapy routine following both arthroscopic and arthroplasty procedures. The study participants received exposure to this intervention during their physical therapy, and thus they felt most comfortable using it. Strength training exercises, implemented shortly following arthroplasty, have proven to be feasible without exacerbating postoperative symptoms such as pain,\textsuperscript{59} and the elastic bands are a user-friendly way for patients to perform their resistance exercises at home. However, the extent to which the use of elastic bands following orthopedic procedures might reduce opioid use has not been examined.

Ultimately, physical therapy itself has been shown to decrease inpatient opioid consumption following orthopedic surgery.\textsuperscript{16} As there was no difference in total opioid use between the treatment group and control group of the present study over the four week follow up period, it is possible that the patients simply benefitted from their physical therapy sessions and there was no added benefit of the pain kit. However, this analysis was beyond the scope of this study. Further, it seems that the timing of physical therapy following surgery matters most.\textsuperscript{16} In a recent review Brown-Taylor et al. concluded that although early physical therapy reduced subsequent opioid use there is limited and inconclusive evidence to establish whether the content and/or location of the physical therapy interventions improves outcomes because of heterogeneity between studies.\textsuperscript{60}

This study is not without limitations. The variability in opioid use between patients was much larger than expected and significantly limited the power to detect a difference between the treatment groups. For the patients who had procedures other than total joint arthroplasty the overall opioid use was much lower than expected. There were various levels of usage of the individual modalities within the kit across the patient population, with no one modality being preferred by all patients. It is possible that the outcome would have been more beneficial towards the pain kit had the researchers controlled for frequency of use of all modalities to make their use even across all participants. However, the approach taken in this study was intended to observe how patients choose to manage their own pain using recovery modalities.

Finally, the treatment group was significantly younger than the control group. Previous research\textsuperscript{60} suggests that younger patients (in the age range of 30-39 years) had a significantly higher reported mean opioid consumption for joint procedures compared with older patients (80-89 years), while the youngest adult patients (18-19 years) who received treatment for fracture fixation reported the highest mean consumption. Given the limitations of the present study, further research is necessary to investigate how other alternative pain-relieving modalities could be applied in clinical practice to reduce opioid use and possibly reduce use of non-opioid medications.

**CONCLUSION**

The results of this study indicate that there is no difference in post-operative opioid consumption in a group who utilized a multimodal pain kit as compared to the control group. This non-pharmacological pain relief kit did not significantly reduce opioid use in this patient population. In general, opioid consumption was very low over the four weeks following surgery and both groups displayed marked symptom relief over the four weeks of the study. While the public's awareness of the opioid epidemic will help further reduce opioid use over time, it is important to continue to search for alternative pain control methods for patients.

**CONFLICTS OF INTEREST**

All authors declare that they have no conflicts of interest.

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The Effects on Knee Swelling, Range of Motion and Pain using a Commercially Available Hot/Cold Contrast Device in a Rehabilitation and Sports Medicine Setting

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Keywords: Physical therapy, modalities, recovery, swelling

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Background and Purpose

Contrast therapy consists of alternating thermotherapy and cryotherapy repeatedly to assist in the management of acute, subacute, and chronic musculoskeletal conditions. This has been utilized for several decades with good to excellent subjective and objective results reported for patients with swelling (acute to chronic), pain, and loss of motion. Typically, the intervention is performed by either the use of a hot and cold whirlpool or by applying hot and cold packs which can be very time consuming and labor intensive. The purpose of this study was to determine the efficacy of a single treatment of the Hyperice X system in reducing knee joint pain, swelling and stiffness in active patients and young injured athletes. A secondary purpose was to measure patient satisfaction with the use of the device.

Subjects

Fifty subjects (34 males and 16 females) with a mean age of 22.2 +/- 4.9 yrs (ranging from 17 to 45 yrs of age) were recruited. Subjects presented with various types of knee pain, both non-operative and operative, secondary to ligamentous, tendinous, cartilage, muscle, and/or meniscus pathology. The subjects were in various stages of rehabilitation with six in the acute stage, 24 in subacute stage, and 20 in the chronic stage. The subjects participated in a variety of different sports at various levels of competition ranging from recreational to professional.

Methods

Subjects were recruited from one of two centers: an athletic training room or an outpatient sports medicine rehabilitation center. They were evaluated for baseline pain using the visual analog scale (VAS), verbal patient satisfaction on a scale of 1-10, verbal assessment of knee tightness, knee circumference, and knee flexion range of motion. The Hyperice X was applied to the knee utilizing the contrast setting for a total of 18 minutes with three six-minute cycles, each consisting of three minutes of heat therapy and three minutes of cold therapy. The contrast therapy was applied at the initiation of the physical therapy session and all subjective and objective measures were repeated immediately post contrast treatment.

Results

The VAS scores significantly improved following the treatment session with the mean score pretreatment of 2.59 and following the treatment of 1.68. Knee circumference improved for mid patella and 5 cm below mid patella, but no significant improvement was noted at the 5 cm above the patella region. Knee flexion improved from 130 degrees...
Contrast therapy consists of alternating thermotherapy and cryotherapy applied repeatedly during a treatment session to assist in the management of acute, subacute, and chronic musculoskeletal conditions. Most commonly, this treatment intervention is performed by either the use of a hot and cold whirlpool or by applying hot and cold packs. Contrast therapy has been utilized for several decades with good to excellent subjective and objective results reported.\(^1\)\(^–\)\(^8\) This therapeutic approach has been advocated for patients with swelling (acute to chronic), pain, and loss of motion. In addition, contrast therapy has been utilized effectively for recovery post exercise and sport participation.\(^1\)\(^–\)\(^8\)

Numerous studies have demonstrated excellent clinical effects with the performance of contrast therapy.\(^1\)\(^–\)\(^3\),\(^9\)\(^–\)\(^11\) Greenhalgh et al.\(^3\) reported in a meta-analysis and systematic review utilizing contrast therapy in the management of both soft tissue injury and post exercise recovery beneficial effects for subjective measures such as fatigue, muscle soreness, and enhanced effects related to optimal recovery. Another systematic review of 23 peer reviewed articles by Higgins et al.\(^1\)\(^2\) determined that contrast water therapy benefits recovery via effects on perceived fatigue following participation in team sports. Weerasekara et al.\(^8\) prospectively studied the effect of contrast therapy on grade I and II lateral ankle sprains. The investigators reported the use of contrast therapy as an effective treatment modality for reduction of pain, improving ROM, and reducing swelling during the transition from acute to chronic management.

Although numerous studies have demonstrated a positive effect of contrast therapy,\(^1\)\(^–\)\(^7\),\(^9\)\(^–\)\(^11\),\(^13\) in the authors opinion this intervention is under-utilized due to difficulty in application and the time required to set up the treatment for use. Contrast therapy utilizing warm and cold-water whirlpools or hot packs and ice packs repeatedly in various timed alternations during the treatment session is both equipment and labor intensive. The researchers postulated that if the application of contrast therapy was simplified, such as utilizing one device with the ability to regulate both heat and cold automatically, this treatment approach could be employed with greater ease. To this end, a new device has been developed called the HyperIce X (HyperIce Co. Newport Beach, CA) which allows the clinician to utilize a single device and one treatment sleeve able to produce heat up to 115 degrees and cold to 35 degrees in alternating cycles that can be easily controlled by the clinician.

The purpose of this study was to determine the efficacy of a single treatment with the Hyperice X system in reducing knee joint pain, swelling and stiffness in active patients and young injured athletes. A secondary purpose was to measure patient satisfaction with the use of the device.

## METHODS

### SUBJECT RECRUITMENT

Fifty subjects with a mean age of 22.2 +/- 4.9 yrs (ranging from 17 to 45 yrs of age) were recruited into the study. Subjects were recruited into one of two centers: a university athletic training room or an outpatient sports medicine rehabilitation center. Subjects presented with various types of knee pain, both non-operative and operative, secondary to ligamentous, tendinous, cartilage, muscle, and/or meniscus pathology. All subjects included in the study met the inclusion criteria.

Inclusion criteria for the investigation were either male or female athletes 18 years of age or older who were experiencing knee pain, swelling and/or stiffness. For the purposes of this study an athlete was defined as "a physically active individual who span the spectrum across age, race/ethnicity, illness or injury condition, and level of ability/disability," by the Sports Physical Therapy Description of Specialty Practice.\(^1\)\(^4\) The subjects were in various stages of the rehabilitation with six in the acute stage, 24 in subacute and 20 in the chronic stage. Exclusion criteria included: an immediate post-operative condition (within three weeks of injury), open wounds or incisions, inability in the judgement of the investigators to be able to complete the study and/or unwillingness to participate.

### OUTCOME MEASUREMENTS

Two specific subjective and two objective outcome measurements were utilized for the study. Subjective measures included pain reporting using a visual analog scale (VAS) and patient satisfaction. Patient satisfaction was evaluated by the researcher asking them how satisfied they were, with patients reporting verbally using a scale from 0 to 10 (with 0 being completely unsatisfied, and 10 completely satisfied). The objective outcomes included circumferential measurements taken at three anatomic landmarks, and active range of motion (ROM) of knee flexion and extension assessed using a standard goniometer.
STUDY DESIGN

The study was reviewed and approved by the Institutional Review Board and all subjects consented to participate in the study.

Once admitted to the study, subjects were evaluated for baseline pain using the VAS, as well as swelling, and stiffness. Swelling was measured using girth measurements for circumference (cm) taken around the knee at the level of mid-patella, 5cm above the border of the patella, and 5cm below the border of the patella. Stiffness was assessed via measurements of active knee flexion and extension range of motion in supine. The baseline measurements were taken by the same clinician at each of the two facilities to ensure reproducibility.

After baseline measurements were collected, the Hyperice X was applied to the knee utilizing the contrast setting, at the beginning of the therapy session. This ran for a total of 18 minutes with three six-minute cycles, each consisting of three minutes heat therapy and three minutes of cold therapy. Immediately post contrast treatment, all objective and subjective assessments were repeated. If a patient became uncomfortable during the 18 minutes that the Hyperice X was on the knee and requested that it be removed, the Hyperice X was removed, and the participant was withdrawn from the study. During this study no subjects prematurely terminated treatment.

STATISTICAL ANALYSIS

Descriptive statistics including mean, and range were calculated for all continuous variables. Pre- and post-session data were compared using the student t test. Significance was set at p<0.05.

RESULTS

The subjects participating in the study consisted of 34 males and 16 females. The mean BMI for males was 25.1 +/- 3.4 and for females 22.4 +/- 2.02. The sports and position played at time of injury are detailed in Table 1. The specific type of injury, stage of the rehabilitation, involved extremity, and whether the dominant or non-dominant side was involved are listed in Table 2.

The VAS scores significantly improved following the treatment session with the mean reported score pretreatment of 2.59 and following the treatment the score reduced to 1.68 (p<0.05). Knee circumference decreased for mid patella and 5 cm below mid patella(p<0.05) but no significant improvement was noted at the 5 cm above the patella region. Knee range of motion improved for both knee flexion and extension. Knee flexion improved from 130 degrees (+/- 18.91) pre-treatment to 134 degrees (+/- 18.08) post treatment. Knee extension improved from 2.72 degrees (+/- 3.37) of hyperextension to 3.44 degrees (+/- 3.50), (p<0.05). Lastly, subjects reported scored their satisfaction with the treatment device to be very high, with a score of 8.8 +/- 1.6 out of a maximum score of 10. Pre and post treatment data can be found in Table 3. During the study all subjects reported no discomfort, pain, or increase in symptoms during the treatment.

DISCUSSION

This is the first study to utilize a commercially available single physical agent unit that provides contrasting heat and cold treatment, managed through an application on a phone or other electronic device. The advantages of such a device include efficiency, portability of treatment, and flexibility often required in the sports medicine environment. The results of this study are significant in several areas.

Each subject wore the device for the entire time of the treatment protocol, with no early termination requested. Overall, the authors believe that contrast therapy, as investigated in this study, produces an alternating pumping action of vasodilation followed by vasoconstriction, thus resulting in a flushing mechanism of fluid from the area. This has been anecdotally reported by clinicians for years and is one of the primary purposes for the use of contrast treatments. The authors of this study believe this is especially beneficial in cases of chronic swelling and possibly subacute conditions. The authors believe in the acute condition, ice, compression, and elevation would be most beneficial.

The subject’s subjective outcome of the VAS scores significantly improved following a single application with the mean score difference of 0.81. The effect on VAS pain score demonstrates the influence on neural transmission that is consistent with both cryo and thermal modalities. Subjects reported a statically significant reduction in their knee pain with a mean difference of -0.91 (p<.001). While this difference is statistically significant, it may not be considered clinically significant dependent of the patient population and diagnoses. Minimum clinically important difference (MCID) is variable based on diagnosis, therefore because this study was performed using a variety of diagnoses the MCID is not established. Anecdotally, subjects often reported following the application of the contrast treatment that their knee “felt good or felt better” following the application of the contrast treatment. The authors were encouraged by this response from almost all subjects, as it has been stated that the number one reason patients seek musculoskeletal treatment is because of a pain and if contrast therapy can reduce a patient’s complaint of pain, their dysfunction may be easier to address.13

Following the application of the device, there were statistically significant improvements in circumferential measurements at the mid patella mark and 5 cm below that point, which represents the region of the joint capsule reflecting a joint effusion reduction. Circumferential measurements did not significantly improve at 5cm above the mid patella. This result would be expected based on the potential influence of any modality on joint swelling. In addition to vascular pumping, the improvement in circumferential measures could be due to a decrease in both interstitial and as well as intracapsular swelling in the knee joint, based on the patient’s case, following utilization of the device. The knee capsule may not extend to 5CM above the patella; therefore no effect is expected.

Statistically significant improvement in knee flexion was seen following the application of contrast treatment. Knee flexion improved with a mean difference of 4.36 degrees (p<.001). Again, this improvement may be due to a decrease in both interstitial and intracapsular swelling as noted.
Table 1. Sports and position for men and women in the study.

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<th>Gender</th>
<th>Sport</th>
<th>Position</th>
<th># Athletes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>Basketball</td>
<td>Center</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Guard</td>
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<tr>
<td></td>
<td>Soccer</td>
<td>Center Back</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Forward</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Goalkeeper</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Midfield</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Soccer College</td>
<td>Defender</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Track and Field</td>
<td>Jumper</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Volleyball</td>
<td>Middle</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Middle Blocker</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Outside</td>
<td>1</td>
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<tr>
<td></td>
<td>Women’s Lacrosse</td>
<td>Attack</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Midfield</td>
<td>1</td>
</tr>
<tr>
<td>Male</td>
<td>Ballet Professional</td>
<td>Dancer</td>
<td>1</td>
</tr>
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<td></td>
<td>Baseball</td>
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<td>Basketball</td>
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<td></td>
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<td>Guard</td>
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<td>Basketball Professional</td>
<td>Guard</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>College Student</td>
<td>Rec Soccer</td>
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<td>Football</td>
<td>Offensive Line</td>
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<td></td>
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<td>Punter</td>
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<td></td>
<td>RB</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TE</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WR</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Football Professional</td>
<td>Quarterback</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Golf</td>
<td>Golf</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Physician</td>
<td>Rec Soccer</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Real Estate</td>
<td>Rec Athlete</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rec Skier</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Teacher</td>
<td>Rec Athlete</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Tennis HS</td>
<td>Tennis</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Track and Field</td>
<td>Track</td>
<td>1</td>
</tr>
</tbody>
</table>

above. At the conclusion of each treatment, subjects were asked to subjectively report their perceived knee tightness. They reported less posterior knee tightness after the contrast treatment, which may suggest the reduction of knee swelling in the posterior compartment of the knee. Knee extension following the contrast treatment improved only slightly by 0.71 degrees (p<.001). This could be attributed to a decrease in joint swelling, the knee subjectively feeling better, patient comfort, or patient relaxation.

Finally, the subjects reported their satisfaction with the use of the during the treatment session. The overall satisfaction score following the session was 8.8 ± 1.6, with a range between 3-10. The most frequent scores given were either a 9 or 10, illustrating an overall high subject-reported satisfaction using the device.
Table 2. Injuries per gender and dominance side.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Injury</th>
<th>Side</th>
<th>Dominance</th>
<th># Athletes &amp; Stage of Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>ACL Tear</td>
<td>Left</td>
<td>Non-dominant</td>
<td>3 Chronic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right</td>
<td>Dominant</td>
<td>1 Chronic</td>
</tr>
<tr>
<td></td>
<td>ACL/MCL tear</td>
<td>Left</td>
<td>Non-dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td>ACL/PTG</td>
<td>Right</td>
<td>Dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td>ACLR</td>
<td>Left</td>
<td>Non-dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td>Acute Knee Pain</td>
<td>Left</td>
<td>Non-dominant</td>
<td>1 Acute</td>
</tr>
<tr>
<td></td>
<td>Chronic knee pain</td>
<td>Right</td>
<td>Dominant</td>
<td>1 Chronic</td>
</tr>
<tr>
<td></td>
<td>MPFL and lateral OCD</td>
<td>Right</td>
<td>Dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td>Patellar Tendinitis/tendinopathy</td>
<td>Left</td>
<td>Non-dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right</td>
<td>Dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td>Patellar tendon debridement</td>
<td>Left</td>
<td>Non-dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td>PCL Tear</td>
<td>Right</td>
<td>Dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td>Male</td>
<td>Achilles Repair</td>
<td>Right</td>
<td>Dominant</td>
<td>1 Chronic</td>
</tr>
<tr>
<td></td>
<td>ACL</td>
<td>Right</td>
<td>Dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td>ACL Recon</td>
<td>Left</td>
<td>Non-dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td>ACL Tear</td>
<td>Left</td>
<td>Non-dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td>ACL, B Meniscus, MCL, OCD</td>
<td>Right</td>
<td>Non-dominant</td>
<td>1 Chronic</td>
</tr>
<tr>
<td></td>
<td>ACL, Partial MCL, Partial Meniscus</td>
<td>Right</td>
<td>Dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td>ACL/PTG</td>
<td>Left</td>
<td>Non-dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right</td>
<td>Dominant</td>
<td>3 Chronic</td>
</tr>
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<td></td>
<td>ACL/QT</td>
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<td>Dominant</td>
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<tr>
<td></td>
<td>ACLR</td>
<td>Left</td>
<td>Non-dominant</td>
<td>1 Chronic</td>
</tr>
<tr>
<td></td>
<td>Acute Knee Pain</td>
<td>Left</td>
<td>Non-dominant</td>
<td>1 Acute</td>
</tr>
<tr>
<td></td>
<td>Chronic knee pain</td>
<td>Left</td>
<td>Non-dominant</td>
<td>2 Chronic</td>
</tr>
<tr>
<td></td>
<td>Knee Pain</td>
<td>Right</td>
<td>Dominant</td>
<td>1 Acute</td>
</tr>
<tr>
<td></td>
<td>MCL Repair</td>
<td>Left</td>
<td>Non-dominant</td>
<td>1 Subacute</td>
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<tr>
<td></td>
<td>MCL Sprain</td>
<td>Left</td>
<td>Non-dominant</td>
<td>1 Acute</td>
</tr>
<tr>
<td></td>
<td>MCL Sprain</td>
<td>Right</td>
<td>Dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td>Meniscus Post-op</td>
<td>Left</td>
<td>Dominant</td>
<td>2 Subacute</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right</td>
<td>Non-dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Non-dominant</td>
<td>1 Chronic</td>
</tr>
<tr>
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<td></td>
<td>Dominant</td>
<td>1 Chronic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Non-dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dominant</td>
<td>1 Chronic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Non-dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dominant</td>
<td>2 Chronic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Non-dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dominant</td>
<td>1 Chronic</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>Non-dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dominant</td>
<td>1 Chronic</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>Non-dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dominant</td>
<td>1 Chronic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Non-dominant</td>
<td>1 Subacute</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dominant</td>
<td>1 Subacute</td>
</tr>
</tbody>
</table>

Table 3. Pre and post treatment measurements.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre (Mean ± SD)</th>
<th>Post (Mean ± SD)</th>
<th>Mean Difference post-pre</th>
<th>CI (95%)</th>
<th>P-values</th>
<th>Effect size (Cohen for repeated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Analog Scale</td>
<td>2.59 ± 2.18</td>
<td>1.68 ± 1.74</td>
<td>-0.91</td>
<td>(-1.22, -0.60)</td>
<td>P&lt;.001</td>
<td>-0.87</td>
</tr>
<tr>
<td>Knee Extension AROM (degrees)</td>
<td>2.72 ± 3.37</td>
<td>3.44 ± 3.30</td>
<td>0.72</td>
<td>(0.33, 1.11)</td>
<td>P&lt;.001</td>
<td>0.61</td>
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<tr>
<td>Knee Flexion AROM (degrees)</td>
<td>130.04 ± 18.91</td>
<td>134.40 ± 18.08</td>
<td>4.36</td>
<td>(3.33, 5.39)</td>
<td>P&lt;.001</td>
<td>2.28</td>
</tr>
<tr>
<td>Knee Circumference (superior patella) (cm)</td>
<td>40.98 ± 4.02</td>
<td>40.81 ± 3.91</td>
<td>-0.17</td>
<td>(-0.43, 0.89)</td>
<td>P=0.19</td>
<td>-0.18</td>
</tr>
<tr>
<td>Knee Circumference (mid-patella) (cm)</td>
<td>38.57 ± 3.50</td>
<td>38.11 ± 3.28</td>
<td>-0.46</td>
<td>(-0.25, -0.68)</td>
<td>P&lt;.001</td>
<td>-0.53</td>
</tr>
<tr>
<td>Knee Circumference (inferior patella) (cm)</td>
<td>35.18 ± 3.08</td>
<td>34.71 ± 3.12</td>
<td>-0.47</td>
<td>(-0.69, -0.24)</td>
<td>P&lt;.001</td>
<td>-0.52</td>
</tr>
<tr>
<td>Patient Satisfaction Post Session</td>
<td>8.8 ± 1.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

G-power: n=34 (alpha=0.05; beta=0.20 / power = .8; effect size = 0.5)
AROM: Active range of motion; cm: centimeters

LIMITATIONS

The investigators of this study feel there were several limitations: First, there was no control group to compare the contrast treatment to. This would have enhanced the results and would have been an important comparison of treatment effects. Second, this study utilized an active population, either collegiate or recreational athletes rendering the results somewhat specific to active individuals. Furthermore, subjects were not separated into different stages of the rehabilitation – which could provide additional insights into effectiveness of contrast treatment over time. In addition, although the results were found to be significant there could exist a margin of measurement error regarding circumference measurements and goniometric measurement. Lastly, there were no follow up assessments performed to determine the lasting effects of the intervention. Further studies need to be performed to determine the effects on the general population and older patients, effects on various stages of recovery, and specific pathologies with the Hyperice X contrast device. In addition, studies to investigate the effects of longer treatment sessions, repeat treatment sessions, and effects over time are needed to enhance the clinical significance of the use of this device and others like it.

CONCLUSIONS

The results of this investigation indicate that a commercially available contrast therapy device was able to provide statistically significant improvement in several key treatment areas, including reductions in pain and swelling, and improvement in knee ROM after only a single treatment. These improvements in objective outcomes show promise for clinical applicability and may be important in the treatment of knee swelling in an athletic population. In addition, the subjects included in this study expressed a high degree of overall satisfaction with the treatment. The researchers also found the device easy to use and clinically practical.

COI

Kevin Wilk is on Medical Advisory Board for Hyperice, no other investigators/authors disclose a potential conflict of interest.

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REFERENCES


Case Reports

Resident Case Series: Blood Flow Restriction as an Adjunct to Strengthening Exercises in Two Patients with Subacromial Impingement and High Irritability

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Keywords: blood flow restriction, hypoanalgesia, pain, subacromial pain, upper extremity

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Introduction
Evidence informed management of individuals presenting with subacromial impingement syndrome (SAIS) includes strengthening exercises directed at the shoulder musculature. Patients with subacromial impingement syndrome (SAIS) can present with pain during and after completion of heavy resistance training limiting the applicability of this recommended treatment approach. Blood flow restriction (BFR) training is indicated for patients who have pain while completing heavy resistance training and may represent an important treatment modification for patients with SAIS unable to fully participate in a strengthening exercise program. The purpose of this case series is to describe the inclusion of BFR in the treatment of two patients with SAIS.

Case descriptions
Two middle aged, non-operative patients with signs and symptoms consistent with SAIS and high levels of irritability were included. Treatment over one month consisted of three commonly used exercises in the treatment of SAIS in conjunction with a standard BFR protocol: 75 reps broken up into sets of 30,15,15,15 with the BFR cuff placed over proximal humerus.

Outcomes
Immediate within session improvements beyond measurement error were observed in resting pain and pain pressure thresholds at three sites. At the end of the course of treatment, clinically meaningful improvements were observed in patient reported outcomes including the PENN Score, ASES score, and the patient-specific functional scale. Clinically meaningful improvements and change beyond measurement error were also observed in range of motion and strength which (assessed via a handheld dynamometer).

Discussion
The incorporation of low load resistance training with BFR may be a useful adjunct for treating patients with SAIS to promote exercise-induced hypoalgesia, decrease pain, and increase function in the upper extremity.
Resident Case Series: Blood Flow Restriction as an Adjunct to Strengthening Exercises in Two Patients with Subacromial...

Level of Evidence

5

BACKGROUND

Shoulder pain is a prevalent musculoskeletal complaint that is often associated with reduced shoulder function, difficulty sleeping, and difficulty completing activities of daily living.1,2 Subacromial impingement Syndrome (SAIS) is the most common cause of shoulder pain accounting for 45-65% of all reported shoulder pain.3 The prevalence of SAIS is higher in the overhead athlete population, the military, and in occupations where an overhead position must be maintained.1,2 In Denmark, one study found that on average 27 work days were lost due to SAIS during the first six months from the time of initial onset of diagnoses. This was three times higher than any other shoulder diagnosis and presents a concern for work time lost due to SAIS.4

There is debate over best practice when it comes to the treatment of individuals presenting with SAIS.5,5 Currently, experts agree that non-surgical management is the recommended treatment approach for individuals experiencing SAIS.2,5,6,7 According to clinical practice guidelines, best practice interventions include exercise, manual therapy, psychosocial interventions, heat or cold applications, acupuncture, and transcutaneous electrical nerve stimulation.8–10 However, despite these recommendations, more than 50% of all patients with diagnosis of SAIS have pain that persists for greater than three years.11 The current literature indicates that current best practice is insufficient for more than half of all patients seeking treatment for SAIS, and therefore this population requires modifications or novel approaches to treatment guidelines.

Blood flow restriction (BFR) is a training method used during exercise where an external pressure system or cuff is applied to an extremity with the intent of partially restricting the arterial blood flow and fully restricting venous blood flow.12–14 Historically, heavy exercise loads of approximately 70% of an individual’s one repetition maximum (IRM) have been deemed necessary to elicit muscle hypertrophy and strength gains.12,13,15 However, with BFR similar gains in strength and hypertrophy with lower loads can be achieved.12,13 Research in BFR has predominantly focused on the benefits it has towards strength and its ability to limit atrophy. Much of this literature has focused on the lower extremity, however a shift has been noted in newer studies showing similar benefits in the upper extremity.16 Results of recent studies examining BFR in the lower extremity indicate that not only does BFR assist with increasing strength, but also has a pain-relieving effect post-BFR.17 Consequently, BFR may represent a novel modification to the rehabilitation process of individuals presenting with SAIS with the potential to improve upon current outcomes by allowing muscle strengthening below the pain threshold. The purpose of this case series is to describe the inclusion of BFR in the treatment of two patients with SAIS.

CASE DESCRIPTIONS

Two patients, referred to physical therapy by primary care sports physicians secondary to gradual onset of shoulder pain prior were included in this case series. Both patients reported a decrease in daily function, increase in shoulder pain, and altered satisfaction with quality of life during the subjective portion of their evaluation and through patient reported outcomes.

Both patients denied significant past medical history including prior history of shoulder pain, shoulder surgery, or neck pain. Patients denied systemic pathologies such as diabetes, hypertension, or peripheral neuropathy.

Patient A was a 51-year-old right hand dominant female who reported an insidious onset of left shoulder pain four weeks prior to the initiation of physical therapy. During the initial examination, she reported 8/10 with activity located over the posterior lateral aspect of her shoulder without radiating symptoms, that would require her to rest for 1-2 minutes for her pain level to drop to 5/10, followed by another 2-3 min before her baseline pain dropped to 1-2/10. Patient reported her pain never dropped below a 1 or 2 out of 10 and her pain was worse with reaching overhead, sleeping on shoulder, and reaching behind her back during dressing activities. Pain decreased minimally with rest and ice. Patient A’s goal for physical therapy was to improve her ability to perform dressing activities behind her back, and to increase her ability to perform reaching and lifting activities.

Patient B was a 46-year-old right hand dominant male, who reported an insidious onset of right shoulder pain three weeks before the initiation of physical therapy. During the initial examination, he reported sharp pain of 3/10 at rest, and 6/10 with activity, which was located over the anterior lateral aspect of his shoulder without radiating symptoms. Pain was worse with lifting >50 pounds to shoulder height and >10 pounds overhead, with reaching behind his back to put on a belt. Patient also reported an increase in pain with weightlifting and tennis activities that he normally completed 4x a week. At initial evaluation he reported having to modify workouts by eliminating overhead pressing, decreasing the number of workouts per week, and decreasing tennis frequency. Pain decreased with rest, modification of lifting activities, and ice. Patient B’s goal was to decrease pain associated with lifting, carrying, and reaching activities, and to return fully to his workout and tennis routine.

OUTCOME MEASURES

Participants were evaluated at initial evaluation and discharge from physical therapy.

PATIENT-REPORTED OUTCOMES

To assess pain, function, and satisfaction with current function, the Pennsylvania Shoulder Score (PENN) was used, which is a validated tool for patients with shoulder pain.
The PENN includes a 3-item pain subscale, a 1-item satisfaction subscale, and a 20-item function subscale. Scores in each subscale were added resulting in a total score from 0 to 100 with higher scores reflecting less pain and greater function and satisfaction with function. The PENN has a minimal clinically important difference (MCID) of 11.4 points. The American Shoulder and Elbow Surgeon Shoulder Assessment Form (ASES) was used to assess patient’s upper extremity function, activities of daily living, and pain. The ASES contains a single 11-point numeric rating scale anchored with 0= no pain at all to 10= pain as bad as it can be to assess pain and a 10-item functional scale with activities scored from 0 unable to do to 3 = not difficult. The pain and function subscales are each weighted at 50 points and combined resulting in a total ASES score of 0 to 100 with lower scores indicating higher levels of pain and disability. This outcome measure has been shown to be reliable, valid, and responsive in upper extremity injuries with an MCID of 6.4 points.

The Single Alpha-numeric Evaluation (SANE) was used to evaluate patients’ current functional level compared to pre-injury function on a 0-100 scale with 100 reflecting normal function. The SANE has an established MCID of 28.8.

Function was further assessed using the Patient Specific Functional Scale (PSFS). Patients were asked to identify three important activities currently limited by their shoulder pain and score each from 0= unable to perform the activity to 10= able to perform the activity at their preinjury level. The PSFS is valid, reliable, and responsive for upper extremity injuries and has an MCID across three activities of 1.2 points.

PRESSURE PAIN THRESHOLD

Pressure pain threshold was assessed as a measure of local (at the shoulder) and remote (distant site) pain sensitization. Immediate changes in pain levels with functional activity have been observed in studies that assessed the effects of BFR on anterior knee pain suggesting a hypoalgesic effect. Therefore, pressure pain threshold (PPT) was assessed prior to and immediately following combined exercise and BFR at each session to assess local and remote changes in pain sensitization within session and between sessions to determine if similar results could be achieved in the upper extremity. This was done using a handheld digital pressure algometer (Wagner Instruments FPX 25, Greenwich, CT) with a 1 cm diameter rubber tip applied at 1 kgf/cm² to ipsilateral supraspinatus, ipsilateral thenar eminence, and contralateral dorsal web space between toes 1 and 2. These locations were selected to assess effects of BFR on pain sensitivity locally (ipsilateral supraspinatus) and remotely (ipsilateral thenar eminence and contralateral web space between toes 1 and 2). The minimal detectable change (MDC) for PPT in patients with SAIS is 1.16 kgf/cm².

IMPAIRMENT-BASED OUTCOMES

Maximal voluntary isometric strength was measured using a handheld dynamometer for external rotation, horizontal abduction, and scaption for BFR intervention. Internal rotation and abduction were also measured for between session comparison. The MDC for external rotation in asymptomatic patients is 6.44 lbs, and 8.77 lbs for internal rotation.

Active range of motion was also measured in flexion, external rotation, internal rotation, and abduction. The MDC in asymptomatic patients for flexion is 8 degrees, while abduction is 4 degrees. External and internal rotation was measured in functional patterns with patients reaching behind the back, however no MDC has been established for these movements.

EXAMINATION

Before determining the shoulder as the primary cause of symptoms, the patients were screened for cervical pathology, bony pathology via radiographs, and systemic pathology as the cause of their shoulder pain. Both patients denied a history of cancer, unexplained weight loss, fever associated with symptoms, night sweats, and non-mechanical night pain. Both patients presented with full, pain free cervical range of motion, intact light touch sensation in dermatomal patterns, and weakness that did not follow myotome patterns suggesting the symptoms were not arising from the neck.

SUBJECT A

Active range of motion (AROM) was limited to 120 degrees of flexion with 6/10 pain, 100 degrees of abduction 7/10 pain, inability to place hand behind her back higher than the posterior superior iliac spine with 9/10 pain and could reach behind her head to the level of the spinous process of the first cervical vertebrae with 5/10 pain. Passive range of motion was limited to 165 degrees of flexion with muscle guarding and 2/10 pain, 150 degrees of abduction with muscle guarding and 4/10 pain, 76 deg off external rotation at 90 deg of abduction with 1/10 pain, and 40 deg of internal rotation with 4/10 pain. She presented with pain and weakness during strength testing using a hand held dynamometer in scaption with 4/10 pain, abduction with 6/10 pain, and external rotation with 6/10 pain, and required 50-60 second rest breaks between handheld dynamometer to allow for patients pain levels to return to baseline levels of 1-2/10 at rest. Subject A also had positive findings on the Neers impingement test, Hawkins-Kennedy, Empty can...
Subject B presented with symmetrical shoulder AROM, however reported pinching at end range abduction and external rotation which was <2/10 pain for both, while also presenting with painful arc sign with flexion. Subject B presented with decreased shoulder strength via handheld dynamometer for scaption, external rotation, internal rotation, and abduction secondary to reports of pain. Subject B also had positive findings on the Neers impingement test, Hawkins-Kennedy, empty can test, painful arc, and external rotation resistance test. Table 1 summarizes these findings.

### Table 1. Initial examination findings

<table>
<thead>
<tr>
<th></th>
<th>Subject A</th>
<th>Subject B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AROM (deg) involved/uninvolved</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>120/160</td>
<td>160/160</td>
</tr>
<tr>
<td>Abduction</td>
<td>100/155</td>
<td>160/160</td>
</tr>
<tr>
<td>Internal rotation</td>
<td>PSIS/L4</td>
<td>C7/T3</td>
</tr>
<tr>
<td>External rotation</td>
<td>C1/C7</td>
<td>T7/T10</td>
</tr>
<tr>
<td>Strength (lbs) R/L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scaption*</td>
<td>5.6/14.1</td>
<td>12.1/12.2</td>
</tr>
<tr>
<td>Horizontal Abduction**</td>
<td>14.1/18.0</td>
<td>12.4/12.1</td>
</tr>
<tr>
<td>External rotation ***</td>
<td>9.0/15.0</td>
<td>15.0/13.4</td>
</tr>
<tr>
<td>Internal rotation ***</td>
<td>11.4/17.0</td>
<td>11.0/13.0</td>
</tr>
<tr>
<td>Abduction *</td>
<td>9.0/15.6</td>
<td>11.2/10.0</td>
</tr>
<tr>
<td><strong>Pain with ROM</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scaption</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Abduction</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Internal rotation</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>External rotation</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td><strong>Michener 5 special tests</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neers</td>
<td>Positive</td>
<td>Positive</td>
</tr>
<tr>
<td>Hawkins Kennedy</td>
<td>Positive</td>
<td>Positive</td>
</tr>
<tr>
<td>Painful arc</td>
<td>Positive</td>
<td>Positive</td>
</tr>
<tr>
<td>Empty can</td>
<td>Positive</td>
<td>Positive</td>
</tr>
<tr>
<td>ER resistance test</td>
<td>Positive</td>
<td>Positive</td>
</tr>
</tbody>
</table>

Key: C= cervical spinous process; L= Lumbar spinous process; PSFS= Patient Specific Functional Scale; PSIS= Posterior superior iliac spine; SANE= The Single Alpha-numeric Evaluation; T= Thoracic spinous process

* measured with HHD in standing; ** measured with HHD in prone; *** measured with HHD in seated

test, Painful arc sign, and External rotation resistance test. Table 1 summarizes these findings.

### CLINICAL IMPRESSION

SAIS was suspected as the underlying cause of both subjects’ complaints based on the subjective findings of insidious onset of pain along with pain with overhead activities. Labral injury, rotator cuff tears, and frozen shoulder were considered less likely as neither subject reported associated trauma or significant loss of ROM. SAIS was further confirmed as their primary medical diagnosis based on a cluster of tests that assist with identifying diagnosis of SAIS. These tests include Neers impingement test, Hawkins-Kennedy, empty can test, painful arc, and external rotation resistance test with three or more positive tests helpful in ruling in SAIS with a specificity of 0.75 and positive likelihood ratio of 2.93.

Both subjects clinical presentation included impairments commonly seen in patients with SAIS which include shoulder weakness, and pain that limits AROM. Subject A presented with high irritability as her clinical presentation included high levels of pain (>7/10 pain), high levels of resting pain, night pain, pain occurring prior to end ranges of motion, and a significant decrease in function as measured by patient reported outcomes. Subject B presented with moderate irritability as his clinical presentation included moderate levels of pain(3–6/10 pain), intermittent resting pain, pain at end range of AROM, and moderate decrease in function as measured by patient reported outcomes.

Due to the clinical presentations of decreased strength, and maximal to moderate irritability, the modality of BFR with exercise was considered as the first line of treatment during exercise interventions for three reasons: 1) the clinical practice guidelines for treatment of patients presenting with SAIS recommend strength training at >60% of 1 RM which was not considered attainable due to high irritability with resisted movements. 2) BFR literature in the upper extremity shows improvements in strength for proximal shoulder muscles with <20% of 1 RM. 3) BFR literature in the lower extremity shows a decrease in resting pain post BFR. Therefore, as BFR could allow for a strengthening effect at a lower dosage of exercise as well as the potential for pain modification, it was included in the plan of care as the first line of treatment.

### INTERVENTION

Subject A was seen for three visits over three weeks and completed one follow up via phone call, while Subject B completed four visits over four weeks. Both subjects were educated on and agreed to the use of BFR at initial evaluation and best practice guidelines were used when applying BFR.

The Delfi Personalized Tourniquet system (Delfi Medical, Vancouver, Canada) was used, with cuff placed around proximal humerus (Figure 2) during three common therapeutic exercises in standard of care of patients presenting with SAIS: side lying external rotation, prone horizontal abduction, and standing scaption. Figure 3 demonstrates start and end positions for all three exercises. Prior to BFR, both subjects completed six minutes of warm up on the upper body ergometer. After completion of warm up, the physical
therapist measured maximal isometric strength in scaption, external rotation at side, and prone horizontal abduction with a handheld dynamometer to determine 20% of their peak isometric strength.\textsuperscript{12,13} For consistency, strength testing was completed in the same order each time as follows: side lying external rotation, prone horizontal abduction, and scaption. The physical therapist repeated the maximal isometric testing at the beginning of each treatment session to progress loads appropriately during each exercise. Immediately after, the subject’s limb occlusion pressure was taken in supine to achieve a personalized Personal Tourniquet Pressure which was set to 50% of limb occlusion pressure per BFR standards. Each exercise was completed for a total of four sets, with one set of 30 repetitions, and three sets of 15 repetitions. After each set, subjects were given 30 second of rest with the cuff inflated. After completion of each exercise, subjects were given one minute of rest time, with the cuff deflated per standard practice.\textsuperscript{12,13} Both subjects were given a home exercise program to be completed on days that they did not come in to PT which included three sets of 12 of side lying external rotation, prone horizontal abduction, and scaption with the weight used during that session’s BFR treatment. These sets and reps were selected in order to achieve the high volume required to induce muscle hypertrophy and compliment the use of BFR. No other interventions were provided during home exercise sessions.

OUTCOMES

Clinically meaningful improvements and changes beyond measurement error were observed in all patient reported outcomes, pain sensitization locally and remotely, and rest-

PATIENT-REPORTED OUTCOMES

A variety of patient reported outcome measures were used to track changes in variables including pain, function, satisfaction, and ADL’s. These outcome measures included the PENN, ASES, SANE, and PSFS (\textsuperscript{Table 2}). Both subjects met all MCID’s for each patient reported outcome measure, and per subject report met goals. Subject A had a change of 46, 13, 30, and 3/6/7 respectively on the patient reported outcome measures. Subject B had similar outcomes with a change of 36, 22, 15, 3/2/5 respectively on the patient reported outcome measures. Subject A reported having no pain or limitation with dressing and grooming activities or work-related activities. While subject B reported returning fully to his weightlifting regimen without pain or limitations. He also reported returning to tennis without limitations due to pain.
PRESSURE PAIN THRESHOLD

Pressure pain threshold was assessed locally (at the shoulder) in two locations, and remotely (dorsal web space of contra lateral foot) as a measure of the effects of BFR on pain sensitization proximal and distal to the cuff. Both subjects demonstrated within session changes, after deflation of the cuff at the end of the third exercise (Table 2). Subject A demonstrated large changes in PPT that exceeded the MDC of 1.16 kgf/cm² every session, but not at every location as noted by not meeting MDC for local sites in Visit 2. Her largest change was Visit 3, over the ipsilateral supraspinatus of her affected UE, with a PPT of 2.09 kgf/cm². Conversely, Subject B had small changes within session to PPT, and only exceeded MDC twice, 1.54 kgf/cm² on Visit 2 to the remote site, and 2.16 kgf/cm² on Visit 4 to the ipsilateral supraspinatus of his affected UE.

However, between session changes for both subjects surpassed the MDC of 1.16 kgf/cm² with an average change of 4.06 kgf/cm² for Subject A, and 2.54 kgf/cm² for subject B (Table 2).

IMPAIRMENT-BASED OUTCOMES

Maximal voluntary isometric strength was measured using a handheld dynamometer for external rotation, horizontal abduction, and scaption for BFR intervention, while internal rotation and abduction were measured for between session comparison. While both subjects demonstrated improvements in external and internal rotation strength compared to baseline, subject B was the only one to meet and exceed MDC for external rotation (6.44 lbs) and internal rotation (8.77 lbs) with a change of 9.3 lbs, and 8.8 lbs (Table 2). There were no established MDC values for scaption, horizontal abduction, and abstraction, however both subjects demonstrated improvements in strength for all directions.

Active range of motion was also measured in flexion, external rotation, internal rotation, and abduction. Subject A met and exceeded MDC for AROM flexion (8 degrees), and abduction (4 degrees), with an improvement of 30 and 60 degrees respectively. Subject B had no limitations in flexion or abduction at initial evaluation, however, was able to report a decrease in pain at end range AROM.

Table 2 includes a summary of between session changes for patient reported outcomes, PPT, strength via HHD, and AROM. Table 3 includes a summary of within session changes to PPT.

DISCUSSION

This case series describes improvements beyond measurement error and clinically important changes in multiple outcome domains which were associated with the inclusion of BFR in the management of two subjects with a working diagnosis of SAIS. This included improvements in patient-reported outcomes, pressure pain thresholds, and impairment-based outcomes such as strength. Importantly, the rationale for including BFR included: its effects on pain, and its ability to assist subjects who are load compromised and judged to have difficulty following SAIS standards of care due to pain and high levels of irritability.

The clinical practice guidelines for treatment of patients presenting with SAIS recommends strength training at >60% of 1 RM which was not considered attainable due to high irritability with resisted movements in these two subjects. Subsequently, BFR was incorporated as BFR is associated with improvements in strength at a much lower dosage (i.e., < 30% of the one repetition maximum). Improvements beyond measurement error were found in shoulder strength for both subjects. Specifically, scaption strength improved by 87% and horizontal abduction strength improved by 59% for Subject A, while baseline ER and IR strength did not change significantly from baseline. Subject B, however, demonstrated improvements in external rotation and internal rotation strength by 69% and 67% respectively. Specific to the upper extremity, the results of a prior study of healthy participants demonstrated up to 30% improvement in strength in the shoulder musculature following a six-week program of upper extremity strengthening exercises combined with BFR at 30% of their one repetition maximum. These results of greater gains in strength observed in the two subjects could be due to lower baseline levels as reflected in their clinical status and/or the influence pain may have had on force production which would have influenced the initial strength findings.

The decision to include BFR in the treatment of these subjects was further driven by the perception of high irritability and concern for their ability to tolerate the strength training parameters set by standard of care in this population, which exceeds 60-70% of 1RM. Prior authors have observed hypoalgesia accompanying BFR applied during lower extremity exercise leading to the suggestion of BFR as a treatment modification for patients in whom pain limits exercise tolerance. For example, in a study of healthy participants, greater hypoalgesia (assessed with PPT) lasting 24 hours was observed in response to a unilateral leg press performed with BFR than when the exercise was performed without BFR. Furthermore, this effect was observed in the exercised lower extremity as well as in remote sites. Similarly, these subjects presented with increased PPT (i.e., decreased pain sensitivity) beyond measurement error at both local and remote sites associated with the inclusion of BFR in a typical strengthening program for a patient with SAIS. These findings add to this body of literature by describing a local and remote hypoalgesic effect in response to upper extremity exercise in two patients presenting with SAIS. Additionally, two studies of participants with anterior knee pain found lessening of clinical pain intensity following the application of BFR during exercise. Similarly, these findings demonstrate improvements in clinical pain associated with the inclusion of BFR to an exercise program for two subjects presenting with SAIS.

In addition to changes in strength beyond measurement error and clinically meaningful improvements in pain, the two subjects also demonstrated clinically meaningful improvements in function. According to clinical practice guidelines, even the application of best practice leads to >50% of all patients to continue to have significant loss of function due to symptoms more than three years after treatment. Additionally, in this population satisfac-
Table 2. Between Session Changes

<table>
<thead>
<tr>
<th>Patient-reported outcomes</th>
<th>Patient A Eval</th>
<th>Patient A DC</th>
<th>Change</th>
<th>Patient B Eval</th>
<th>Patient B DC</th>
<th>Change</th>
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<tbody>
<tr>
<td>Penn shoulder score</td>
<td>34/100</td>
<td>80/100</td>
<td>46*</td>
<td>53/100</td>
<td>89/100</td>
<td>36*</td>
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<tr>
<td>ASES</td>
<td>65/100</td>
<td>78/100</td>
<td>13*</td>
<td>71/100</td>
<td>93/100</td>
<td>22*</td>
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<tr>
<td>SANE</td>
<td>65%</td>
<td>95%</td>
<td>30*</td>
<td>70%</td>
<td>85%</td>
<td>15</td>
</tr>
<tr>
<td>PSFS-1</td>
<td>Reaching: 6</td>
<td>Reaching: 9</td>
<td>3*</td>
<td>Tennis: 6</td>
<td>Tennis: 9</td>
<td>3*</td>
</tr>
<tr>
<td>PSFS-2</td>
<td>Dressing: 2</td>
<td>Dressing: 8</td>
<td>6*</td>
<td>Weight training (press): 6</td>
<td>Weight training (press): 8</td>
<td>2*</td>
</tr>
<tr>
<td>PSFS-3</td>
<td>Lifting: 2</td>
<td>Lifting: 9</td>
<td>7*</td>
<td>Pull ups: 3</td>
<td>Pull ups: 8</td>
<td>5*</td>
</tr>
<tr>
<td>Pressure Pain Threshold (kgf/cm2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Ipsilateral supraspinatus</td>
<td>3.88</td>
<td>7.29</td>
<td>3.41*</td>
<td>4.01</td>
<td>6.32</td>
<td>2.31*</td>
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<tr>
<td>Ipsilateral thenar eminence</td>
<td>3.5</td>
<td>7.74</td>
<td>4.24*</td>
<td>4.6</td>
<td>6.74</td>
<td>2.14*</td>
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<tr>
<td>Contralateral foot</td>
<td>3.87</td>
<td>8.4</td>
<td>4.53*</td>
<td>3.71</td>
<td>6.89</td>
<td>3.18*</td>
</tr>
<tr>
<td>Isometric strength (lbs)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Scaption</td>
<td>5.6</td>
<td>10.5</td>
<td>4.9</td>
<td>12.2</td>
<td>18.8</td>
<td>6.6</td>
</tr>
<tr>
<td>Horizontal abduction</td>
<td>14.1</td>
<td>19.6</td>
<td>5.5</td>
<td>12.1</td>
<td>18.1</td>
<td>6</td>
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<tr>
<td>External rotation</td>
<td>9</td>
<td>10.5</td>
<td>1.5</td>
<td>13.4</td>
<td>22.7</td>
<td>9.3*</td>
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<tr>
<td>Internal rotation</td>
<td>11.4</td>
<td>13.5</td>
<td>2.1</td>
<td>13.0</td>
<td>21.8</td>
<td>8.8*</td>
</tr>
<tr>
<td>Abduction</td>
<td>9</td>
<td>11</td>
<td>2</td>
<td>10.0</td>
<td>16.1</td>
<td>6.1</td>
</tr>
<tr>
<td>Active range of motion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>120 deg</td>
<td>150 deg</td>
<td>30*</td>
<td>160</td>
<td>160</td>
<td>0</td>
</tr>
<tr>
<td>External rotation</td>
<td>C1</td>
<td>C5</td>
<td>-</td>
<td>C7</td>
<td>T1</td>
<td>-</td>
</tr>
<tr>
<td>Internal rotation</td>
<td>PSIS</td>
<td>L4</td>
<td>-</td>
<td>T7</td>
<td>T7</td>
<td>-</td>
</tr>
<tr>
<td>Abduction</td>
<td>100 deg</td>
<td>160 deg</td>
<td>60*</td>
<td>160</td>
<td>160</td>
<td>0</td>
</tr>
</tbody>
</table>

ASES= The American Shoulder and Elbow Surgeon shoulder assessment form; C= cervical spinous process; DC= Discharge; L= Lumbar spinous process; PSFS= Patient Specific Functional Scale; PSIS= Posterior superior iliac spine; SANE= The Single Alpha-numeric Evaluation; T= Thoracic spinous process

*= met or exceeded minimal detectable change or minimal clinically important difference

Table 3. Within session changes to Pressure Pain Threshold (kgf/cm2)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ipsilateral supraspinatus</td>
<td>1.92*</td>
<td>0.26</td>
<td>2.09*</td>
<td>0.42</td>
<td>0.65</td>
<td>0.53</td>
<td>2.16*</td>
</tr>
<tr>
<td>Ipsilateral thenar eminence</td>
<td>1.85*</td>
<td>0.76</td>
<td>1.71*</td>
<td>0.74</td>
<td>0.23</td>
<td>0.32</td>
<td>0.91</td>
</tr>
<tr>
<td>Contralateral foot</td>
<td>1.68*</td>
<td>2.9*</td>
<td>1.4*</td>
<td>0.11</td>
<td>1.54*</td>
<td>1.06</td>
<td>0.91</td>
</tr>
</tbody>
</table>

Key: *= met or exceeded minimal detectable change

The majority results are only achieved in 60% of cases at two-year follow up. Furthermore, one study demonstrated functional improvement through the increase in Penn shoulder scores in patients with SAIS. They found improvements from a score of 59 to 81 at two-year follow up. While the time frame in these cases were shorter than the aforementioned study, both subjects demonstrated similar improvements in Penn shoulder scores, and met MCID with the use of BFR.
Limitations of this case series include the inclusion of only two subjects, as is typical of a case series, a short duration of care and follow up, and findings that may not translate to other patients presenting with SAIS. The case series design does not allow determination of cause and effect. Nonetheless, this case series is helpful in describing the clinical decision-making process and application of two patients with SAIS in whom treatment modification was considered necessary due to their high levels of irritability during the initial presentation.

CONCLUSION

Incorporating low load resistance training with BFR was demonstrated to be a useful adjunct for treating two patients with SAIS as it promoted exercise-induced hypoalgesia, a decrease in resting pain, and increase function in the upper extremity as noted by improvements subjectively and through patient reported outcomes. This case series describes clinically meaningful results when incorporating low load resistance training with BFR in patients with SAIS presenting with high levels of baseline irritability suggesting the need for consideration of modifications of recommended best practice for such patients. BFR was selected as the treatment modification as it has been associated with hypoalgesia and results in strength gains at lower intensities. BFR warrants further clinical consideration as an alternative intervention in patients who are unable to participate in standard of care secondary to pain and high levels of irritability.

SUBJECT CONSENT

Subjects were informed prior to treatment that data concerning the case would be submitted for publication.

RESIDENT’S CASE REPORT

Case report was completed during University of Florida Health Sports Residency approved by the American Board of Physical Therapy Specialties (ABPTS)

COI

The authors have no conflict of interest to disclose.

Submitted: December 27, 2021 CDT, Accepted: April 09, 2022 CDT

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Introduction
Avulsion fracture of the ischial tuberosity is uncommon. Patients typically present with symptoms consistent with hamstring strain. The purpose of this case report is to describe an avulsion fracture of the ischial tuberosity and subsequent recovery in an athlete with an endocrine disorder.

Case Description
A 15-year-old United States of America Gymnastics level 9 gymnast presented with right hamstring pain after regular practice. She had been diagnosed with isolated growth hormone deficiency at age 4 and was treated with growth hormone replacement therapy until age 14. Six months before presentation, she experienced the insidious onset of dull, aching pain in her right hamstring, near the junction of the thigh and buttocks, that was believed to be the result of a chronic hamstring strain. The pain increased gradually over a year and was relieved with rest, massage, and dry needling. Two days before presentation, she felt a “snap” and pain while performing a switch leap during regular practice. She had sharp localized pain in the proximal hamstring with walking and sitting. She was diagnosed with a minimally displaced avulsion fracture of the ischial tuberosity.

Outcome
With nonoperative treatment, the fracture healed at three months, which is longer than the expected six weeks. Although return to sports is expected three months after this injury, it did not occur until six months in this patient. She was unable to participate in competitive level 9 gymnastics until 12 months after injury.

Discussion
This case highlights that delayed recovery can occur after avulsion fracture of the ischial tuberosity in adolescent athletes with a history of growth hormone deficiency and treatment using growth hormone.

Level of Evidence
5
sion fracture of the ischial tuberosity in an athlete with an endocrine disorder has not been reported. The authors present the case of an adolescent gymnast with a history of growth hormone deficiency (GHD) who sustained an avulsion fracture of the ischial tuberosity. The purpose of this case report is to describe an avulsion fracture of the ischial tuberosity and subsequent recovery in an athlete with an endocrine disorder.

CASE DESCRIPTION

The subject of this case report and her parents were informed that the data concerning the case would be submitted for publication and provided consent. A 15-year-old United States of America Gymnastics (USAG) level 9 gymnast presented with right hamstring pain after regular practice. She had been diagnosed with isolated GHD at age 4 and treated with growth hormone replacement therapy until age 14. After cessation of the HGH intervention, she continued to have normal physical growth, as indicated by records from her pediatric endocrinologist. She had delayed menarche at 16 years and had a history of secondary amenorrhea despite normal weight for her age.

Six months before presentation, she experienced the insidious onset of dull, aching pain in her right hamstring, near the junction of the thigh and buttocks, that was believed to be the result of a chronic hamstring strain. The pain increased gradually over a year and was relieved with rest, massage, and dry needling. Two days before presentation, she felt a "snap" and pain while performing a switch leap during regular practice. She had sharp localized pain in the proximal hamstring with walking and sitting.

OUTCOME

EXAMINATION

Upon physical examination, the subject had tenderness over the ischial tuberosity and painful restriction of right hip flexion, especially with knee extension in this position. Although radiographs were normal, computed tomography showed an asymmetric 6-mm widening in the right ischial tuberosity epiphysis compared with the other side (Figure 1). Magnetic resonance imaging of the pelvis showed edema of the ischium near the origin of the hamstring tendon at the fracture site (Figure 2). She was diagnosed with a Type 2 avulsion fracture of the ischial tuberosity (displacement of 0–2 cm) according to the classification system proposed by McKinney et al. She chose nonoperative treatment and was subsequently treated with rest, ice, and non-weightbearing ambulation with crutches. Her serum growth hormone level (327 pmol/L) was within normal range. Radiography indicated a bone age of 15 years, but her chronologic age was 15 years 4 months.

The subject was advised to continue to be non-weightbearing until she was pain-free with radiographic fracture healing, which occurred three months after the injury.

INTERVENTIONS AND OUTCOMES

The subject underwent rehabilitation with the athletic trainer. Starting three months post injury, her rehabilitation was focused on gaining hip range of motion for two weeks followed by strengthening of hip, lower extremity and core muscles, and gait training. Patient also underwent training for proprioception, running, and sprinting. She was then allowed to begin vault training at four months, and running at five months, after her injury. She could perform switch leaps and splits seven months after injury. She participated in a USAG level 9 competition 12 months after the initial injury. At a three-year follow-up, she continued to practice gymnastics and compete in level 10 USGA competitions without any symptoms related to her avulsion fracture of the ischial tuberosity.

DISCUSSION

Although growth plate injuries are common in adolescents performing gymnastics, the present case report suggests that gymnasts who have a history of growth hormone replacement therapy should be aware of the potential delay in clinical recovery after physeal avulsions. Chronic pain in any joint in a competitive gymnast should be evaluated for widening of the growth plate with conventional radiographs. This patient’s long recovery may be attributable to her history of growth hormone replacement therapy and delayed physeal maturity.

The most effective treatment strategy for avulsion fractures of the ischial tuberosity is unknown. Eberbach et al. conducted a meta-analysis of 14 studies comprising 596 patients with pelvic apophyseal avulsion fractures. The authors recommended surgery for pelvic apophyseal avulsions with displacement >15 mm. The present patient chose non-surgical treatment because it was expected that she would...
Figure 2. Coronal magnetic resonance image of the right pelvis showing edema (arrows) of the ischium around the hamstring tendon insertion.

have a short recovery and rapid return to gymnastics. However, her return to full weightbearing at three months was longer than that reported by Eberbach et al., who found a mean time to full weightbearing of 4.9 weeks (range 3–6 weeks) after nonoperative treatment. They also reported that the time to return to preinjury-level sport was 3.1 months (range 2–6 months) with nonoperative treatment and 2.4 weeks (range 1–6 months) after surgical treatment. In contrast, this patient required 12 months to recover fully from this injury.

The atypical presentation of chronic pain preceding an avulsion fracture of the ischial tuberosity and delayed recovery in this patient may be attributed to her history of GHD. Previous studies have reported on the adverse effects of GHD on bone metabolism and fracture healing. Other factors associated with stress fractures in female athletes include the concomitant conditions of amenorrhea, osteoporosis, and eating disorders. Although this patient did not have a history of eating disorder, she had a history of delayed menarche and secondary amenorrhea and a younger bone age than chronological age, which is common in competitive gymnasts. Estrogen plays an important role in the physiology of bone marrow density (BMD) and bone formation as it inhibits bone remodeling and bone resorption. In an estrogen-deficient state, BMD is decreased, thus leading to an increased risk of fragility fracture. Several other factors may be responsible for delayed recovery and return to play in athletes after injury; these include the use of a generalized, one-size-fits-all return-to-play protocol rather than an individualized approach based on sport and injury; poor communication between treating physician and trainers; and psychological factors such as anxiety, fear of decreased performance, and fear of reinjury.

CONCLUSION

The authors report an avulsion fracture of the ischial tuberosity in a female gymnast with GHD who had a delayed recovery after nonoperative treatment. This case highlights the importance of a comprehensive evaluation, including for possible endocrine disorders, in adolescent athletes presenting with avulsion fracture of the pelvis including those of the ischial tuberosity.

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Clinical Commentary/Current Concept Review


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An athlete’s body plays an important role in their performance and well-being. However, game-relevant skills are better determinants of success, compared with physical fitness, in technically-driven team sports. In the professional era, over utilization of resources, in pursuit of physical optimization, can detract from time spent on priorities. Athletes’ non-strategic, time-demanding focus on physical preparation/treatments resembles avian ‘avoidance preening’, whereby stressful situations trigger birds to excessively preen in place of more productive activities. The purpose of this commentary is to explore the behaviors of resource-rich professional teams and the roles of staff dedicated to optimizing physical performance, including circumstances that foster avoidance behavior and create the potential for practitioners to encourage co-dependent relationships with athletes. To cultivate healthy/productive environments, the following is recommended: I) recognition of non-productive avoidance behaviors; II) eschewing unjustified, fear promoting, pathoanatomical language; III) fostering collaborative approaches; IV) encouraging utilization of psychology services; V) recognizing that optimal physical function and feeling good is rarely the primary goal in professional team sports.

Level of Evidence

5

INTRODUCTION

Preening is a body-maintenance behavior seen in birds, which involves use of the bill to support health and structure of the feathers (e.g. position feathers, interlock feather barbules, clean and keep parasites in check).1 This conditioning of the outer layer, often referred to as a bird’s integument, supports the critical function of flight in avian species.2 Due to its functional role, this behavior may be considered more critical than the bodily grooming observed in land-based mammals.2 Similarly, athletes’ bodies play a significant role in their performance and well-being, which means that body-maintenance likely holds more importance than in non-athletes. In athletes, physical function and overall sports performance is not only linked to feelings of self-worth and mental wellbeing, but also supports the livelihood of individual athletes, sports teams, and leagues. Like a bird’s integument, a high-functioning body is critical to athletes thriving.

Despite preening being a critical behavior to support flight in avian species, indulgence in excessive preening does not necessarily lead to improved flight. Preening is also energetically demanding3 and can have indirect costs by detracting from other productive behaviors.4 In some cases, preening has been described to be a displacement behavior in response to stressful situations.5 For example, European Starlings will break off their battles to preen6 and some Tern species will preen when they have been alarmed by a potential predator.5 This behavior is not serving to ‘condition the integument’ but is used as an avoidance technique during times of stress. Humans are also known to display avoid-
ance behavior to threatening situations, possibly as an attempt to reduce the unpleasant affective experience.

In the professional era of sport, large economies and an intensified focus on performance outcomes can contribute to stressful environments. These growing economies have also led to an increase in available resources to support athlete preparation (e.g., sports science, sports medicine, and sport technology). In some cases, team’s management hold the belief that a greater number of staff will inevitably contribute to improvements in athleticism, healthier athletes, and better sport performances.

Abundant resources focused on physical preparation, combined with stressful environments, has led to some examples of support staff spending excessive amounts of time with athletes on ‘body work’ (e.g., massage, joint manipulation, deep tissue focus, electrical muscle stimulation, cupping, dry needling, resistance training etc.). Currently, there is little evidence that this type of support will help players perform better during competition. In contrast, the excessive amount of time spent on ‘body work’ may reduce time spent on more important performance related coaching interventions that improve decision making, communication, cohesion, tactics, strategy, and game relevant skills.

It is obviously non-desirable for support staff to prevent players from focusing on high-priority, performance enhancing activities. In the animal kingdom, avoidance preening/grooming has been described in animals that are experiencing an increase in stress due to a perceived threat. In humans it is documented that ‘people tend to approach positively evaluated stimuli and to avoid negatively evaluated ones.’ In this commentary, it is proposed that the behavioral response to stress in team sports can encourage a non-desirable avoidance behavior (e.g. excessive body work), which is analogous to avoidance preening in birds.

THE CEILING EFFECT OF ‘CONDITIONING THE INTEGUMENT’

Physical preparation is important for team sports, from the perspective of both conditioning required to compete at the highest level and resilience to injury, which in turn optimizes availability. However, game-relevant skills, decision-making and strategy have been shown to be a better determinant of performance compared with physical fitness, in technically driven team sports. In this respect, the most valuable players on a team rarely possess the greatest strength or aerobic/anaerobic capacity. Although it is the practitioner’s responsibility to strive for physical optimization, there is an equal need to acknowledge the training principle of diminishing returns, and understand where these training modalities sit on the hierarchy of team sport performance needs. Experienced coaches will quickly recognize that when compared to fitness, technical and tactical aspects of the sport are clearly a priority. This concept may be frustrating for motivated support staff who believe that the team’s performance will benefit if they are allowed to provide athletes with frequent, lengthy manual therapy sessions. It may seem counterintuitive to some professionals that less engagement with athletes can be beneficial for performance. However, an athlete’s time is a limited resource and reducing time spent on body work can increase opportunities to focus on skills, tactics, and decision-making, which could have a greater impact on both individual and overall team success.

THE RESOURCE RICH MODERN PROFESSIONAL ATHLETE

In elite sporting environments, resources have historically been limited. However, the evolving professionalization of sport has greatly reduced many previous constraints. Modern-day professional athletes can now devote large portions of their day to performance enhancing activities, and in the top tier of professional sport, financial resources are impressive. Indeed, it is now common to see sporting franchises valued at over US $1 billion and individual team sport athletes commonly earn salaries in excess of US $10 million each season. As a result, there are improved support staff to athlete ratios. In some cases, high profile athletes have their own ‘team’ of practitioners, solely devoted to taking care of one person. This 24/7 extreme support has created a new phenomenon, whereby athletes can spend large portions of their time ‘taking care of their body’. When athletes are paid millions of dollars, there can be an associated pressure on both the athlete and the support staff to ensure that optimal health, fitness, and motivation are achieved. In professional sport, focusing on activities that ‘feel good’ and fit within a support practitioner’s comfort zone can easily become a priority, limiting the time spent on higher impact technical and tactical development (e.g., practice with teammates, studying film, meeting with coaches, discussing strategy with teammates in ways that contribute to team social dynamics critical to team success). This behavior appears analogous to avoidance preening in birds, which can occur as a response to overwhelming stress and may take away from more productive activities.

ALLOPREENING - THE ROLE OF MEDICAL AND PERFORMANCE PROFESSIONALS

Although avian preening is primarily an individual behavior, some species engage in allopreening, a term that reflects interaction between two or more birds. This behavior is thought to do more than assist in effective grooming and may contribute to socialization and communication. Preening and allopreening are not mutually exclusive, and the conditions that promote these behaviors can vary.

Medical and performance staff often collaborate with athletes in the care and preparation of their bodies. Although good sensations and a positive mood are desirable, the intense focus on activities that ‘feel good’, but do not necessarily contribute to a performance outcome, can occur knowingly or unknowingly. In the authors’ experience, it is common for practitioners perceiving job pressure to initiate athlete interactions by imparting fear via pathoanatomical diagnoses and classification of ‘faulty’ movement patterns. For example, many practitioners continue to assess movement dysfunction when assessing the sacroiliac joint, suggesting to athletes their ‘pelvis is off’ or ‘stuck’, yet there
is evidence undermining these assessments and treatment paradigms. Once the athlete is sufficiently concerned, an intervention is proposed. It is clear that communication style and persuasion techniques during an athlete-clinician encounter can positively or negatively influence an athlete's 'buy-in' and subsequent expectations. The concept of 'Therapeutic Presence' outlines the importance of a patient feeling safe and secure in the treatment setting and believing that treatment will produce favourable outcomes. Indeed, there is evidence that beliefs of medical practitioners are 'socially transmitted' to patients, and have a quantifiable impact on treatment outcomes. However, clinicians should be aware that inducing an external locus of control, creating co-dependencies, and distracting the athlete from other priorities can all be considered non-desirable outcomes. In some cases, this behavior may even have a negative impact on individual and team performance. For example, unhealthy dependencies may lead an athlete to believe that only one person will be able to 'know my body' and therefore be in a position to 'fix me'.

Cultivating apprehension and using catastrophic language, particularly in relatively non-threatening situations, can create further fear avoidance behaviors. This may encourage the athlete to invest 'extra' time working on their body, at the expense of higher priority activities that could directly affect individual and team success. Medical and performance staff may also fall into the trap of viewing their 'value' based on how much time the athlete utilizes their services or 'treatment'. Treating an athlete may boost the self-esteem of the medical and/or performance professional, especially in cases where the athlete is of notable celebrity. These situations can result in an unhealthy co-dependency between the athlete and support staff.

WARNING SIGNS OF AVOIDANCE BEHAVIOR AND CO-DEPENDENCE

In the competitive world of professional team sports, it is often desirable for support staff to display their talents. Because a tangible link between player support and overall team performance is difficult to quantify, coaches and front office executives tend to desire staff who keep busy and are well-liked by athletes. However, an environment that contributes to health, well-being, and performance improvements, is easier to achieve if support staff are discouraged from promoting avoidance behavior and co-dependent relationships with athletes. Warning signs of avoidance behavior and co-dependence may include: isolation of the athlete from other staff members; suggesting that the athlete cannot perform unless touched by a medical/performance staff member; alignment with "guru" philosophies that are not evidence based and can therefore only be delivered by one practitioner; aversion to collaboration with other medical/performance colleagues on staff; significantly decreasing amount of time spent on sport based activities (e.g. practice, film) in favour of 'working on the body', without the presence of injury. While authentic relationships, that reflect trust and foster a therapeutic presence between support staff and players, are to be encouraged, this should not be at the detriment of a highly functional team environment. The challenge for support staff is to connect with players in ways that cultivate commitment to high-priority activities, that ultimately lead to improved player resilience and team performance.

PSYCHOLOGICAL SUPPORT SERVICES AND SCOPE OF PRACTICE

When addressing psychological concepts associated with anxiety, anger management, and relationships with teammates and coaches, it is important that medical and performance professionals work within their scope of practice and do not attempt to engage in advanced psychological services. Indeed, holistic approaches to athlete health and performance should incorporate services from appropriately qualified psychology professionals. While maintaining appropriate scope of practice is necessary, support personnel play a large role in developing the environment around athletes, including psychological concepts. In professional sports teams, medical and performance professionals usually spend more time with athletes than any other group, and thus, their opportunity to influence is great. Therefore, the authors believe it is the responsibility of support staff to be aware of their level of influence, recognize priorities and work to create supportive environments, in conjunction with utilization of appropriate psychological services.

PRACTICAL APPLICATIONS

To cultivate healthy working environments around the modern professional team sport athlete, it is proposed that awareness around the following concepts are critical: i) early recognition of support staff and athlete avoidance behaviors; ii) eschew pathoanatomical language and diagnosis that often induces unjustified fear; iii) foster collaborative care approaches to avoid the opportunity for athletes to develop the belief that only one person can 'fix me' or 'know my body', iv) message to support staff that improving physical function is not the primary goal, but is a means to support sports practice, competition and performance; v) encourage the athlete to utilize psychology services, recognizing this may be in the absence of clinical diagnosis, but in the seeking of optimal health and performance.

Practitioners employed in positions to support professional athletes often enter a sociopolitical environment that is stressful in many unique ways. As the professional sports industry matures, support staff are transitioning from small groups of generalists to larger teams of experts. The challenge for experts working in this environment is to resist personal needs, be aware of priorities and focus on activities that contribute to a healthy and competitive team culture, where performance of the player and the team remain the focus.

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inal data from human subjects, therefore institutional review board approval was not required.

COI STATEMENT

The authors declare no potential conflicts of interest.
REFERENCES


OFFICIAL PROGRAMME

DAY 1 PROGRAMME
- Opening ceremony
- Symposium: The unbreakable young world athlete
- Symposium: The adolescent athlete
- Break
- Symposium: Tendinopathy – understanding the underlying pathology
- Lunch and activity break
- Symposium: Muscle injury prevention and rehabilitation update
- Patient voices via live session or video interview/clip
- Patient voices coffee break
- Parallel 50-minute applied sessions repeated twice
  - Overuse Injuries in adolescents
  - Lower limb tendinopathy
  - Muscle injury diagnosis and rehabilitation
  - ACL injuries in the young athlete – best care in the interest of the athletes
  - The hyperflexible young athlete
  - Poster/Infographic competition
  - Gala dinner and party

DAY 2 PROGRAMME
- Symposium: The brain in sports related injury/pain: Local structural damage or central changes
- Networking break
- Parallel 50-minute applied sessions repeated twice
  - Athletes with multifactorial painful conditions
  - Get control over shoulder instability and pain in athletes
  - Handling concussions in the real world
  - Diagnosing and treating hip pain female athletes
  - Rehabilitation of athletes in contact and collision sports
- Lunch and physical activity break
- Symposium: Physical activity: What the sports physical therapist needs to know
- Physical activity break
- Symposium: Motivation for exercise as medicine
- Oral abstract competition: Six best rated abstracts
- Closing ceremony

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INTRODUCTION
The International Journal of Sports Physical Therapy is pleased to publish abstracts from the Fourth World Congress of Sports Physical Therapy. The World Congress of Sports Physical Therapy is presented biennially by the International Federation of Sports Physical Therapy (IFSPT) in conjunction with its member organizations. It is designed for sports physical therapists and other disciplines who train and rehabilitate active individuals of all ages, genders, abilities and level of participation. The Congress was developed to provide high quality education using current research, the most expert presenters and the newest methods to restore all active persons to play.

The IFSPT Fourth World Congress of Sports Physical Therapy will be held August 26-27, 2022 in Nyborg, Denmark, in conjunction with the Danish Sports Physiotherapy Group.

Registration is still open.

The variety of presentations during this congress are examples of the contemporary sports physical therapy research activities taking place around the world. The abstracts presented in the following pages were selected by the Scientific Committee, which included members from Danish Sports Physiotherapy Group and from the International Federation of Sports Physical Therapy. It should be noted that abstracts have not been reviewed by the Editorial Board, Associate Editors or Editor-in-Chief of the International Journal of Sports Physical Therapy.

Each abstract presents only a brief summary of a research project/presentation and does not permit full assessment of the scientific rigor with which the work was conducted. While the abstracts offer only preliminary results that may require further refinement and future validation, they do serve an important role of sharing new research ideas from around the world. This sharing of ideas helps to encourage worldwide dialogue among researchers, clinicians, and educators that will ultimately contribute to the sports physical therapy body of knowledge.

Notice: The abstracts enclosed are presented as prepared by the authors. The accuracy and content of each abstract remain the responsibility of the authors.

THE ALFA CARE PRIZE

What is the AlfaCare prize?
The AlfaCare prize award is for a passionate early career sports physical therapist to assist them in attending the World Congress of Sports Physical Therapy in Nyborg, Denmark, August 26-27, 2022. The amount of the award is 1000€.

Who is AlfaCare?
AlfaCare is a supplier of clinic equipment and other products for preventing and relieving muscle and joint pain and sports injuries. In their home market, Scandinavia, they work with their own brands as well as a distributor of a wide range of leading brands. AlfaCare is the IFSPT platinum titling sponsor, and is the kind contributor of funds for the AlfaCare Prize.

The purpose of the prize
Early career individuals often find it a challenge to gain funding to attend a world-class congress such as the World Congress of Sports Physical Therapy. However, these individuals are the future of sports physical therapy, and the IFSPT and AlfaCare recognize the need to assist them in the development of their career in sports physical therapy, as well as create ambassadors for the field. The 1000€ prize will help the chosen individual attend the Fourth World Congress of Sports Physical Therapy, then return to their member organization and share the knowledge they obtained with their peers.

The winner will also be encouraged to attend the Fifth World Congress of Sports Physical Therapy in Oslo, Norway in 2023 and speak about their experience and how it has impacted their practice as well as how it has helped their member organization.

Eligibility Criteria
• Graduate and licensed physical therapist in their member country for seven years or less
• At least two years of sports physical therapy practice experience
• A current member in good standing of their IFSPT member organization
• Good communication skills
• Proven presentation skills

Information about this year’s Alfa Care Prize winner may be found after the abstracts in this document.
1 Exploring students’ participation in and perceptions of resistance training in their high school weight room.

Ms. Joanne Parsons, Ms. Gabby Masi
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Introduction: Greater muscular fitness is associated with increased function and a longer life. Building muscular fitness during the time of peak physical maturation is key, but there is limited research concerning adolescents and their participation in activities that develop that fitness.

Aim: To explore former students’ participation in and perceptions of their high school weight room.

Materials and Methods: We advertised an online survey via social media and university digital message boards that targeted 2012-2019 high school graduates. We asked if their high school had a weight room, their pattern of weight room use, and their perceptions of what encouraged or deterred use of the space.

Results: Of the 92 (71 female) respondents, 78 (85%) reported having a school weight room. Sixty-two of the 78 reported they used the space: 39% <1x/week, 32% 1-2x/week, 23% 3-5x/week, and 4% other frequency. All of the male respondents who had a school weight room used it, compared to only 73% of the female respondents. Fifty-one percent of users rated the weight room ≤6 on a 10-point “welcoming” scale. The convenience of location and no cost, presence of friends, natural light, and sufficient space made the weight room appealing to students. Busy, unorganized spaces and a perceived intimidating/judgmental atmosphere discouraged use.

Conclusion: Less than 25% of respondents met participation guidelines (≥3x/week) for muscle building activities through their school weight room, and half did not consider the space overly welcoming. Respondents identified features that, with some minor changes, could encourage use of the space.


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Introduction: Twenty percent of patients receiving total hip or knee replacement (TJR) report non-optimal postoperative outcome. Increasing preoperative lower-limb-strength prior to TJR may improve postoperative functional performance.

Materials and Methods: Eligibility criteria: RCTs 1) comparing preoperative lower-limb-exercises before TJR with standard care 2) explicitly reporting the exercise intensity and 3) reporting functional performance were included.

Information Sources: Cochrane Central, MEDLINE, EMBASE, and PEDro were searched in August 2021.

Risk of bias: Cochrane Risk of Bias tool was used to evaluate the risk of bias. Screening of eligible studies, data extraction and risk of bias assessment were conducted by two independent reviewers.

Synthesis of results: Primary outcome was functional performance assessed 2-4 months postoperatively. Secondary outcome measures included maximal knee-extensor strength 2-4 months postoperative and functional performance and knee-extensor strength 10-12 months postoperative. Random effects meta-analyses were performed to synthesize the results.
Results: Seven RCTs including 234 participants were included.

A moderate effect favoring prehabilitation training on sit-to-stand performance was observed three months postoperatively (SMD(95%CI) (0.77; 0.43 to 1.12), along with moderate-to-large effects on Timed Up&Go (-1.33; -2.55 to -0.11), walking speed (-0.78; -1.16 to -0.41) and knee extensor-strength (0.55; 0.11 to 0.99).

Small-to-moderate effects favoring prehabilitation were observed twelve months postoperatively for sit-to-stand (0.49; 0.12-0.86), walking speed (-0.37; -0.74 to -0.00), stair climbing (-0.55;-1.03 to -0.06) and knee-extensor strength (0.49; 0.16 to 0.81).

Conclusion: Prehabilitation prior to TJR induce long-lasting improvements in functional performance and knee extensor muscle strength that are of moderate-to-large effect size.

4 Substantial deficits in hip muscle strength and functional performance in patients with hip abductor tendon ruptures compared with healthy controls

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Introduction: Patients with hip abductor tendon ruptures (HATR) experience pain and problems in daily living and sport. However, the degree of their impairments is unclear.

We aimed to investigate patient reported outcomes (Copenhagen Hip and Groin Scale (HAGOS)(0-100 scale) and Oxford Hip Score (OHS)(0-48 scale)), maximal hip muscle strength (abduction, extension and external rotation) and functional performance on the chair-stand-test (CTS) in patients with HATR compared with age and gender matched healthy controls. Furthermore, we investigated associations between hip abduction strength, pain and function.

Methods: 71 patients (100% females, mean age 56 ± 13) with clinical and MRI verified HATR and 25 healthy controls (100% females, mean age 53 ± 12) without hip pain were included in the study. All participants completed HAGOS and OHS, had their maximal hip strength measured using a hand-held dynamometer and completed the CTS.

Results: Patients reported substantial deficits in all HAGOS scores (median values 13-43 points) and OHS (median 23 points). Compared with controls, patients had significantly lower abduction (0.5 ± 0.2Nm/kg vs. 1.0 ± 0.3Nm/kg, p<0.001), extension (0.4 ± 0.2Nm/kg vs. 0.8 ± 0.3Nm/kg, p<0.001) and external rotation (0.3 ± 0.1Nm/kg vs. 0.6 ± 0.1Nm/kg, p<0.001) strength and completed significantly fewer CTSs (12 ± 4 vs. 18 ± 5, p<0.001). Patients’ maximal hip abductor strength was associated with HAGOS ADL scores and with number of completed CTSs.

Conclusion: Patients with HATR demonstrated substantial muscular and functional deficits compared with healthy controls without hip pain, which was also reflected in their substantial impairments in patient reported outcomes.

5 The relationship between symptoms associated with menstruation and sports activity restriction among female athletes in schools and local sports clubs.

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Introduction: Many women have symptoms associated with menstruation that may affect their sports activities. However, there is a lack of research on what symptoms associated with menstruation can affect sports activities.
Aim: This study aimed to clarify the relationship between the severity of symptoms associated with menstruation and the restriction of sports activities.

Materials and Methods: A cross-sectional online survey was conducted on women athletes aged 16 to 30. The severity of symptoms while menstruation was assessed using the Menstrual Distress Questionnaire (MDQ). The degree of restriction of sports activities due to symptoms was asked to be answered as an 11-point scale ranging. Spearman’s rank correlation coefficients were calculated for the relationship between MDQ subscales and the sports activity restriction. A logistic regression analysis was conducted to examine the influence of the MDQ subscales on the sports activity restriction. The independent variables were the 6 MDQ subscales. The dependent variable was used by coding the degree of sports activity restriction <4 as "0: almost no limitation" and ≥4 as "1: limitation".

Results: The final number for analysis was 157. All 6 MDQ subscales showed a significant correlation with the degree of sports activity restriction (r > 0.4, p<0.05, respectively). The results of the logistic analysis showed that the subscale for pain was significantly related to the restriction of sports activities (p<0.05).

Conclusion
This study indicated a relationship between various symptoms associated with menstruation and restriction of sports activities, especially the possibility that pain may affect the restriction of sports activities.

7
Diagnostic labels and advice for rotator cuff-related shoulder pain influence perceived need for shoulder surgery: An online-randomised experiment.

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Introduction: There is no research on how diagnostic labels for rotator cuff-related shoulder pain interact with advice from health professionals nor the direct effect of advice for rotator cuff-related shoulder pain.

Aim: To examine the effects of diagnostic labels and advice, and interactions between labels and advice, on perceived need for shoulder surgery for rotator cuff-related shoulder pain.

Material and Methods: We conducted a 2×2 factorial randomised experiment in people with shoulder pain. Participants read a scenario describing a patient with rotator cuff-related shoulder pain and were randomised to one of four combinations of labels and advice given by a health professional: bursitis plus guideline-based advice, bursitis plus standard advice, rotator cuff tear plus guideline-based advice, and rotator cuff tear plus standard advice. Guideline-based advice included encouragement to stay active and positive prognostic information. Standard advice stressed treatment is needed for recovery. Perceived need for surgery was the primary outcome.
Results: 2,024 responses (99.8% of 2,028 randomised) were analysed. Both labelling as bursitis (vs. rotator cuff tear) (mean effect: -0.5 on a 0-10 scale, 98.3% CI -0.7 to -0.2) and guideline-based advice (vs. standard advice) (mean effect: -1.0, 98.3% CI -1.3 to -0.7) decrease perceived need for surgery and secondary outcomes of perceived need for imaging and to see a specialist, and perceived seriousness of the condition. There was little-to-no evidence of an interaction between labels and advice for any outcome.

Conclusion: Labels and advice influence management preferences for rotator cuff-related shoulder pain, although the effect of advice is stronger.

8 The Effects of Maturation on Landing Mechanics in Male Youth Soccer Players: A Systematic Review. Mr. Alex Meredith,1 Miss Karen Crook,2 Mr Cian Dunne,3 Dr Osman Ahmed4

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Introduction: Maturation is the process whereby the body develops towards a biologically advanced state, and is classified into three stages (“Pre”, “Circa” and “Post”). During peak height velocity (PHV) there is an increased risk of injury, and high training loads and tissue vulnerability are both thought to be responsible for this. Compromised neuromuscular control during PHV, commonly referred to as “adolescent awkwardness”, has also been suggested as a risk factor for this increased risk.

Aim: To undertake a systematic review to establish whether landing biomechanics and neuromuscular control alter throughout maturation.

Materials and Methods: Databases including: Cochrane, Google Scholar, Medline, PubMed, Scopus, and Sport Discus were searched from the study inception date until March 2020. Studies investigating biomechanics or neuromuscular control in male adolescent footballers in different maturation status were systematically reviewed and evaluated by two authors, with seven studies included in the final review.

Conclusion: A range of methodological approaches have been used to determine maturation status and showed alterations in landing mechanics from maturation. Knee valgus decreased during maturation, however limb asymmetries showed increased valgus on the right leg compared to left (especially in Circa-PHV groups). Pre and Circa-PHV showed increased landing forces relative to body weight. Increased peak ground reaction force in the left leg Circa-PHV, but right leg Post-PHV. Limb asymmetries were most evident in Circa-PHV. Future research should further explore the limb asymmetries highlighted in this systematic review, which in turn could benefit injury prevention for the developing athlete.

9 The association between sense of coherence, physical fitness and activity level in Swedish adolescents: an analysis of gender differences. Ms. Anna Hafsteinsson Östenberg, Mr Haris Projskic, Mr Anton Enberg, Ms Marie Alricsson

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Introduction: Mental health problems is a big part of burden of disease and affect adolescent worldwide. A salutogenic perspective of health is personal experience, helping individuals coping stressors. Previous research indicates physical activity as one behavior positively affect adolescents’ health.

Aim: The study aimed to investigate sense of coherence (SOC) association with physical fitness and activity level in adolescents.

Materials and Methods: A total of 3,315 male and female adolescent between age 14-18 years old, were included. The participants performed physical tests measuring cardiovascular ability and muscular strength. Questionnaires was used to measure activity levels and SOC value. Multiple linear regression analyses were performed to determine whether there was any association between SOC and independent variables.
**Results:** Boys reported higher SOC value in every age group comparing to girls. The only variable in regression analysis with significant results for both sexes were sedentary (boys $p = .002$; girls $p = .013$). VO2max was significant negative associated with SOC for boys ($\beta = -.109$, $p = 0.26$). The regression analysis had a small variability (3.3% for girls and 4.3% for boys).

**Conclusion:** Low sedentary levels was positively significantly associated with SOC for both genders indicating overall movement as the most important factor in the analysis. However, emotional support in vulnerable environments may have bigger impact on SOC value for adolescents.

10 The relationship between the intrinsic foot muscles and plantar fascia in repetitive rebound jump and jump landings in adolescent athletes

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**Introduction:** Jumping and jump landing ability have been reported to be associated with the intrinsic foot muscle (IFM) and plantar fascia morphology in adults, however this is unknown in adolescent athletes.

**Aim:** This study aimed to investigate the relationship between the IFM and plantar fascia morphology, measured by ultrasound imaging, and the repetitive rebound jumping and jump landing ability in adolescent athletes.

**Materials and Methods:** Thirty-four boy adolescent athletes participated in this study. B-mode ultrasonography was used to obtain images of the IFM and plantar fascia morphology (thickness and cross-sectional area (CSA) of the abductor hallucis (AbH), flexor hallucis brevis (FHB), flexor digitorum brevis (FDB), and thickness of the plantar fascia). The repetitive rebound jump performance was evaluated using the Optojump™ system. Participants were instructed to jump five times continuously with one leg and to jump as high as possible with minimal ground contact time. The jump landing was assessed by measuring the dynamic postural stability index (DPSI) using forward one-legged jump landings.

**Results and Conclusion:** The thickness and CSA of the AbH and FDB were positively correlated with the jump height and reactive jump index. In the multiple regression analysis, the AbH and FDB thickness was associated with jump height and the FDB thickness was associated with rebound jump index ($p<0.05$), indicating that AbH and FDB thickness might facilitates adolescent athletes to jump higher with minimal contact time in repetitive rebounding movements. The IFM (especially AbH and FDB) should be focused on examining the sports performance in adolescent athletes.

11 Characteristics of falls among men's wheelchair rugby players in the Rio 2016 and Tokyo 2020 Summer Paralympic Games

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**Introduction:** Wheelchair rugby is a contact sport with many falls that can lead to injuries, yet the characteristics of the falls are still under-reported.

**Aim:** We aimed to investigate the fall characteristics of men's wheelchair rugby players by functional classification, using all 36 official match videos from the Rio 2016 and Tokyo 2020 summer Paralympic Games.

**Materials and Methods:** The match videos from the national wheelchair rugby teams that entered in the Rio 2016 and Tokyo 2020 summer Paralympic Games were analyzed to evaluate the number of
falls, direction of the fall, and the body part first in contact with the floor. All 182 men's wheelchair rugby players (Rio 2016, 94; Tokyo 2020, 88) were classified as low-point players or high-point players depending on their functional classification.

**Results and Conclusion:** A total of 200 falls were detected, 27 (13.5%) for low-point players and 173 (86.5%) for high-point players. Significant differences were noted between low-point players and high-point players in the direction of the fall and body part first in contact with the floor. High-point players had more falls in the forward and left-right directions, whereas low-point players were characterized by a higher percentage of falls in the left-right and backward directions. Additionally, high-point players landed on the floor with their hands with high frequency, whereas low-point players landed with their elbows and shoulders more often. Our findings suggest the significance of devising measures to prevent falls during men's wheelchair rugby games according to their physical functional classification.

**Introduction:** The diagnostic labels clinicians use, seem to impact patients' expectations of treatment, prognosis and understanding of their pain. “Subacromial impingement” is a diagnostic label currently under scrutiny, due to biomechanical inaccuracy and the barriers to non-surgical treatments it might cause. “Rotator cuff syndrome” has been suggested as a more appropriate label. However, it's unknown how this label is perceived by patients.

**Aim:** To explore the impact it has on patients to receive the diagnosis “rotator cuff syndrome.”

**Materials and Methods:** Semi-structured interviews were conducted with 7 patients recruited from a specialized shoulder unit in secondary care in Denmark. All patients had received the diagnosis “rotator cuff syndrome” and an individualized explanation thereof, based on uniform concepts. Data was analysed using the General Inductive Approach.

**Results:** The analysis identified 3 main and 8 sub-themes. Most patients did not remember receiving a diagnosis and expressed no need for one, as they had received a meaningful and thorough explanation of their pain. The explanation was perceived as indicating that symptoms had muscular origin, facilitating physiotherapy and exercise as chosen management strategies.

**Conclusion:** Our analysis revealed that “rotator cuff syndrome” was associated with an understanding of physiotherapy and exercise as relevant management strategies. Patients did not express the need for a specific diagnosis, as they felt they had received and adequate and comprehensive explanation. The
13 Strength, function and overall health before and after surgical or conservative treatment of proximal hamstring avulsion.

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Introduction: Proximal Hamstring Avulsion (PHA) is a rare injury and happens with hyperextended knee and hyperflexed hip.

Aim: The aim of the study was to investigate the effect of surgical and conservative treatment of PHA.

Patients with MRI-verified PHA were included and had either surgery or training. At baseline, at 6 and 12 months follow-up, all patients answered Perth Hamstring Assessment Tool (PHAT), Hip Sports Activity Scale (HSAS), an overall-health Visual Analog scale and had their knee flexion strength measured at 30 degrees using a handheld dynamometer.

Results: 13 patients had surgery (mean age 51 ± 15, 46% females, 15 days after injury) and 13 patients had training (mean age 50 ± 17, 46% females, 64 days after injury). In the surgical group, the median PHAT score increased from 41 to 70 to 82 (p<0.001), their overall health: 50 to 80 to 80 (p=0.025) and their HSAS: 0 to 3 to 3 (p<0.01). In the training group, the PHAT score increased from 51 to 68 to 77 (p<0.001). Overall health improved from 69 to 75 to 80 (p=0.025), while HSAS went from 0 to 1 to 1 (p<0.01). Median knee strength improved in the surgical group from 0.22 to 0.67 to 1.07 Nm/kg (<0.001) and in the training group from 0.24 to 0.44 to 0.48 Nm/kg (p<0.001).

Conclusion: At 12 months follow-up, both groups improved PHAT and overall health. However, the surgical group improved more in knee flexion strength and were able to participate in sports at a higher level than the training group.

14 Are progressive shoulder exercises feasible in patients with glenohumeral osteoarthritis or rotator cuff arthropathy tear eligible for shoulder arthroplasty?

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Introduction: Little is known about the feasibility of applying progressive shoulder exercises (PSE) to patients with glenohumeral osteoarthritis (GOA) or rotator cuff arthropathy tear (RCAT).
**Aim:** To investigate whether 12 weeks of PSE is feasible in patients with GOA or RCAT eligible for shoulder arthroplasty. Moreover, to report changes in shoulder function and range of motion (ROM) following the exercise program.

**Materials and Methods:** 20 patients were included. 18 patients (11 women, 14 with GOA) aged 70 (57-80) years performed 12 weeks of PSE with 1 weekly physiotherapist-led and 2 weekly home-based sessions. Feasibility was measured by drop-out rate, adverse events, pain exacerbation (VAS) and adherence to PSE. At baseline and end of treatment, patients completed the Western Ontario Osteoarthritis of the Shoulder (WOOS) score, and Disabilities of the Arm, Shoulder and Hand (DASH).

**Results:** Two patients dropped out. No adverse events were observed. Sixteen of the eighteen patients (89%) had a high adherence to PSE and acceptable pain levels were reported during the intervention. WOOS improved with a mean of 23 points (95% CI 13; 33), and DASH improved 13 points (95% CI 6; 19).

**Conclusion:** Adherence to PSE was high and drop-out rates were low. PSE is feasible, safe and may relieve shoulder pain, improve function and ROM in patients with glenohumeral OA or CTA. The patient-experienced gains after PSE seems clinically relevant and should be compared to arthroplasty surgery in a RCT setting.

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**Acute anterior cruciate ligament rupture: neuromuscular control during stair descent and anterior tibia translation.**

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**Introduction:** Anterior cruciate ligament rupture has direct impact on knee stability and specifically stretch reflex excitability. However, literature on neuromuscular deficits in patients with acute anterior cruciate ligament deficit (ACL-D) is sparse.

**Aim:** To investigate neuromuscular activity in patients with an acute ACL-D compared to matched controls with an intact ACL (ACL-I) during stair descent and anterior tibia translation.

**Materials and Methods:** Surface electromyography (EMG) of vastus medialis (VM) and lateralis (VL), biceps femoris (BF) and semitendinosus (ST) of 15 acute ACL-D (1-3 weeks post-injury) and 15 ACL-I matched controls was recorded during stair descent and anterior tibia translation. The movements of stair descent were divided into preactivation (PRE), weight-acceptance (WA) and push-off (PO) phases; reflex activity into preactivation, short, medium, and late latency responses. Kruskal-Wallis tests and post-hoc analyses (Dunn-Bonferroni corrected) were used to compare normalized root mean squares for each muscle, limb, movement, and reflex phase between groups ($\alpha = 0.05$).
Results: During PRE, hamstrings of the involved leg of ACL-D showed approximately 30 – 50% less activity compared to either leg of ACL-I (all significant). During WA and PO, VL of ACL-D (involved leg) revealed approximately 40% less activity compared to ACL-I (p<0.05). Short latency response of BF and ST of ACL-D (involved leg) was 2 to 5 times significantly increased compared to ACL-I (matched, non-involved leg).

Conclusion: After acute ACL rupture, neuromuscular alterations are found in both legs during stair descent and reflex activity, emphasizing the need for early focus on neuromuscular control and bilateral treatment.

16 Persistent concussion symptoms and the effect on quality of life in female athletes – a qualitative study.

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Introduction: Persistent concussion symptoms (PCS) can last for months or years and affect a significant number of people suffering from commotio cerebri.

Aim: This project highlights the influence PCS has on quality of life (QoL) in female athletes, including the importance of QoL in returning to sports.

Materials and Methods: This project is a qualitative study. Empirical data is generated by semi-structured interviews, where the phenomenological and hermeneutic approach is used to gain insight into their life-world. The analysis is developed on the basis of the systematic text condensation of Malterud, in which the theory from Kajandi on QoL and coping strategies are being used to interpret the statements from the participants.

Results: The informants reported lower QoL due to the incurrence of PCS. Emerged themes in the interviews were Symptoms, QoL, Behavior change, Handling, and Sports life. Impact on social life and feelings of neglect in the handling from the health care system and in sports life. Self-awareness and energy management were highlighted as important in PCS management.

Conclusion: PCS is found to have a negative impact on the participants' QoL, especially on their identity, self-perception, social life, and physical activity in connection with sports. However, social support, acceptance of the condition, and self-awareness showed to help raise the QoL. As health professionals, we are responsible for informing early in the process about what options the patient has for interdisciplinary treatment.

17 Characteristics of falls among wheelchair rugby and wheelchair basketball players in the Rio and Tokyo Paralympic Games: a video analysis.

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Introduction: Falls during wheelchair sports are very serious, however, few research have been reported on wheelchair sports and falls.

Aim: To identify the fall characteristics of athletes in wheelchair rugby and wheelchair basketball during the Tokyo 2020 Paralympic Games and compare these with those of the Rio 2016 Paralympic Games.

Materials and Methods: We obtained video footage from the International Paralympic Committee of the Tokyo 2020 Paralympic Games that included 8 teams from each of the 18 wheelchair rugby and 10 wheelchair basketball games (men and women). The data were analyzed to evaluate the number of falls, class difference (low or high pointer), time of play during the fall, phase of play, contact with other athletes, fall direction, fall location, and the body part that first contacted the floor during the fall. These data from the Rio 2016 and Tokyo 2020 games were compared.
Results and Conclusion: Overall, 430 falls (rugby, 104; men's basketball, 230; and women's basketball, 96) occurred (average per game: 5.8, 23.0, and 9.6, respectively), and the number of falls increased from Rio 2016. There were significant differences between the three sports in terms of type of fall, direction, site of fall, and body part contacted, but no difference in trend from Rio 2016. The Tokyo 2020 Games were characterized by a significant increase in the number of falls in low pointers in men's wheelchair basketball. Continuing to collect data on falls in wheelchair sports will allow for analysis of the mechanisms of falls and injuries.

18 Age-related hip joint flexibility and hamstring extensibility in adult non-professional table tennis players: An exploratory cross-sectional study.
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Introduction: Flexibility of the lower extremity contributes to the movement pattern of table tennis strokes. Rotation of the hip joints is an important component for generating high force and acceleration during topspin forehand and backhand. Restricted extensibility of hamstring muscles has been demonstrated to predispose an individual to various musculoskeletal overuse injuries and influence an individual's functional level. Age-related differences of joint and hamstring flexibility have been established in various sports, however, information on table tennis is lacking.

Aim: To explore age-related hip range of motion (hip-ROM) and hamstring extensibility in adult table tennis players.

Materials and Methods: Twenty-two right-handed table tennis players (10 females, 12 males) volunteered to participate. They were divided into 2 groups (G1: ages 18-28 years; G2: ages 32-45 years). Hip-ROM was measured using a goniometer and hamstring extensibility was quantified using the sit-and-reach test. Test results were normalized to participant height and weight to express flexibility without units. Independent samples t-tests were used to analyze significance of differences between groups (p<0.05).

Results: Significant differences between groups were found for passive (G1: 9.7 ± 2.1 versus G2: 7.7 ± 1.7; p=0.03) and active (G1: 9.4 ± 2.2 versus G2: 7.5 ± 1.6; p=0.04) external hip-ROM of the left leg.

Conclusion: Right-handed table tennis players aged 32-45 years seem to demonstrate decreased external hip-ROM of the left leg compared to players aged 18-28 years. Whether this decrease is an age-related, sport-specific functional adaptation and may influence stroke kinematics and kinetics needs to be further investigated.

19 Immediate effects of hip foam roller and stretch on golfers' driving performance
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Introduction: It is evident that golfers are less likely to stretch as a warm-up (12.2%). In recent years, research papers have been scattered about the combination of foam roller and stretching (FR+ST) aimed at improving flexibility and performance. However, the effects of FR+ST on the performance of golfers has not been clarified.

Aim: The purpose of this study was carried out to examine the immediate effects of FR+ST to the leading hip on driving performance in golfers.

Materials and Methods: The subjects were 22 males. The study design was crossover design, and the subjects predetermined the exercises in both the FR+ST group and Swing (SW) group. The washout period was set at least one week. The evaluation items were ball speed, club speed, flight distance (carry), launch angle, and spin rate. Within group comparisons before and after exercise in each group and intergroup comparisons between the FR+ST
and SW group were performed by paired t-test or Wilcoxon rank test. Significant differences were set at the level of .05.

**Results:** Flight distance and the spin rate were significantly greater after the exercise than before the exercise only in the FR+ST group (p<0.05). A significantly higher value was observed only in the flight distance in the FR+ST group compared to that in the SW group.

**Conclusion:** It was suggested that FR+ST might be useful for increasing the flight distance. Between-group comparisons showed no significant differences other than in flight distance, suggesting that factors affecting flight distance need to be clarified.

**20**

**Early open kinetic chain allows better muscle strength recovery at time to return to running after anterior cruciate ligament reconstruction.**

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**Introduction:** After anterior cruciate ligament reconstruction (ACLR), muscle strengthening is a key element in return to running (RTR) for athletes attempting to return to their sport.

**Aims:** To determine whether the early associated use of open kinetic chain (OKC) and closed kinetic chain (CKC) improved quadriceps and hamstring strength in athletes after ACLR. Secondary objective was to assess whether the early use of OKC had an influence on graft laxity at 3 and 6 postoperative months.

**Methods:** This study (IRBN:PCE-06.18-038) included two groups (OKC+CKC group vs CKC group) of 15 athletes (26.5±5 years old, Marx score = 16, Tegner score ≥ 9) who had an ACLR with hamstring graft. OKC protocol were introduced at 4 weeks after ACLR (29.7±8.4 days).

At 3 months (99.9±14.5 days), an evaluation of quadriceps and hamstring strength was performed by isokinetic device (60°·s⁻¹). Peak torque (PT), limb symmetry index (LSI) and the relative peak torque (PT/WB) were calculated for the quadriceps and hamstring during isokinetic assessment. Comparative measurement of laxity, by GNRB, was performed at 3 and 6 postoperative months.

**Results:** Quadriceps and hamstring strength in the OKC+CKC group was higher than in CKC group for LSI (respectively p = 0.02 and p = 0.003) and for PT/WB (respectively p < 0.001; p < 0.001). At 3 and 6 months the laxity, there was no statistically significant difference.

**Conclusion:** Early combination of OKC and CKC may allow better correction of quadriceps and hamstring strength deficits for RTR without increasing graft laxity.

**21**

**Kinematic differences in the shoulder girdle during the tennis serving motion between the standing and sitting positions.**

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**Introduction:** The serving motion of wheelchair tennis players be causing more shoulder injuries than that of tennis ones. This is thought to be partly due to changes in shoulder girdle motion caused by restricted movement of the lower limbs and trunk, but the differences in specifics are unclear. If this difference in movement can be clarified, it might help prevent injuries in the serving motion of wheelchair tennis players.
**Aim:** To compare the kinematics of the scapula and shoulder during the tennis serving motion between standing and sitting positions.

**Materials and Methods:** The shoulder girdle motion during tennis serve was measured in 22 able-bodied tennis players in standing and sitting positions with an electromagnetic tracking device (Liberty, Polhemus, Inc.). The scapular motion relative to thorax, humerus motion relative to thorax, and humerus motion relative to scapular during cocking phase (from the arm elevation to the maximum external rotation) were calculated.

**Results:** In the sitting position, the scapular internal rotation displacement during the cocking phase was 7.2° greater (Standing: -3.6 ± 9.3°, Sitting: 3.6 ± 10.6°, p<0.01) and the scapular posterior tilt displacement was 2.6° less (Standing: 11.1 ± 7.7°, Sitting: 8.5 ± 5.4°, p<0.05) than in the standing position.

**Conclusions:** The scapular motion during the serving motion in the sitting position showed an increase in internal rotation and a decrease in posterior tilt compared to the standing position. The repetition of these movements may increase the incidence of shoulder joint injuries in wheelchair tennis players.

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**The FIFA Injury Prevention Programs Reduce the Incidence of Groin Injury: A Systematic Review and Meta-Analysis of Randomized Controlled Trials.**

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**Introduction:** Groin injuries are among the most common and time-consuming injuries in sports. Consequently, implementing sports injury prevention programs (IPPs) such as the Fédération Internationale de Football Association (FIFA) 11, 11+ and modified 11+ has grown in interest lately.

**Aim:** To evaluate the effectiveness of IPPs such as 11, 11+, and modified 11+ in reducing the incidence of groin injuries among athletes.

**Materials and Methods:** This meta-analysis was based on the PRISMA protocol. Two investigators independently searched for relevant studies published from 1985 to 2022 using the following databases: Cochrane Library, PubMed, Web of Science, and PEDro. The keywords used in the search strategy were ‘neuromuscular training’, ‘injury prevention programs’, ‘FIFA’, ‘groin injury’, ‘athlete’, and combinations of these search terms. Included studies had to be randomized controlled trials using the 11, 11+ and modified 11+ IPPs. Studies not reporting specific groin injuries were excluded. The random-effects model by the RevMan Meta-Analysis software (version 5) was used in analyzing the extracted data.

**Results:** The pooled results of 9322 athletes showed 35% groin injuries reduction per 1000 hours of exposure compared to the control group with an injury risk ratio (IRR) of 0.65 (95% confidence interval [CI], 0.49–0.85).

**Conclusion:** This meta-analysis demonstrates that the 11, 11+, and modified 11+ IPPs decreased the risk of groin injuries among athletes.
Injury Prevention Programs Reduce the Incidence of Sport-Related Head Injury: A Systematic Review and Meta-Analysis of Randomized Controlled Trials.

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Introduction: Sport-related head injuries, including concussion, are becoming a rising public health and sports medicine issue around the world. To avoid these injuries, it is necessary to investigate the effectiveness of injury prevention programs (IPPs) in reducing sport-related head injury.

Aim: To evaluate the effectiveness of IPPs in reducing the incidence of sport-related head injury among athletes.

Materials and Methods: Two investigators independently searched for relevant studies published from 1985-2022 using the following databases: Cochrane Library, MEDLINE, AMED, PubMed, Web of Science, and PEDro. The keywords used in the search strategy were ‘neuromuscular training’, ‘injury prevention programs’, ‘FIFA’, ‘head injury’, ‘athlete’, and variations of these search terms.

Included studies had to be randomized controlled trials using IPPs for athletes with the primary outcome being head injury rate. There were no restrictions of age or playing level. The random-effects model was used in analyzing the extracted data by the RevMan Meta-Analysis software version 5.

Results: The pooled results of 10524 athletes showed 34% sport-related head injury reduction per 1000 hours of exposure compared to the control group with an injury risk ratio (IRR) of 0.66 (95% confidence interval [CI] 0.47–0.92).

Conclusion: This meta-analysis demonstrates that IPPs decreased the risk of sport-related head injury among athletes and therefore reducing healthcare costs and athletes’ absenteeism.
Injury prevention programs that include balance training exercises reduce ankle injury rates among soccer players: a systematic review and meta-analysis.

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Introduction: The ankle is one of the most common sites of injuries among soccer players. There is evidence that the incidence of ankle injuries can be reduced by improving proprioception and ankle stability via balance training exercises.

Aim: This review aimed to investigate how ankle injury rates among soccer players are influenced by injury prevention programs (IPPs) that include balance training.

Materials and Methods: Two investigators independently searched for relevant studies using different electronic databases. The keywords used in the search strategy were "balance", "injury prevention programs", "ankle", "soccer". The main inclusion criteria were randomized controlled trials used IPPs that include balance training on soccer players without any restrictions of age or playing level, while the primary outcome was ankle injury rate. The random-effects model was used in analyzing the extracted data by the Comprehensive Meta-Analysis software version 3.

Results: Nine articles met the inclusion criteria. The pooled results of IPPs that include balance training exercises among 4,959 soccer players showed 36% ankle injury reduction per 1000 h of exposure compared to the control group with an injury risk ratio [IRR] of 0.64 (95% CI 0.54 to 0.77). Moreover, the pooled results of the Fédération Internationale de Football Association (FIFA) IPPs showed 37% ankle injury reduction [IRR 0.63; 95% CI 0.48 to 0.84], and balance-training exercises alone showed 42% ankle injury reduction [IRR 0.58; 95% CI 0.41 to 0.84].

Conclusions: This meta-analysis demonstrates that balance exercises alone or combined with an IPP decrease the risk of ankle injuries. PROSPERO CRD42017054450.

Acute peripheral fatigue induces brain activity changes during predefined and reactive balance tasks.

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Introduction: Decreased balance ability may increase injury risk. Also, acute physical fatigue (APF) affects balance performance. Recently, reactive balance tasks were developed to assess balance in a more sport related context. Furthermore, it is unknown if APF induces changes in brain activity during different balance tasks.

Aims: To study whether (1) APF fatigue alters brain activity during one predefined and one reactive balance task, and (2) performance on these balance tasks.

Materials and Methods: Twenty healthy participants volunteered for this cross-over study. APF was induced through a 30-second modified Wingate-protocol. Brain activity was measured through electroencephalography during both balance tasks and computed by means of spectral power analysis. The predefined balance task was the Y-balance test (YBT), while the neurocognitive balance test encompassed the reactive balance test (RBT).

Results: Decreased RBT accuracy was observed after APF (p < 0.05), yet YBT performance and RBT visuomotor reaction time remained unaffected. APF induced α- and β-spectral power increments in the prefrontal, motor and posterior parietal cortex during YBT performance (p < 0.05). For the RBT, an α-
spectral power increment in the posterior parietal cortex and a β-spectral power increment in the pre-frontal cortex were observed due to APF (p < 0.05).

Conclusions: APF induces different changes in brain activity during both balance tasks. It is likely that different central mechanisms are affected depending on the type of balance task. Further research is needed in an applied setting to gain insight in the possible interaction between APF and injury occurrence.

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Relationship between the morphology of the intrinsic foot muscles and plantar fascia and the balance index during single-leg drop landing.
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Introduction: In recent years, it has been found that muscle cross sectional area (mCSA) of intrinsic foot muscles and plantar fascia (PF) thickness are related to static posture maintenance ability. However, it is unclear whether the intrinsic muscles and plantar fascia is related to the ability to shock absorb during landing.

Aim: The aim of this study is to investigate the relationship between the morphology of the intrinsic foot muscles and PF and the ability to shock absorb during single-leg drop landing.

Materials and Methods: For the 21 subjects, mCSA [mm²] of the abductor hallucis, flexor hallucis brevis (FHB), and flexor digitorum brevis and PF thickness at the heel [mm] were measured with an ultrasound imaging system. The subject performed a single-leg drop landing on a force plate from a height of 20 cm, and the peak vertical ground reaction force (peak-vGRF) [%BW], peak onset time [ms], rate of force development [%BW/s], and the center of pressure (COP) length [%foot length] were calculated. Pearson's or Spearman's rank correlation coefficient was used for statistical analysis. The significance level was set at 5%.

Results: A significant negative correlation was found between mCSA of the FHB and peak-vGRF (r = -0.47, p = 0.03), and between PF thickness and the COP length (r = -0.51, p = 0.02).

Conclusions: The mCSA of the FHB and the PF thickness might be related to the shock-absorbing effect and postural control after landing, respectively.

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Introduction: Musculoskeletal injuries cause 10 million medical visits every year and the primary cause of attrition and medical separation in the US military. Properly returning soldiers to full duty after injury is important for reducing long-term sequelae and re-injury risk.

Aim: The purpose of this study was to develop a prediction model for re-injury after being cleared for full duty after an injury.

Materials and Methods: A cohort study to develop an injury prediction model. Soldiers cleared for unrestricted full military duty from 3 large military hospitals after sustaining a musculoskeletal injury were enrolled. Medical history, demographics, physical performance (Y-Balance Test™, Functional Movement Screen™, triple hop, closed chain ankle dorsiflexion, 2-mile run, 75% bodyweight carry time), and past injury history were assessed. Monthly text messages to soldiers and medical records were used for injury surveillance.
Results: 469 soldiers (65 females), ages 18-45 participated. 15 variables were included in the model. The Area Under the Curve was 0.74 (95CI: 0.69-0.80), indicating good performance. The calibration score of the model was 1.02 (95CI: 0.95-1.09) indicating very good performance. With an injury incidence in our cohort of 38.0%, the treat all net benefit was 0.000, and the net benefit of our predictive model was 0.251. This means 25 additional soldiers were correctly identified as high risk for injury compared to not using a prediction model at all.

Conclusion: This multivariable model accurately predicted injury risk, providing guidance for decision-making about when soldiers are ready to return to full duty with lowest risk of subsequent injury.

30 Soccer-Related Injuries Pre- and Post-COVID-19 Lockdown: A Prospective Epidemiological Study.

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Introduction: The Coronavirus disease (COVID-19) caused a global lockdown, followed by the Ministry of Sports announcing suspension of all sports activities, which has forced soccer players to train indoor or stop training.

Aim: The purpose of this study was to evaluate the consequences of COVID-19 lockdown on the injury rate among soccer players.

Materials and Methods: A total of 45 soccer teams (630 players) competing in the amateur leagues, were followed for two seasons (pre- and post-COVID-19 lockdown). The medical staff of participating teams were requested to report all injuries during matches and/or training. Exposure during all matches and training were calculated.

Results: The incidence of soccer-related injuries significantly increased post COVID-19 lockdown by 47.25% among amateur soccer players.

Conclusion: This study indicates that COVID-19 lockdown has an impact on the overall injuries among soccer players.
Adaptability and neurocognitive functional performance: physical fatigue negatively affects accuracy in the reactive balance test.

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Introduction: Adaptability and neurocognitive performance tests have recently been put forward as relevant concepts within the functional performance spectrum. Physical fatigue is known to decrease an athlete’s functional test performance, but to date it is not known if acute physical fatigue affects adaptability and neurocognitive performance tests.

Aim: To assess the impact of acute physical fatigue on traditional and neurocognitive functional performance tests (FPT) in healthy recreational athletes.

Materials and Methods: We included twenty recreational athletes (age = 24 ± 3 years) in a randomized counterbalanced cross-over study. We evaluated fatigue impairments following a 30 second all-out effort in three traditional and one neurocognitive FPT. The traditional FPT encompassed the single leg hop for distance (SLH), countermovement jump (CMJ) and Y-balance test (YBT). The neurocognitive FPT encompassed the reactive balance test (RBT). A 30 second modified Wingate was used to induce acute physical fatigue.

Results: Acute physical fatigue was successfully induced as indicated by a significant increase in heart rate, systolic blood pressure, blood lactate levels and rating of perceived exertion (p < 0.001). Acute physical fatigue induced significant decreases in RBT accuracy (p = 0.004) and SLH performance (p < 0.001). YBT, CMJ and RBT visuomotor reaction time remained unaffected by acute physical fatigue.

Conclusions: Acute physical fatigue decreases accuracy in the RBT and impairs SLH performance. YBT and CMJ performance remained unaffected by acute physical fatigue. Clinicians should be aware of this divergent neurocognitive functional impairments caused by one all-out effort to allow well-informed selection of functional performance tests.

2D kinematic analysis software: reliability and application in running.

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Introduction: Runners perform gait analyses for preventing injury and/or improving performance. This mainly consists of kinematics assessments which need to be reproducible for consistent data interpretation.

Aim: To assess the reproducibility of the relevant parameters measurement in the frontal/sagittal planes using the Simi-Aktisys®-2D software, at 3 stages of the running cycle: Initial contact (IC), Midstance (MS) and Toe-off (TO).

Materials and Methods: 18 active subjects were equipped with 5 active markers in the frontal and sagittal planes and then alternatively evaluated 4 times (twice/day, two days) by two random investigators. Each run lasted 90s at their comfort speed on a treadmill whilst twelve running kinematics variables were recorded. Intra- and inter-rater reliabilities of measured parameters were calculated using absolute differences and intraclass correlation coefficients (ICC). ICC were interpreted as poor (< 0.5), moderate (0.5–0.75), good (0.75–0.9) or excellent (>0.9). The standard error of measurement (SEM) and smallest detectable difference (SDD) were calculated.

Results: Intra-rater intra-day reliability was excellent for all variables at each stage, except for trunk angle...
at TO (ICC=0.78) and crossover at MS (ICC=0.73) for which it was respectively good and moderate. Inter-rater intra-day reliability was moderate to good for all variables at IC and MS stages, but moderate to poor at TO. Intra-rater inter-day reliability was moderate to good, but poor at TO for femoral adduction (ICC=0.48) and pelvis angle (ICC=0.42).

**Conclusion:** The Simi-Aktisys®-2D software can be reliably used for running gait analyses at IC and MS stages, but not at TO.

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*Mind the Gap: Properties of the Bone-Patellar Tendon-Bone (BPTB) Graft Harvest Site following Anterior Cruciate Ligament Reconstruction (ACLR)*

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**Introduction:** Using BPTB autografts for ACLR comes with a cost. Patients who receive BPTB grafts experience prolonged quadriceps weakness and anterior knee pain impacting rehabilitation. Altered tendon structure may explain this morbidity.

**Aim:** To investigate the morphological and viscoelastic properties of the central (graft site) and adjacent regions of the patellar tendon 1.3±0.3 months after ACLR.

**Materials and Methods:** Four men and six women (22±8 years-old, BMI:25.3±4.5 kg/m², Quadriceps Strength Index:40±18%) were included. Morphology (thickness) and viscoelastic properties (shear modulus and viscosity) were collected bilaterally from the graft site (central), and adjacent tendon (medial, lateral) using ultrasound and continuous shear wave elastography. Limb(2) by region(3) repeated measures ANOVA were performed for thickness, shear modulus, and viscosity.

**Results:** A 2-way interaction effect (p<0.001) was observed for thickness characterized by thicker tendon in the involved versus uninvolved limb. The central region displayed the largest difference between limbs (mean difference =0.37 cm), followed by the medial (mean difference =0.19 cm) and lateral (mean difference =0.10 cm) regions. Main effect of region on shear modulus (p=0.049) was observed. No specific direction of the effect, however, was identified likely due to the large spread in data. No significant findings were observed for viscosity.

**Conclusion:** The patellar tendon after BPTB graft harvest was thicker, possibly due to collagen fiber proliferation, and the asymmetry in thickness was as expected, not uniform across the tendon. For viscoelastic properties, a less clear pattern emerged. Viscoelastic properties seem to not be uniform across the patellar tendon regardless of side, the details of which will be investigated in the future.
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Introduction: Prediction models are derived to better understand injury risk, but poor methodology is common.

Aim: To compare performance between injury prediction model that did and did not categorize predictors, and to compare selection of predictors for a final model when using univariable significance versus assessing non-linear relationships.

Materials and Methods: This was a validation and replication of a previous prospective prediction model. A cohort of 1466 healthy military service members followed for one year after physical performance, medical history, and sociodemographic variables were collected. The first model was the original model which dichotomized 8 predictors. The second model (M2) included the 8 original predictors and the third model (M3) included 15 predictors. For M2 and M3, continuous predictors were kept continuous and were assessed for non-linearity. Model performance was assessed with R2, calibration slope, and discrimination. Decision curve analysis was performed with risk thresholds from 0.25 to 0.50.

Results: 478 personnel sustained an injury. The original model demonstrated poorer R2 (Original: 0.07; M2: 0.64; M3: 0.65), calibration slope (Original: 0.86 (0.62, 1.10); M2: 0.93 (0.77, 1.09); M3: 0.90 (0.75, 1.05)), and discrimination (Original: 0.62 (0.58, 0.66); M2: 0.90 (0.89, 0.92); M3: 0.90 (0.89, 0.92)). At 0.25 injury risk, M2 and M3 demonstrated a 0.47 net benefit improvement, at 0.50 injury risk, M2 and M3 demonstrated a 0.36 net benefit improvement compared to the original model.

Conclusion: Model performance was substantially worse in the original model, resulting in very poor performance compared to the other two models. This highlights the importance of following established recommendations when developing prediction models.

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Does the use of i-FACTOR bone graft affect bone healing in those undergoing periacetabular osteotomy (PAO) for hip dysplasia?
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Introduction: Periacetabular osteotomy (PAO) is a common treatment for hip dysplasia. Bone union post-operatively is important for success.

Aim: To compare, in patients with and without the use of i-FACTOR bone graft during PAO surgery for hip dysplasia, (i) bone healing at six-weeks post-operatively (ii) rate of complications.

Methods:
Design: Retrospective review of case records.
Participants: Patients aged 15-50 years undergoing PAO surgery for hip dysplasia. Group 1: patients with i-FACTOR, Group 2: No i-FACTOR.

Primary outcome: Rate of bone healing on radiographs at 6-weeks.

Data Analysis: Likelihood of bone healing was compared using logistic regression with Generalised Estimating Equations and expressed as odds ratios (OR) (95% confidence intervals (CI) and p values). The occurrence of complications was extracted from surgical records.
Results: The i-FACTOR group had 3-times greater odds of partial/full union than those without ((adjusted OR 3.3 (95%CI: 1.032-10.330, p=0.044)). The i-FACTOR group had 89% partial/full union at 6-weeks, compared to 69% of the non-i-FACTOR group. Half of patients had leaking of bone graft in the i-FACTOR group versus 10% in the non-i-FACTOR group. Nearly a third (26%) of the i-FACTOR group and 12% of the non-i-FACTOR group had neuropraxia of the lateral femoral cutaneous nerve (LFCN).

Conclusion: Patients undergoing PAO surgery for hip dysplasia with i-FACTOR had 3-fold greater odds of partial/full bony union six-weeks post-operatively compared to those without i-FACTOR. The prevalence of complication rates was low; however, the rate of LFCN neuropraxia and bone graft leakage was higher in the i-FACTOR group.

Objective: To investigate if physical impairments change in adults with DDH pre- to post-PAO, and to compare with asymptomatic participants.

Methods:
- Systematic review with meta-analysis.
- A literature search was performed in five databases
- Studies were considered if patients were above 15 years, treated with PAO for DDH and if they reported physical impairment outcomes.
- Two independent reviewers performed data extraction and assessed methodological quality.

Results: Of 5,017 studies, 24 were included with 2190 patients. The methodological quality scores ranged from 39% to 88%. With low level of evidence, meta-analysis showed 58% (95%CI: 39-76%) of patients had a positive anterior impingement test, pre-PAO and 1-3 years later. Five years after PAO, the proportion fell to 17% (95%CI: 11-24%). Prior to PAO, patients with DDH walked with a lower peak hip extension angle, compared to asymptomatic participants (SMD 0.65 (95%CI 0.21-1.10).

Best evidence synthesis of non-pooled data showed limited evidence of increased walking velocity, stride length and improved hip flexion and extension moment 18-months post-PAO compared to pre-op. Cadence, hip abduction and hip flexion strength did not change pre- to post-PAO.

Conclusion: Prior to PAO, most patients with DDH have a positive anterior impingement test. Compared to asymptomatic participants, patients with DDH demonstrate physical impairments during walking which appear to improve after surgery.
Rehabilitation strategies for lateral ankle sprain do not reflect established mechanisms and risk factors for re-injury: A scoping review

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Introduction: Many athletes suffer recurrent lateral ankle sprain (LAS) on return to sport. Common inciting events for re-injury include changing direction and jumping/landing; this is often mediated by excessive supination at initial contact and/or delay in Peroneus muscle activation. To optimally reduce the risk of recurrent LAS, rehabilitation interventions must reflect the aetiology and mechanisms of these injuries.

Aim: Determine if rehabilitation programs in the current literature address common impairments and mechanisms underpinning recurrent LAS.

Materials and methods: We searched six electronic databases. Inclusion criteria were RCT’s including patients with acute LAS, managed through exercise-based rehabilitation. Each exercise was categorised by the primary impairment(s) addressed (muscle strength, mobility, neuromuscular training, joint positional sense), and by its: direction of movement (uni- vs multiplanar); base of support (single vs double limb); open vs closed chain; and use of a flight phase.

Results: The most addressed impairment was somatosensory function (48%), followed by plantar flexion muscle strength (29%), and sagittal plane mobility (14%). Most exercises were limited to the sagittal plane (48%), with only 30% incorporating multiplanar movements. Two thirds of exercises (118/177) involved closed kinetic chain training, of which, half were undertaken on single leg (59/120). Just 18% of all exercises (33/177) incorporated a flight phase.

Conclusion: Rehabilitation strategies for LAS largely comprise simple exercises that do not reflect established mechanisms and risk factors associated with re-injury. Future interventions can be enhanced by incorporating more open chain joint position sense training, multiplanar single limb challenges, and jumping and landing exercises.

The forefoot transverse arch and dynamic posture stability classified by maturity offset in Japanese adolescent athletes.

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Introduction: The peak height velocity (PHV) at the adolescent is known as individuals and effect the musculoskeletal development and physical performance, yet the relationship between foot morphological characteristics and physical performance in accordance with maturity level is not discussed.

Aim: We aimed to investigate the differences the foot morphology and balance ability regarding the PHV.

Materials and Methods: 43 male adolescent athletes were participated in the study. They were divided three groups; pre-PHV(Chronological age: 12.0±1.3 years), circa-PHV(13.3±0.7 years), post-PHV(15.0±1.3 years) regarding on the maturity offset (Sluis et al., 2014). Navicular height and forefoot transversal arch height/width were measured as a foot morphological assessment. Dynamic postural stability index (DPSI) was measured as a dynamic balance assessment. The higher value of DPSI indicates instability.

Results and Conclusion: Variation of the navicular height was not significantly differences between groups (p=0.98). Regarding the foot transverse arch, changing of medial sesamoid height was significantly increased in post-PHV compared than pre-
PHV (p < 0.05). In addition, changing of width between lateral-sesamoid and second metatarsal head was significantly increased in post-PHV compared with circa-PHV (p < 0.05). DPSI was significantly increased in post-PHV compared with circa-PHV (p < 0.05). The value of maturity offset was significantly positive correlated with DPSI (p < 0.05). Our findings suggest that there were difference foot morphological characteristics and dynamic posture stability classified based on maturity offset. Further, the foot morphology change caused by weight bearing might be more common in the forefoot. We would conduct the prospective study to clarify the causal relationship between these factors.

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Online information about the management of anterior cruciate ligament ruptures in Australia: a content analysis.

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Introduction: Most people who suffer an anterior cruciate ligament (ACL) injury search for information online.

Aim: Summarise the proportion of webpages on ACL rupture management that present evidence-based information.

Materials and Methods: We examined webpage information on ACL ruptures identified through (1) Google searches using terms synonymous with ‘anterior cruciate ligament rupture’ and searching ‘knee surgeon’ linked to each Australian capital city, and (2) websites of professional associations. The primary outcome was the proportion of webpages that suggest people can return to at least some form of sport with non-surgical management. Secondary outcomes included webpage information on return to sport with ACL reconstruction (ACLR) and non-surgical management, benefits, harms, and risk of osteoarthritis related to these options, and activity modification.

Results: Out of 115 webpages analysed, 48% suggested people can return to at least some form of sport with non-surgical management. Almost half of webpages suggested most people will return to some form of sport following ACLR (41%) and mentioned benefits of ACLR (43%). Fewer webpages mentioned benefits of non-surgical management (14%), approximately two in three people return to pre-injury level of sport following ACLR (4%), risk of re-injury following ACLR (23%), most people return to sport within 9 months of ACLR (27%), activity modification as a management approach (20%), and ACLR will reduce the risk of osteoarthritis (23%).

Conclusion: Most online information on ACL rupture management isn’t aligned with the best available evidence. Inaccurate information could mislead patients’ treatment choices and create unrealistic expectations for return to sport.

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Pain provocation tests and clinical entities in male footballers with longstanding groin pain: Relationships to pain intensity and disability.

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Introduction: Pain provocation tests are used to examine and classify longstanding groin pain into clinical entities (adductor-, iliopsoas-, inguinal- or pubic-related). It is unknown how pain provocation tests and clinical entities relates to self-reported pain intensity and disability.

Aim: To investigate how the number of positive pain provocation tests and clinical entities correlate with pain intensity and disability measured by the Copenhagen five-second squeeze test (SSST) and the
Hip And Groin Outcome Score (HAGOS), respectively.

**Materials and methods:** Both groins of forty male footballers (mean 24 [SD: 3.2] years; 182 [5.7] cm; 78 [6.6] kg) with longstanding groin pain for median 8.5 (IQR: 4-36) months were examined and classified into number of clinical entities (0-7) based on findings from 33 pain provocation tests.

**Results:** 21/40 footballers had ≥ 10 positive pain provocation tests. 118 clinical entities were classified in 35/40 footballers. The number of positive tests (range 2-23) correlated with pain intensity (SSST r = 0.70 [95% CI: 0.50, 0.83]) and disability (HAGOS sub-scales Pain r = -0.38 [95% CI: -0.69, -0.06], Symptoms -0.52 [-0.73, -0.24], ADL -0.48 [-0.71, -0.18], Sport -0.62 [-0.81,-0.36]). The number of classified clinical entities (range: 1-7) showed similar but weaker correlations to pain intensity and disability.

**Conclusion:** In footballers with longstanding groin pain, the number of positive pain provocation tests and clinical entities correlate weak to strongly with pain intensity and disability. Consequently, when pain and disability is severe, patients are more sensitive to pain provocation tests and have more clinical entities.

### Feasibility and acceptability of exercise therapy for tendinopathy: a convergent segregated mixed methods systematic review.

**Introduction:** Tendinopathy is frequently managed using exercise therapy. For exercise to be effective, it needs to be feasible to deliver, and acceptable to those undertaking it. No synthesis of the research evidence on feasibility and acceptability of exercise for tendinopathy management has been conducted to date.

**Aim:** To synthesise the qualitative and quantitative evidence on feasibility and acceptability of exercise for tendinopathy management.

**Materials and Methods:** Convergent segregated mixed-method systematic review using JBI methodology and following an a priori registered protocol. Eligibility criteria included: i) Participants aged ≥18 with any location or severity of tendinopathy; ii) studies exploring any aspect of feasibility of delivering and/or acceptability of undertaking exercise for tendinopathy from patients’ or providers’ perspectives; iii) studies conducted in any country ranked very high in the human development index and published from 1998 to 2021.

**Results:** Ninety-six reports (85 quantitative; 11 qualitative) from 94 studies representing 4,211 participants and 20 countries were included in the review. Quantitative findings demonstrated that self-reported adherence and attendance to supervised exercise was good (70-80% and 90% respectively), that fidelity was seldom reported, and that exercise therapy for tendinopathy was considered acceptable, when reported. Qualitative findings highlighted the need
for an individualised person-centred approach facilitated by a strong therapeutic alliance and the provision of appropriate patient education.

**Conclusion:** Physiotherapists should be aware of the potential barriers and facilitators to engaging with exercise for tendinopathy, the impact of patients’ and physiotherapists’ prior beliefs, and the importance of education, self-management and the patient-physiotherapist relationship.

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**Quantifying gender differences after an anterior cruciate ligament injury: a systematic review and meta-analyses of 122,839 adolescents and young adults.**

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**Introduction:** Evidence suggests gender differences exist after anterior cruciate ligament (ACL) injury despite surgical management and rehabilitation.

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**Aim:** To investigate gender differences in self-reported activity and knee-related quality-of-life after ACL injury.

**Methods:** We searched eight electronic databases to December 2021. Observational or interventional studies of ≥10 women and 10 men were included if they reported gender-stratified data and/or gender analysis on a valid self-report measure of activity or knee-related quality-of-life after ACL injury. We performed meta-analysis with GRADE level of evidence.

**Results:** We included 246 studies (n = 122,839, 43% women, mean age 26 years). 107 studies reported sufficient data to contribute to one of 36 meta-analyses. After ACL injury, low-certainty evidence shows that women had 23-25% reduced odds of returning to pre-injury sport within 1-year post ACL injury and/or reconstruction (44 studies, OR 0.75 95% CI 0.62, 0.91), 1-5 years (OR 0.76 95% CI 0.70, 0.83) and 5-10 years (OR 0.77 95% CI 0.57, 1.04) compared to men. This corresponded with a clinically meaningful inferior 10-point difference on the KOOS-Sport/Rec subscale within the first post-injury year (low-certainty evidence pooled SMD -0.30 95% CI -0.35, -0.26). Low-certainty evidence suggests women experienced inferior knee-related quality of life on most (21/28; 75%) knee-related quality of life meta-analyses, although most were not clinically significant (i.e., failed to reach minimal clinically important difference).

**Conclusions:** Low-certainty evidence suggests inferior outcomes for women compared to men after ACL injury. Women benefit from gender-specific rehabilitation (e.g., access, social support, strength training) to enhance post-injury outcomes. Future studies should report and analyse outcomes by gender.
Long-term prognosis of individuals with plantar heel pain.
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Introduction: Plantar heel pain (PHP) used to be considered a self-limiting condition, where pain was thought to resolve within a year after onset. However, several studies with varying quality of outcomes and small sample-sizes have questioned the benign nature of PHP.

Aim: To explore the long-term prognosis of individuals treated for PHP.

Materials and Methods: Patients treated for PHP at Aalborg University Hospital between 2011-2018 were asked to complete online questionnaires. Data were collected from participants in 2021-2022. Questionnaires included demographic and participant characteristics, heel pain during the past 4 weeks, mean pain intensity during the past week (0-10 numerical rating scale), work situation, comorbidities, and the EQ5D.

Results: So far, 300 individuals completed the questionnaires (45% response rate). Mean age was 54 years (+12) and median period of PHP was 18 months (IQR 6-50). At follow-up, 53% (95%CI 47-59%) still reported PHP during the past week with a median pain intensity of 5 (IQR 3-7). 76-86% of those reported concomitant musculoskeletal pain. Among those still experiencing PHP, 10% changed their work assignments, and 19% took sick leave due to PHP (median days off work 21 (IQR 7-70)), and 19% reported depressive symptoms on the EQ5D.

Conclusion: Despite specialised care, more than half the participants still reported PHP up to 10 years after treatment. The condition was associated with change work assignments and sick leave among participants still experiencing PHP. These results emphasise the substantial impact and burden PHP has on individuals and highlights the need for more effective treatments.
Conclusion: Despite specialised care, more than half the participants still reported PHP up to 10 years after treatment. The condition was associated with changed work assignments and sick leave among participants still experiencing PHP. These results emphasise the substantial impact and burden PHP has on individuals and highlights the need for more effective treatments.

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Influence of hip abductor strength on pelvis and knee position during a single-leg landing test.
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Introduction: Knee-straining sports increase the risk of anterior cruciate ligament (ACL) injuries. Therefore, current research focuses on identifying and minimizing possible modifiable risk factors and improving injury prevention programs, like the influence of gluteus muscles on the leg axis during landing tasks.

Aim: The aim of this study was to investigate whether the hip abductor strength has an influence on the biomechanics of the pelvis and knee position in the frontal plane during a single-leg landing task.

Materials and Methods: 28 healthy participants performed a single leg landing test (LT). The sway maximal amplitude medial-lateral (SMA m-l) during LT were recorded using a force plate. During LT additionally, knee and pelvic-thigh angles were estimated using a 2D video analysis. The participants were manually tested for hip abductor strength (microFET®2).

Results: The Pearson correlation between the pelvic-thigh angle at LT and the hip abductor strength was $r = 0.18$, $p = 0.21$. The pelvic-thigh angle and knee angle showed no correlation to the SMA m-l ($r = -0.01-0.09$). The correlation between pelvic-thigh and knee angle was $r = 0.76$, $p < 0.01$.

Conclusion: Neither knee position during landing or pelvic-thigh angle are predictive values for the subjects' stability and control during landing. The pelvic-thigh angle at landing test cannot be explained by a strength status of the hip abductors. The implementation of motor learning and the use of a feedforward strategy, aiming to decrease valgus moments in landing might be of further interest for the determination of gluteus muscles role during landing tasks.

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Breaking Down Breakdance.
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Introduction: Breakdance becomes an Olympic sport in 2024, however there is minimal literature on injury epidemiology and no literature on training history or normative data.

Aim: The purpose of this study was to describe injury and training profiles, along with the results of a short performance test battery in a group of professional breakdancers (breakers).

Materials and Methods: Fourteen professional breakers attended a training summit that included a performance test battery. Injury and training history were obtained through interview. Injuries were classified by body part and injury type. Isometric hip abduction/adduction (at 30° hip flexion) and shoulder external/internal rotation (at 90° shoulder abduction) strength were tested using fixed dynamometers. Counter movement jumps were tested using force plates (2000 Hz). Descriptive statistics were used.

Results: Breakers were $24.1 \pm 5.4$ years old, with $12.6 \pm 4.1$ years experience breaking. On average the breakers trained $27.2 \pm 10.4$ hours per week, $7.0 \pm 7.1$ hours were dedicated to non-breaking training.
Modalities. There were an average of 3.2 injuries per breaker. The most commonly injured body part was the knee. Categorized by injury type, joint injuries were most common at the knee, and muscle injuries most common at the thigh. Strength and counter movement jump data are presented on the infographic.

Conclusions: The results of this study highlight the importance of developing injury prevention strategies for breakers. Although a small sample, this study provides the first functional data on breakers. These findings can inform future rehabilitation, screening batteries, and preventive efforts.

A pilot observational study to identify the number and type of training and competition injuries in mixed martial arts (MMA).

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Introduction: Mixed-martial arts (MMA) has become one of the most popular sports globally over the last 30 years, however there is a limited understanding as to the number and type of injuries that occur in the sport.

Aim: To identify the number and type of injuries that are sustained in MMA across training and competition and see how this compares to other combat sports. The intention to better understand the number and type of injuries in the sport aims to assist practitioners to enhance safety measures within the sport.

Materials and Methods: A pilot cross-sectional retrospective observational cohort design collected and reported on the clinical injury history (42 weeks) of 32 professional MMA athletes. Medical record data included: age, weight, diagnosis, mechanism, exposure type and training information related to session, training phase and technical theme.

Results: 93 injuries were reported, 78.5% from training and 15.1% from competition. 92.31% of competition injuries resulted from striking: fractures (38.46%), concussion (15.38%) and ligamentous (15.38%) injuries were the main type. Training injuries were primarily caused by grappling (61.54%): discogenic (20%), ligamentous (18.46%) and articular (15.38%) were most prevalent. The head and face (69.23%) were most injured in competition and upper limb (23.08%) in training.

Conclusion: MMA demonstrates differences in training and competition injuries by type and location, reflective of characteristics of injuries observed in MMA and other combat sport styles. There are several limitations of this study which limits its extrapolation of results. Further research should be conducted more longitudinally and on larger populations.
Does land-based exercise-therapy improve physical activity in people with knee osteoarthritis? A systematic review with meta-analyses.

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Aim: We aimed to investigate the effects of exercise-therapy on physical activity in people with knee osteoarthritis (KOA).

Methods: Systematic review and meta-analysis of randomised controlled trials investigating land-based exercise-therapy on physical activity, fitness and general health in people with KOA. We updated a Cochrane review (2013) search on exercise-therapy for KOA in April 2021 and applied the Cochrane Risk-of-Bias Tool to included articles. Standardised mean differences (SMDs) and 95% confidence intervals (CI) were calculated. GRADE was used to assess certainty of the evidence.

Results: Twenty-three trials (2789 participants) evaluating the effects of resistance-training (n=10), walking (n=6) and mixed-exercise programs (n=7) were identified.

Low to moderate certainty evidence indicated small increases in physical activity for exercise-therapy compared to non-exercise interventions in the short-term (SMD, 95% CI = 0.29, 0.09 to 0.50), but not the medium- (0.03, -0.11 to 0.18) or long-term (-0.06, -0.34 to 0.22). Low certainty evidence indicated large increases in physical activity for walking programs (0.53, 0.11 to 0.95) and mixed-exercise programs (0.67, 0.37 to 0.97) compared to non-exercise in the short-term. Low and very low certainty evidence indicated moderate and small increases in physical activity for exercise-therapy combined with non-exercise compared to non-exercise alone at medium- (0.45, 0.19 to 0.71) and long-term (0.29, 0.01 to 0.69).

Conclusion: Walking and mixed-exercise, but not resistance-training, may improve physical activity in people with KOA in the short-term. Combining exercise-therapy with education or behaviour change techniques may increase physical activity in the long-term, although the evidence is very uncertain.

Force and moment arm distribution between the vastus medialis and lateralis in adolescents with patellofemoral pain.

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Introduction: Alteration in the force distribution among quadriceps heads is one possible underlying mechanism of patellofemoral pain. Currently, no non-invasive experimental techniques can measure individual muscle force in vivo in humans. However, individual muscle force can be approximated from a combination of biomechanical and muscle activation measures under specific conditions.

Aim: To determine whether the force, torque distribution, or resting moment arms relative to the patellar centre of the vastus medialis and lateralis differ between adolescents with and without patellofemoral pain.
**Material and Methods:** Twenty adolescents with patellofemoral pain and 20 matched control participants were included. We quantified muscle volumes and resting moment arms from magnetic resonance images and fascicle lengths from panoramic ultrasound. Muscle activation was estimated using surface electromyography during submaximal isometric wall-squat and seated tasks. We estimated the muscle forces as the product of muscle physiological cross-sectional area and activation. Muscle torques were estimated as the product of the moment arm and force.

**Results:** Across force levels, the force ratio (vastus medialis over vastii) was 33.7±7.7% for controls and 33.7±9.1% for adolescents with patellofemoral pain. No group differences in the distribution of vastus medialis and lateralis force, torque or moment arm were identified (group effect: p>0.36, >0.34, =0.83, respectively).

**Conclusion:** Although a relative loss of vastus medialis strength has been associated with patellofemoral pain in adults, we provide no evidence that lower vastus medialis (relative to vastus lateralis) force or torque generation exists in adolescents with patellofemoral pain for the tasks and positions investigated in our study.

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**Manual estimation of hip abductor strength – a practical alternative to conventional assessment tools?**

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**Introduction:** Information about gluteus muscles strength, symmetry or pain are of interest in many sport settings. Various studies have proven the reliability of handheld dynamometers for measuring isometric muscle strength. However, in clinical practice, this requires the availability of a device-based assessment tool in every situation.

**Aim:** The study aimed to assess the validity of hip abductor muscles strength between-limbs differences estimation subjectively done by the examiner by relating it to handheld dynamometry.

**Materials and Methods:** 28 healthy participants were tested in terms of the strength of hip abductor muscles using manual muscle testing and a handheld dynamometer MicroFET®2. Three repetitions in a supine position using each method were carried out bilaterally by the same examiner. The between-limbs differences expressed in percentages (%) determined using the two assessment methods were statistically analysed in terms of a relationship by a linear Pearson’s correlation coefficient (r) and coefficient of determination.

**Results:** The handheld dynamometer testing showed excellent reliability ICC [0.89-0.94]. The correlation between the hip abductor force ratio and the tester’s self-assessment was r=0.57 (p<0.05), with binominal correctly asymmetry detection in 85%. Hip abductor strength was in average overestimated by 5%; MinMax[-40%;49%] on the right side compared to the left side.

**Conclusion:** In terms of clinical relevance, self-assessment might be a promising and feasible tool for a fast and economic determination of between-
limbs differences strength. Still, no valid grading seems possible and transferability of results to intersession reliability and certain diseases and sport settings needs to be proven.

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"I feel like I have lost part of my identity" A qualitative study exploring patients with chronic ankle instability

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Introduction: Lateral ankle sprain (LAS) is the most common ankle injury in sports, and one in two patients will develop chronic ankle instability (CAI). Current guidelines focus on the biomechanical and physiological impairments associated with CAI. There is a lack of research describing the psychological and social impact of CAI on the patient and their expectations and thoughts about care.

Aim: To explore the thoughts and expectations of patients with CAI concerning their condition and expectations of care in an orthopedic setting.

Materials and Methods: A qualitative study comprising semi-structured one-to-one interviews with nine patients screened and diagnosed with CAI. Interviews were recorded with the consent, fully transcribed, and analyzed using systematic text condensation with an inductive goal free approach.

Results: From the analysis, seven themes emerged. The themes were Injury history and symptoms (LAS during sport and pain and instability), Information from health professional (conflicting information about management and prognosis), Management (mental and physical challenges), Expectation and hope (explanation of symptoms and prognosis, imaging able to provide clarification of condition), Activity and participation (restricted in sport and daily life and feeling uncertain), Support (support from family and friends) and Identity (low ability to participate in sport and social life result in loss of identity).

Conclusion: The experience of living with CAI exceeds an experience of pain and instability. Patients described a loss of identity, having to manage uncertainty regarding their diagnosis and prognosis and had hopes of imaging being able to explain their condition.
Hop tests as predictors of future knee-related outcomes following anterior cruciate ligament injury: a systematic review and meta-analysis.

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**Introduction:** After anterior cruciate ligament (ACL) injury, functional deficits (e.g., strength/power) are common and hop tests are used to assess knee function and guide progression of rehabilitation.

**Aim:** To investigate the prognostic capacity of hop tests following ACL injury.

**Materials and Methods:**
- **Design:** Systematic review with meta-analysis.
- **Data Sources:** Six databases searched up to June 2021.
- **Eligibility criteria:** Studies reporting associations between hop tests following ACL injury and future (≥3 months) outcomes.

**Results:** 41 included studies (13,096 participants), all assessed the single-forward hop test and 32 assessed repeated-forward hop tests (crossover-hop, triple-hop and 6m-timed hop), up to one year after ACL injury or reconstruction (ACLR). Higher single- and repeated-forward hop scores were associated with higher odds of return-to-sport 1-3 years post-ACLR (odds ratio (OR) 2.15; 95%CI 1.30 to 3.54; OR 2.11; 95%CI 1.23 to 3.60, respectively). These tests were also associated with better self-reported symptoms and function 1-37 years after ACL injury and reconstruction (OR 2.51; 95%CI 1.62 to 3.88; and 4.28; 95%CI 1.65 to 11.08, respectively). Achieving ≥90% limb symmetry on the single-forward hop was associated with lower odds of knee osteoarthritis 5-37 years after ACL injury and reconstruction (OR 0.46; 95%CI 0.23 to 0.94). Higher scores on a repeated-forward hop was associated with success without ACL reconstruction post-injury (OR 1.57; 95% CI 1.03 to 2.40).

**Conclusion:** Hop tests are prognostic indicators for important outcomes in individuals after ACL injury and might be used to stratify individuals at risk of poor medium- to long-term outcomes to target rehabilitation interventions.
Which youth are most likely to respond to neuromuscular training injury prevention warm-ups?

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Introduction: Neuromuscular training (NMT) warm-up programs can reduce injury risk among youth, but some individuals do not respond to NMT warm-up programs as well as the average participant.

Aim: Factors predicting the response to NMT in reducing injury risk are unknown, making this the aim of the study.

Materials and methods: This is a secondary analysis of the intervention groups of randomized controlled trials evaluating NMT warm-up programs in youth basketball (n = 494), youth soccer (n = 378), junior high school physical education (PE; n = 903). A total of 1651 youth (11-18 years) with complete data were included. Analyzed covariates were age, sex, height, weight, sport/PE, one-year injury history, number of weekly NMT sessions, and timed single-leg balance. Generalized estimating equation analysis was used to estimate odds ratios (OR) with clustering on team/class, exchangeable correlation structure, robust variance estimator, and offset for exposure hours.

Results: Based on the multivariable model, individuals with history of injury (OR = 1.73, 95% CI: 1.23-2.43) and females (OR = 1.56, 95% CI: 1.13-2.15) had higher odds of injury during the NMT intervention. Balance time (OR = 0.96, 95% CI: 0.92-1.00) and number of weekly NMT sessions (OR = 1.06, 95% CI 0.67-1.68) did not show an effect. When participants averaged 3 NMT sessions per week, soccer players had lower (OR = 0.90, 95% CI: 0.38-2.11) and basketball players had higher odds of injury (OR = 3.74, 95% CI: 1.87-7.48) compared to PE.

Conclusions: History of injury and being female increased the odds of injury. Higher weekly adherence was protective in soccer players. Future studies should focus on primary prevention, taking these findings into account.

Effects of 448 kHz capacitive resistive monopolar radiofrequency of the lumbar region on muscle tissue elasticity.

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Introduction: Worldwide, low back pain (LBP) is highly prevalent injury. LBP symptoms may impair performance for athlete.

Aim: Our purpose was to clarify the effects of 448 kHz monopolar radiofrequency (CRMF) and other physical stimulation of the lumbar region on muscle tissue elastic modulus.

Materials and Methods: The participants were 20 university students (12 participants in the LBP group with current LBP symptoms, and 8 participants in the previous LBP group who had LBP symptoms within the past 6 months) who were engaged in sports activities on a daily basis.

Muscle tissue elasticity was assessed in the lumbar multifidus muscle (MF) and iliocostalis lumborum muscle (erector spinae muscle [ES] group) during supine rest and seated stretching using a shear wave ultrasound imaging system.
Temporal changes were examined in the LBP group for 448 kHz CRMRF, Hot pack, Sham-high-frequency thermal stimulation (Sham) on MF and ES tissue elastic modulus.

**Results:** In terms of the temporal changes induced by each physical stimulus on MF and ES tissue elastic modulus, significance was shown for the interaction of MF during seated stretching ($F_{4,76} = 3.937$, $p=0.006$, $\eta^2=0.168$).

With follow-up testing, we found that 448 kHz CRMRF significantly decreased MF tissue elastic modulus immediately after the intervention compared with Sham ($p=0.019$).

**Conclusion**
This study revealed that 448 kHz CRMRF immediately increased MF extensibility.

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**An analysis of burnout and availability of wellbeing and mental health support among healthcare professionals working in the sporting environment.**

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**Introduction:** Burnout commonly occurs among healthcare professionals, sports coaches and trainers. Healthcare professionals working in sport are known to be exposed to stressful working conditions, but there is limited literature exploring burnout among healthcare professionals working in sport. Therefore this study set out to explore burnout and mental wellbeing among healthcare professionals working in sport.

**Methods:** A cross-sectional survey study, using an electronic questionnaire.

Data gathered for workplace supervision, wellbeing and mental health resources, Maslach Burnout Inventory- human services survey (MBI), Demographics. Descriptive analysis was completed using percentage difference, mean and standard deviations.

**Results:** 55 responses were obtained.
Which exercise therapy class is best for Rotator Cuff-Related Shoulder Pain? A systematic review and network meta-analysis.

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Introduction: Rotator cuff-related shoulder pain (RCRSP) is a prevalent musculoskeletal disorder frequently managed conservatively with exercise therapy. There is no consensus on which exercise therapy class is most effective.

Aim: To compare the efficacy of different exercise therapy classes to better establish a treatment hierarchy for RCRSP.

Materials and Methods: A systematic review including network meta-analysis (NMA) with comparative standardised mean difference effect sizes was conducted. Trials with at least two exercise therapy arms were included and based on the available data, categorised into three dominant therapy classes (resistance, flexibility, proprioception) across six core outcome domains (disability, physical function capacity, function, pain, range of motion and quality of life). A hierarchical Bayesian model was conducted to account for reporting of multiple data points within trials, with the analysis combined across all outcomes. Results were summarised through effect size estimates expressed relative to resistance dominant therapies, and Surface Under the Cumulative Ranking curve (SUCRA).

Results: Ten studies comprising eleven head-to-head comparisons with 573 participants and 161 outcomes were included. Pooled effect size estimates provided some evidence that flexibility (SUCRA: 0.68; d(Resistance:Flexibility_0.5)=0.15 [95%CrI: -0.03 to 0.32]) and to a lesser extent proprioception (SUCRA: 0.52; d(Resistance:Proprioception_0.5)=0.11 [95%CrI: -0.09 to 0.28]) dominant therapies were superior to resistance (SUCRA: 0.30) dominant therapies for management of RCRSP.

Conclusion: Therapies focussing on flexibility and proprioceptive exercise appear superior to those focussing on resistance exercise for the management of RCRSP. Future research and clinical practice should consider these findings when addressing more specific research questions and prescribing exercise.

Brain plasticity in patients with lateral ankle sprain and chronic ankle instability: a systematic review.

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Introduction: Lateral ankle sprains (LAS) are one of the most prevalent injuries in sport. It is still regarded as an innocuous sport injury in spite of an increased re-injury risk and almost half of LAS patients developing chronic ankle instability (CAI) with persistent dysfunctions and potential long-term sequelae. In addition, researchers found preliminary evidence of neuroplasticity at the spinal and supraspinal level after (repeated) LAS. Nevertheless, An overview of possible brain adaptations after LAS and CAI is currently lacking.

Aim: To systematically review and synthesize the literature on brain plasticity following LAS and CAI.

Methods: Included studies investigated functional and/or structural brain adaptations in patients with LAS or CAI. We used 7 electronic databases and performed the last search on 19 October 2021.
**Results:** Ultimately, we included 14 articles. 1 study included LAS patients, 13 patients included CAI patients. Following LAS, white matter microstructural changes occurred in the cerebellum. In CAI patients brain plasticity was demonstrated in the somatosensory, prefrontal and motor cortex, pre- and postcentral gyrus, superior parietal lobe and cerebellum. CAI patients mainly demonstrated alterations in corticomotor excitability and inhibition, grey matter volume, oxyhaemoglobin and event-related desynchronisation.

**Conclusion:** The included studies demonstrated brain adaptations after LAS and in CAI patients. These alterations might explain the persisting dysfunctions, increased re-injury risk and long-term sequelae seen in these populations. Clinicians should be aware of brain plasticity since it may not be so harmless after all. Rehabilitation programs should integrate sensorimotor and motor control rehabilitation strategies.

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**Who Develops Knee OA 5 Years After ACL Rupture? A Delaware-Oslo Cohort Study.**

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**Introduction:** Anterior cruciate ligament (ACL) ruptures are common and a devastating traumatic knee injury in young adults with highly variable outcomes. Developing knee osteoarthritis (OA) is one of the most concerning long-term outcomes.

**Aim:** To use subgroups of ACL injured individuals previously identified by latent class analysis based on patient characteristics, patient-reported outcomes (IKDC, KOS, Global Rating Score), and functional performance to determine subgroup differences in the development of posttraumatic OA at 5 years after ACL rupture.

**Materials and Methods:** Four previously identified subgroups at baseline were used: (Group 1[n = 64]: younger(24.6 ± 1.3) with good patient-reported outcomes; group 2[n = 77]: younger(22.7 ± 0.9) with low patient-reported outcomes; group 3[n = 36] older(31.3 ± 2.7) with poor patient-reported outcomes; group 4[n = 19] older(36.3 ± 3.0) with good patient-reported outcomes. Presence of joint changes in line with the development of OA were graded using the Kellgren-Lawrence (KL) system and operationally defined as KL grade of ≥1. Chi square tests assessed differences between subgroups and radiographic OA presence in the involved knees at 5 years after ACL rupture. 196 individuals had radiographs at 5 years and were included in the analysis.

**Results:** There were no significant differences in percentage of OA among subgroups(p = 0.059). 30% of group 1, 31% of group 2, 50% of group 3, and 53% of group 4 had involved knee OA.

**Conclusions:** Group 4, the oldest subgroup, had the highest prevalence of OA at 5 years. Though lower, the prevalence of OA at 5 years in the two young groups is highly concerning.

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**Who Develops Knee OA 5 Years After ACL Rupture? A Delaware-Oslo Cohort Study**

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The predictive validity of the Brazilian Adductor Performance Test for the risk of hip adductors injury in elite soccer athletes.

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Introduction: Injuries are very common in professional soccer athletes and can negatively affect performance and career, as they are associated with reduced athlete performance.

Aim: Our objective was to validate the Brazilian Adductor Performance Test (BAPT) as a test able of predicting muscle injuries of the hip adductors.

Materials and Methods: A methodological study of development and predictive validity, in which 108 soccer athletes were evaluated and followed up for three months and evaluated regarding their history of adductor injury in the six months before the evaluation. The Shapiro-Wilk test was the normality test. The Mann-Whitney U test was used to compare BAPT scores between injured and uninjured athletes. Binary logistic regression was performed to identify the athletes' risk of injury from the BAPT score. The ROC curve was used to determine the cut-off point for the number of repetitions in the BAPT and Spearman's bivariate correlation to identify factors that could influence the test score.

Results: There was no difference in BAPT scores for hip adductor injury history (p = 0.08). There was a significant deficit in BAPT scores for the injured athletes at the three-month follow-up (p = 0.0001). The cut-off point identified was 33 repetitions. Low BAPT scores increase the chance of injuring the adductor by 20% (Odds ratio = 1.20%, p = 0.001). Furthermore, age, weight, and height factors do not influence the BAPT result.

Conclusion: This study evidenced a significant deficit in BAPT scores for injured athletes compared to uninjured ones.

Static stretching effects in cold exposures.

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Introduction: Exposure to cold is known to affect physiological reactions such as tissue metabolic rates, neuromuscular function, and athletic performance. Musculotendinous stiffness also increases in cold exposures so that static stretching is considered important. However, the effects of static stretching in cold exposures are not determined well yet.

Aim: To determine the effects of static stretching on the ankle plantar flexors in cold exposures.

Materials and Methods: Ten healthy young male university students (22.4 ± 1.1 years) volunteered for this study. All participants were exposed to the 2 following conditions - warm (25°C) and cold (10°C) for 30 minutes. The skin and muscle temperatures were measured with a probe thermometer. Static stretching of the ankle plantar flexors and the ankle dorsiflexion range of motion (ROM) measurements were conducted using a dynamometer.

Results: The skin temperature and the muscle temperature in the cold condition were significantly lower than in the warm condition (p<0.05). Hence, no significant differences of the ankle dorsiflexion ROM changes with static stretching were found between the cold and the warm conditions.

Conclusion: Although skin and muscle temperatures were significantly lower in the cold conditions than the warm condition, the static stretching effects on ROM were unchanged. In cold environments, static stretching is indicated to be beneficial for maintaining ROM.
Effect size thresholds to interpret comparative interventions for tendinopathy management: A meta-analysis.

Mr. Paul Swinton, Ms J Shim, Ms A Pavlova, Ms R Moss, Mr C Maclean, Mr D Brandie, Ms L Mitchell, Ms E Parkinson, Mr D Morrissey, Ms L Alexander, Ms K Cooper.

Robert Gordon University, United Kingdom

Introduction: The purpose of this meta-analysis was to develop tendinopathy specific effect size thresholds to interpret relative effectiveness of interventions compared within a single study.

Methods: A literature search for interventions comparing exercise, non-exercise and combined therapies for the management of tendinopathy was conducted. Controlled trials comprising active interventions with any persons with a diagnosis of rotator cuff, lateral elbow, gluteal, patellar or Achilles tendinopathy of any severity or duration were included. Controlled standardised mean difference effect sizes were combined with Bayesian hierarchical models. To obtain symmetric distributions centred on zero, the sign of effect sizes were randomly flipped and boot-strap samples used to create meta-analysis models with the small, medium and large effect thresholds calculated from the 0.625-, 0.75-, and 0.875-quantiles, respectively. Analyses were combined across all tendinopathy locations and separated according to outcome domains including disability, function, pain, physical function capacity, range of motion and quality of life.

Results: Data were obtained from 181 studies. Across all tendinopathy locations and outcome domains the meta-analysis models identified 0.15 [75%CrI:0.10-0.20], 0.36 [75%CrI:0.29-0.42], and 0.71 [75%CrI:0.62-0.84] as the small, medium, and large thresholds, respectively. Consistent estimates were obtained across all outcome domains.

Discussion: Previous non-context specific effect size thresholds used to interpret comparative effectiveness (e.g., small: 0.20, medium: 0.50 and large: 0.80) for tendinopathy management are reasonable but may slightly underestimate each category, and by extension, sample size requirements. It is recommended that the context specific thresholds obtained in the present study be used to interpret and inform future tendinopathy research.

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Comparative efficacy of exercise, non-exercise and combined therapies for the management of tendinopathy. A systematic review and network-meta analysis.

Mr. Paul Swinton1, Ms J Shim, Ms A Pavlova, Ms R Moss, Mr C Maclean, Mr D Brandie, Ms L Mitchell, Mr L Greig, Ms E Parkinson, Mr D Morrissey, Ms L Alexander, Ms K Cooper
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Introduction: The purpose of this large systematic review and network meta-analysis (NMA) was to compare the efficacy of common therapies used to manage the most prevalent tendinopathies.

Methods: A search for interventions comparing exercise, non-exercise (e.g. electro-therapy, injection, manual-therapy, kinetics, non-active, and surgery), and combined therapies was conducted.

Interventions with any persons with a diagnosis of rotator cuff, lateral elbow, gluteal, patellar or Achilles tendinopathy of any severity or duration were included. Controlled standardised mean difference effect sizes were used with Bayesian hierarchical NMA models combining data across tendinopathy locations and separating results across six outcome domains including disability, function, pain, physical function capacity, range of motion and quality of life. Results were summarised through pooled effect size estimates and Surface Under the Cumulative Ranking curve (SUCRA).

Results: A total of 201 studies comprising 460 treatment arms and 11,888 participants were included. In all but one model, the SUCRA and pairwise effect sizes indicated the superiority of interventions combining exercise and non-exercise therapies relative to all other classifications. Median effect size estimates indicated that the combination of exercise with non-exercise therapies tended to improve outcomes by effect sizes of approximately 0.1 to 0.3. Less consistency was observed in the treatment hierarchy across the remaining broad treatment classes; however, non-active treatments ranked lowest.

Discussion: The findings from this large systematic review and NMA indicate that clinicians and researchers should consider prescribing and further studying the combination of exercise with other conservative modalities such as electrotherapy for the management of common tendinopathies.

Triceps surae muscle forces during the eccentric heel drop exercise in patients with Achilles tendinopathy compared to controls.

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Introduction: Achilles tendinopathy (AT) is an overuse injury in which excessive loading is associated with degenerative changes in the Achilles tendon. A differential distribution in triceps surae muscle forces has been found during isometric conditions for the AT group, however, it remains unknown whether this also occurs during dynamic exercises.

Aim: The aim of this study was to investigate the individual triceps surae muscle forces during the execution of the bilateral and unilateral heel drop exercise in patients with AT compared to a control group.

Materials and Methods: Eight AT patients (6F & 2M, 35 ± 15.2 yr) and nine controls (4F & 5M, 25.5 ± 7.2 yr) participated in this study. Joint kinetics, kinematics and electromyography of the soleus (SOL), gastrocnemius medialis (GM) and gastrocnemius lateralis (GL) were recorded during the execution of a bi- and unilateral heel drop exercise. Individual triceps surae muscle forces were determined through a combination of experimental data and musculoskeletal modelling.

Results: Although not significant, the AT group had a greater SOL force at the peak plantarflexion moment of 0.78 and 1.76 N/kg for the bilateral and unilateral drop, compared to controls reaching 0.61 and 1.31 N/kg, respectively. Correspondingly for the bilateral drop, lesser GM (0.71 N/kg) and GL force (0.17 N/kg) are used compared to the control group (0.75 N/kg [GM] and 0.22 N/kg [GL]). Similar results were obtained for the unilateral variant.
**Conclusion:** In the current study, triceps surae muscle forces are not different between the two groups during eccentric tasks.

**Objective:** To analyze the inclusion of biopsychosocial model domains in clinical practice guidelines (CPGs) for RTS after ACL injury.

**Search strategy:** Two independent reviewers developed the search strategy.

**Data Sources:** Ovid/Medline®, Embase®, and PEDro without restriction dates.

**Study Selection:** CPGs for RTS after ACL injury, at any age or sport level, and published in English.

**Data Extraction:** Two independent reviewers codified the RTS criteria recommended in the CPGs according to ICF domains and used the AGREE II for critical appraisal.

**Results:** A total of 715 records were identified, and seven CPGs were included. The frequency distribution of the biopsychosocial model domains was as follows: body functions (37.77%), activity and participation (20.00%), body structure (13.33%), environmental factors (11.11%), and personal factors (8.88%). In the AGREE II Checklist, the lowest mean domain scores were for rigour of development (37.86 ± 36.35) and applicability (49.29 ± 22.30). 71.42% were of low or moderate quality.

**Conclusion:** The CPGs cannot address the biopsychosocial model domains satisfactorily and some do not address all components of the ICF conceptual model, emphasizing the body functions and activity and participation domains. Therefore, the functioning model advocated by the World Health Organization (WHO) has not yet been adequately incorporated into the recommendations for RTS after ACL injury.

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**Inclusion of biopsychosocial model domains in clinical practice guidelines for return to sport after ACL injury: A systematic review.**

**Mr Jeffeson Hildo Queiroz,² Ms Yanka Murakawa,² Mr Shamyr Castro,² Mr Gabriel Almeida,¹,² Mr. Rodrigo Oliveira,¹,²**

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**Context:** The return to sport criteria can be understood from the International Classification of Functioning, Disability, and Health (ICF) which emphasizes an individual-centered approach and inclusion of all domains of human functioning, ensuring the multifactorial and biopsychosocial nature of decision-making.
The effects of Motor Imagery on therapeutic regimes in athletes with lower limb sport injuries.

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Background: Lower limb sport injuries affect athletes’ career as it has a connection between bio-psycho-social factors and well-being. Motor Imagery (MI) has been progressively included in rehabilitation as an adjunct therapeutic modality for sports injuries management.

Objectives: This systematic review evaluated the efficacy of MI intervention in athletes with lower limb sport injuries that could affect their pain levels, muscle strength, and sport's functional ability.

Methodology: A systematic search of the research literature was administered for RCT studies in athletes with lower limb musculoskeletal sports injuries. We searched 3 major databases, PubMed, Scopus and ScienceDirect with the search period ranging from their inception until the December of 2020. Study quality was assessed using Downs and Black Scale. The data was recorded and extracted with the use of Mendeley software.

Results: The search strategies depicted an exploratory pool of 5,021 possible articles. Upon completion of the selection procedure only 4 RCT studies met the inclusion criteria with a total of 80 injured athletes (n = 38 with ankle sprain and n = 42 with ACL injury). In 3 studies MI efficacy on pain and/or muscle strength and/or functional ability in both ACL and ankle sprain sport injuries was found.

Discussion: The results suggested that the use of MI as an adjunct therapeutic modality should be effective on pain, muscle strength and functional ability in lower limb sport injuries. Further research is needed on a larger scale of RCT studies and on targeted athletic groups with less clinical heterogeneity of lower limbs sports injuries.

Should we be assessing for balance impairments in Achilles tendinopathy?

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Introduction: Alterations in triceps surae muscle activation patterns and Achilles tendon mechanical properties are associated with Achilles tendinopathy. These impairments are also related to balance. Balance has not been investigated in a large cohort with Achilles tendinopathy and it is unknown if differences exist among previously established subgroups.

Aim: The purpose of this study was to evaluate single leg balance in individuals with midportion Achilles tendinopathy.

Materials and Methods: Participants were categorized into four subgroups: Older activity-dominant (OAD), young activity-dominant (YAD), psychosocial-dominant (PD), and structure-dominant (SD). Participants completed single leg balance
tasks with eyes open and eyes closed for maximal time up to 60 seconds. One-way ANOVA was completed comparing single leg balance in seconds on the symptomatic limb among subgroups.

**Results:** 106 participants (mean±SD; 47.3±12.1; 50 female) with midportion Achilles tendinopathy were categorized as OAD (n=35), YAD (n=33), PD (n=23), SD (n=15). There was a significant main effect of group for eyes open (49.0±18.0 s, 56.6±10.9 s, 37.6±21.2 s, 42.9±24.1 s; p=.001) and eyes closed (12.1±14.5 s, 21.8±18.8 s, 5.6±8.0 s, 4.9±5.0 s; p<.001). The PD group demonstrated significantly decreased single leg balance with eyes open compared to the YAD group (p=.001). Both the PD and SD groups demonstrated significantly decreased single leg balance with eyes closed compared to the YAD group (p<.001).

**Conclusion:** Current gold standard of treatment is tendon loading exercise. However, individuals with psychosocial and structural impairments also present with balance deficits. Balance training may be an appropriate adjunct to exercise treatment for these individuals.

**Symptom duration is not of relevance for injury severity or recovery with treatment in Achilles tendinopathy.**

**Introduction:** In patients with Achilles tendinopathy, it is often assumed that a longer duration of symptoms is related to worse tendon health and recovery.

**Aim:** To explore how Achilles tendinopathy symptom duration impacts tendon health and patient outcomes following 12 months of a comprehensive rehabilitation program.

**Materials and Methods:** 136 participants (49% female, age 47±13 years) with midportion Achilles tendinopathy were allocated into 4 groups based on duration of symptoms: “0-3 months”, “>6-12 months”, “>12 months”. Outcomes including the Victorian Institute of Sport Assessment-Achilles (VISA-A), Foot and Ankle Outcomes Survey-Quality of Life subscore (FAOS-QoL), heel-rise endurance test, and ultrasound examination measuring tendon thickening were evaluated at baseline, 4-, 8-, and 12-months while participants completed a comprehensive rehabilitation program with a physical therapist. Main effects of group, time, and interaction effect (Group*Time) were evaluated using General Linear Mixed Models.

**Results:** No significant effect of group was observed for any outcome measures at baseline. No significant interaction effects were observed among any outcomes, indicating similar improvement for all groups. Significant effects of time were observed for VISA-A (p<.001), FAOS-QoL (p<.001), and heel-rise work (p<.001) in all groups.

**Conclusion:** Clinical presentation and tendon health measures were similar at baseline, regardless of symptom duration. Additionally, each group responded similarly to treatment over 12 months. Therefore, clinicians should not rely on symptom duration for treatment decisions or outcome expectations for patients with Achilles tendinopathy.
Static Foot Posture Measures: Is there variance between Achilles Tendinopathy subgroups?

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Introduction: Achilles Tendinopathy has been proposed as a "pronation-related injury" with overpronation suggested to be an important factor in the etiology of Achilles Tendinopathy. Recent research has identified distinct subgroups of patients with Achilles Tendinopathy. Clinical Measurements to determine static foot posture are easily accessible to clinicians, however it is unknown if static foot posture is of relevance for subgrouping.

Aim: The aim of this study was to evaluate if static foot posture varies among subgroups of individuals with Achilles Tendinopathy.

Materials and Methods: Subjects with midportion Achilles Tendinopathy were classified into four subgroups based on the patient characteristics and domains of tendon health: Older Activity Dominant (OAD), Younger Activity Dominant (YAD), Psychosocial Dominant (PD), and Structural Dominant (SD). Static foot posture measurements were taken by a physical therapist and include: Foot Posture Index (FPI), Longitudinal Arch Angle (LAA), Navicular Drop, and Navicular Drift. A one-way ANOVA was used to compare static foot posture measurements between subgroups.

Results: 122 Subjects (Age 47.2±12.1, 55 females) were included and classified into the subgroups: OAD (n=38), YAD (n=33), PD (n=26), SD (n=15). There were no significant differences in FPI (4.1±3.5, 4.5±2.6, 3.6±3.3, 4.1±3.6; p=.794), LAA (145±9.6, 145.2±11.6, 144.5±13.0, 140.1±7.8 deg; p=.411), Navicular Drift (5.9±3.4, 6.9±4.3, 5.9±4.5, 3.9±3.6 mm; p=.123), and Navicular Drop (7.7±3.8, 8.1±4.1, 7.5±4.6, 6.4±4.5 mm; p=.641) between the subgroups.

Conclusion: Static foot posture measurements are not different between subgroup, therefore may not be of relevance for the clinical evaluation of patients with Achilles Tendinopathy.

Achilles tendon neovascularization decreases with exercise treatment.

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Introduction: Neovascularization (the formation of intratendinous blood vessels) has been shown to occur in patients with Achilles tendinopathy. The presence of neovascularization is a sign of tendon pathology. The impact of exercise treatment on neovascularization remains unknown.

Aim: The objectives were 1) to measure the difference in neovascularization area before and after exercise treatment 2) to explore if the degree of change in neovascularization area relates to changes in tendon structure and symptom severity.

Materials and Methods: 21 subjects with Achilles tendinopathy and neovascularization were recruited from an ongoing clinical trial. Power Doppler imaging recorded video clips of neovascularization, and Quantitative Analysis software measured the neovascularization area. B-mode ultrasound imaging was used to measure tendon cross-sectional area and thickness. The Victorian Institute of Sports Assessment-Achilles (VISA-A) questionnaire measured symptom severity. Subjects completed tendon loading exercises under the guidance of a physical therapist. Subjects were evaluated at baseline and after 8 weeks. The changes in the outcomes were used for analysis. A correlation analysis was used to explore associations between change in neovascularization area and change in tendon structure and symptom severity.

Results: Neovascularization area decreased by mean±SD -3.1±17.4 mm². There was a moderate correlation between the changes in neovascularization area and symptom severity (r = -0.459, p = .037) but not for measures of tendon structure ([CSA p = 0.246], [thickest portion p = 0.093]).
**Conclusion:** Following exercise treatment of Achilles tendinopathy, there was a decrease in neovascularization area that related to improvements in symptoms.

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**Application of an Online Prevention Protocol Reduces Anterior Cruciate Ligament Injuries Risk Factors Among Female Athletes.**

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**Introduction:** Anterior cruciate ligament (ACL) injury is one of the most common sports injuries, which often requires ligament reconstruction surgery, especially for athletes who want to go back to sport and competition. However, after the reconstruction, the prolonged rehabilitation period will delay the athletes' return to sport. Furthermore, recent studies connect ACL reconstruction with long-term complications, knee joint degeneration, and osteoarthritis.

**Aim:** To study the effect of the Knäkontroll ACL prevention protocol on the mechanical risk factors of developing non-contact ACL injuries among female athletes.

**Methods and materials:** A pre-post intervention design was followed. Tuck jump test, static balance, dynamic balance, and hop tests were tested pre-intervention, 2 and 4 weeks after the intervention. The Knäkontroll ACL prevention program was performed three times per week for four weeks. Instructions and videos were delivered via video calls (remotely) in the first session of each week, and the remaining two sessions were done as a home program. The exercises gradually increased in level based on the participant's progression.

**Results:** Thirty females (age 21.4 ± 2.7) playing different sports at an amateur level participated voluntarily. There were statistically significant improvements in all outcome measures at 2 and 4 weeks after the prevention protocol (P < 0.001).

**Conclusion:** The Knäkontroll ACL prevention protocol effectively reduces ACL injuries risk factors by improving the static and dynamic balance, jump and hop abilities. It can also be applied to athletes remotely as a quick intervention before sporting events.

### 75
**The Capability of a Screening Questionnaire in Detecting Sports-Related Sudden Cardiac Death (SSCD) Risk Factors Among Active Bahraini Population.**

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**Introduction:** Sport-Related Sudden Cardiac Death (SSCD) is a leading cause of mortality in the athletic population. Cardiovascular pre-participation screening can be lifesaving. Yet, there are no definite recommendations nor official screening protocols to specify who and how they should be screened in Bahrain or the region.

**Aim:** To design a multi-phase screening protocol starting with a self-administered screening questionnaire as the first phase.

**Materials and methods:** Exploratory research using an online self-administered questionnaire. It was designed based on evidence-based international recommendations and aims to identify risk factors, signs, and symptoms of SSCD, family history, drugs, and supplements across the Bahraini population. Experts in the field validated the questionnaire followed by a pilot study.

**Results:** 421 individuals participated in the questionnaire (age range 15-69), mainly males (70%). The questionnaire revealed that 83% of the participants did not perform any medical examinations before physical activity, 9% experience tiredness and shortness of breath during exercise compared to their peers, 8% reported irregular heartbeats while exercising, and 5% complained from lightheadedness during training. Moreover, 21% of them indicated a
history of familial death due to a heart condition before 50, 24% have a family history of SCAs, 26%, and 25% have a family history of cardiac disorders and a history of SSCD related signs and symptoms, respectively.

**Conclusion:** According to the American Heart Association, the detected signs and symptoms predispose individuals to develop cardiac pathologies. Thus, the developed questionnaire may help detect hidden risks of SSCD in athletes.

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**Use of Ultrasound Imaging to Facilitate Transition from Non-Surgical to Surgical Management of Acute Achilles Tendon Rupture.**

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**Introduction:** Presence of Achilles tendon gap and gap width observed with ultrasound imaging can be used to aid in diagnosis and treatment decisions following acute Achilles tendon rupture and re-rupture. Aim: To describe the use of ultrasound imaging to transition from non-surgical to surgical management and report on the patient and clinician perspectives on dealing with the dreaded re-rupture.

**Materials and Methods:** Measures of psychosocial factors (Tampa Scale of Kinesiophobia TSK-11) and function (seated heel-rise test). B-mode ultrasound imaging was performed to assess Achilles tendon gap and length.

**Results:** The 22-year-old male heard a “pop” in his ankle when planting and cutting during an intramural soccer game. B-mode ultrasound confirmed rupture and the patient was referred to an orthopedic surgeon. Based on small tendon gap (< 5 mm), non-operative management was initiated. However, the patient slipped (week 3) and reported pain and difficulty with heel-rise. Ultrasound confirmed re-rupture with gap of (> 5 mm). Surgical repair was performed 4 days later.

9 weeks post surgery, patient had TSK-11 of 16. B-mode ultrasound demonstrated a 3 cm tendon elongation with clinical findings of 6.4 cm seated heel-rise height differential. The patient verbally expressed hesitancy with walking, despite minimal kinesiophobia. Treatment with progressive tendon load exercise, education, and objective measures were considered key for successful outcome by both patient and clinician.

**Conclusion:** Ultrasound imaging facilitated efficient and successful transition from non-operative to operative management following re-rupture.

Psychological readiness should be monitored, particularly in those with significant pivots in rehabilitation strategies.

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**Intensive supervised rehabilitation versus less supervised rehabilitation following anterior cruciate ligament reconstruction? A systematic review and meta-analysis**

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**Introduction:** It is unknown if supervision leads to superior outcomes following ACL reconstruction.

**Aim:** To investigate whether intensive supervised rehabilitation following ACL reconstruction leads to superior self-reported function and sports participation compared to less supervised rehabilitation.

**Materials and Method:** We performed electronic database searches in several key databases and trial registries (e.g., MEDLINE, Embase, ClinicalTrials.gov) to April 2020.

We included randomised controlled trials (RCTs) comparing supervised rehabilitation to rehabilitation...
with a similar protocol that used less supervised sessions for athletes following ACL reconstruction. Two reviewers independently screened studies and extracted data. The Physiotherapy Evidence Database (PEDro) scale was used to evaluate methodological quality and GRADE to evaluate overall quality of evidence. Self-reported function and sports participation were the primary outcomes. Data were pooled using random effects meta-analyses.

**Results:** Our search retrieved 4075 articles. Seven articles reporting on six RCTs were included (n = 353). Very-low to low-certainty evidence suggests intensive supervised rehabilitation is not superior to less supervised rehabilitation following ACL reconstruction for improving self-reported function, sports participation, knee flexor and extensor strength, range of motion, sagittal plane knee laxity, single leg hop performance, or quality of life.

**Conclusion:** Based on uncertain evidence, intensive supervised rehabilitation is not superior to less supervised rehabilitation for athletes following ACL reconstruction. Although high-quality RCTs are needed to provide more certain evidence, clinicians should engage athletes in shared decision making to ensure athletes’ rehabilitation decisions align with current evidence on supervised rehabilitation as well as their preferences and values.

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**Transient Experimental Knee Deafferentation Impacts Sensorimotor Neural Activity for Knee Motor Control: A Preliminary Analysis.**

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**Introduction:** After anterior cruciate ligament injury, a multitude of factors (joint deafferentation, surgery, rehabilitation, etc.) contribute to neural alterations for knee sensorimotor control. An improved understanding of the injury associated contributions to sensorimotor control would assist in the development of targeted nervous system interventions.

**Aim:** To evaluate if intraarticular experimental knee joint deafferentation alters knee sensorimotor neural activity.

**Materials and Methods:** 4 healthy college aged recreational athletes participated (23.3 ± 1.0 years, 166.4 ± 8.4cm, 63.6 ± 4.8kg). Functional magnetic resonance imaging was used to quantify blood-oxygen-level-dependent signal with a 3-Tesla MR scanner using a 16-channel, phased array head coil. A unilateral knee flexion/extension task paced to an auditory metronome (1.2Hz) was performed under sham and deafferented conditions. The motor task consisted of alternating rest (n = 5) and movement (n = 4) blocks, each 30-seconds in duration. Task-related neural activity was contrasted between conditions with a single-group paired t-test analysis and restricted to the left superior parietal lobule (SPL) and supplementary motor area (SMA) as regions of interest due to their roles in sensorimotor coordination. A significance level of p < 0.05, z-threshold > 3.1 corrected for multiple comparisons using a gaussian random field cluster approach.

**Results:** The deafferentation condition increased neural activity in the left SPL (z-max = 9.49, p < 0.001, 534 voxels) and decreased in the left SMA (z-max = 6.83, p < 0.001, 111 voxels).

**Conclusion:** Experimental deafferentation decreased neural activity in the SMA indicating a potential role of knee sensory receptors for motor planning. Joint deafferentation also increased neural activity in the SPL a key region for multisensory-cognitive processing.

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**Asymmetrical Loading within the Patellar Tendon after Anterior Cruciate Ligament Reconstruction (ACLR) using Patellar Tendon Graft: Case Report.**

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**Introduction:** Patellar tendinopathy is common after ACLr using patellar tendon graft. Altered loading within the tendon may explain this morbidity. The loading behavior across the medial vs. lateral patellar tendon after ACLr, however, remains unknown.

**Aim:** To quantify differences in patellar tendon strain at the medial and lateral aspects of the tendon on the surgical knee and contralateral knee of an athlete after ACLr using patellar tendon graft.

**Materials and Methods:** A 24-year-old female football athlete 6 years after ACLr performed isometric knee extensions at 20%-40%-60%-80%-100% of her maximal voluntary contraction (MVC) on a dynamometer with the knees at 60°. Simultaneous ultrasound images of the patellar tendon were taken by a clinician during contractions. The process was repeated for the medial and lateral aspects of the tendon bilaterally. Tendon strain was calculated using the ratio between the tendon length during contraction and the length at rest.

**Results:** Higher strain was observed in the medial side of the tendon (11-28%) when compared to the lateral side (2-12%) of the ACLr limb during all levels of effort. Conversely, higher strain was observed in the lateral side (16-33%) of the tendon when compared to the medial side (11-28%) in the contralateral limb. MVC was lower in the ACLr limb (182Nm) compared to the contralateral side (232Nm).

**Conclusion:** The medial versus lateral patellar tendon strain relationship during knee extension were different between limbs in an athlete after ACLr. This alteration in patellar tendon loading pattern may partly explain morbidities after ACLr using patellar tendon graft.

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**Exercise therapy for tendinopathy: A scoping review mapping interventions and outcomes.**

Ms. Lyndsay Alexander,¹ Mr David Brandie,² Dr Victoria Tzortziou Brown,³ Mr Leon Greig,¹ Ms Isabelle Harrison,¹ Mr Colin MacLean,⁴ Ms Laura Mitchell,³ Prof Dylan Morrissey,⁴ Dr Rachel Moss,³ Ms Eva Parkinson,¹ Dr Anastasia Pavlova,¹ Dr Joanna Shim,¹ Dr Paul Swinton,¹ Prof Kay Kay Cooper¹

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**Introduction:** Tendinopathy is a common condition leading to pain, disability and reduced quality of life/participation. Exercise is the mainstay of conservative management and a mapping of this area is required to inform future research, both primary and secondary, and ultimately practice.

**Aim:** To map the evidence on exercise interventions and outcomes for tendinopathy.

**Methods:** JBI Scoping Review methodology and a-priori protocol guided this review. Inclusion criteria included i). Participants - studies including any age or gender with any tendinopathy, ii). Concept – Exercise therapy (any type or format) intervention, delivered in any setting by any professional with any outcomes related to evaluating exercise interventions for tendinopathy, iii). Context – any setting in any developed nation listed as having very high human development and published from 1998-2021.

**Results:** 22,550 sources were identified and 555 studies were included in the review representing 25,490 participants from 31 countries. Main tendinopathies reported were rotator cuff related shoulder pain (RCRSP), Achilles, lateral elbow and patellar. Strength training approaches were most common followed by flexibility and motor re-training / proprioception exercise. Exercise interventions across
tendinopathies were poorly reported with around 15% classed as fully reproducible using the TIDieR checklist.

There was variation across tendinopathies in domains (disability, pain and physical function capacity) reported with corresponding variation in primary outcome measures related to these.

**Conclusion:** Core recommendations to guide future research include specific study designs, study reporting and the need to understand clinician and patient experience.

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**81 Shared Decision-Making and Patient Education in Managing ACL Injury: Understanding Treatment Options.**

**Ms. Angela Smith, Dr. Karin Silbernagel, Dr. Lynn Snyder-Mackler**

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**Introduction:** Many clinicians are unaware of how to integrate the current evidence in the management of ACL injuries in order to counsel their athletes to determine the best treatment option. The shared decision-making model can be applied to acute ACL injury, including the decision for operative vs. non-operative management.

**Aim:** To implement the use of a research-based algorithm to guide clinicians in the management of acute ACL injuries using shared decision-making framework, starting with education on treatment options and outcomes.

**Materials and Methods:** The ACL Injury Treatment Algorithm was developed by incorporating the best available evidence into a clinical guideline that aids the physical therapist in the education and treatment of athletes with acute ACL injuries. The algorithm is rooted in the findings of the DE-OSLO Cohort Study, a longitudinal cohort study of 300 ACL-injured participants followed from injury through 10-year follow-up. The algorithm has been used for over 20 years in a large outpatient clinic with a high volume of ACL-injured athletes, with recent updates in conjunction with the development of new evidence.

**Results:** Clinicians have successfully implemented the algorithm, starting with evidence-based education, to determine the best treatment pathway for each individual by discussing treatment options and outcomes and considering the contextual factors impacting each athlete's treatment decision.

**Conclusion:** Use of this algorithm supports a shared-decision making model whereby clinicians are able to share the best available evidence and athletes are supported to consider their options and make informed decisions regarding treatment for their ACL injury.
Variation in hip muscles force production following two types of femoro-acetabular impingement surgery.

Mr Guillaume Servant, Mr Panayotis Christofilopoulos, Mr Eusthatios Kenanidis, Mr Hugo Bothorel, Mr. François Fourchet

Introduction: Femoroacetabular impingement (FAI) can be treated surgically by arthroscopy (AS) or hip dislocation (HD). While the positive effects of aforementioned surgeries on patients' quality of life are well known, the pre- to postoperative changes in force production of hip muscles were rarely evaluated.

Aim: To evaluate whether AS and HD surgical procedures significantly affect hip muscles strength in FAI patients.

Material and method: Forty-two patients (69% women) aged 20-45 years at index surgery underwent AS (n=29, 69%) or HD (n=13, 31%). Each patient was tested before (T1) and 3 months after surgery (T2). The force production of the hip muscles was measured in isometric mode using a handheld dynamometer on both sides.

Results: No T1-T2 significant differences could be noted on the non-operated side. On the operated side, the AS group exhibited a decreased strength of hip flexors (7.7±2.2 vs 7.1±2.0 Nm/kg, p=0.047), abductors (2.6±0.6 vs 2.3±0.6 Nm/kg, p<0.001) and external rotators (7.1±4.2 vs 6.3±4.0 Nm/kg, p=0.038). The HD group exhibited a decreased strength of the gluteus muscle (8.8±3.1 vs 7.7±2.3 Nm/kg, p=0.003), abductors (2.3±0.6 vs 1.9±0.3 Nm/kg, p=0.009), as well as internal (7.9±3.4 vs 5.9±2.4 Nm/kg, p=0.013) and external rotators (7.9±3.3 vs 5.6±2.2 Nm/kg, p=0.017).

Conclusion: Abductors and external rotators strength was affected by both surgeries. Hip dislocation seems to additionally decrease gluteus and internal rotators strength while arthroscopy might decrease hip flexor strength. According to pain level, specific reinforcement is therefore necessary for patients with FAI if they are treated surgically.

Mapping practitioners approaches to running-related injury (RRI) prevention and management and their views on a proposed digital RRI intervention.

Ms. Kathleen Walker, Professor Nicola Phillips, Dr. Liba Sheeran

Introduction: Developing a digital RRI prevention and management intervention requires involvement of all stakeholders, including practitioners e.g physiotherapists, coaches and trainers. To develop an acceptable and effective intervention it is important to explore current practitioner RRI prevention or management approaches and their views on a proposed digital RRI prevention and management intervention.

Aim: 1) Establish participants' approaches to RRI prevention and management. 2) Map participants' views on the content of a proposed digital RRI prevention and management intervention.

Materials and Methods: Following convenience sampling 6 online focus groups were conducted with 18 participants: 14 physiotherapists, 1 strength and conditioning coach and 3 personal trainers. Data analysis was via thematic analysis. Transcripts were coded and central themes and sub-themes identified.
Results: Data analysis identified 5 key themes: 1) Approaches to Injury Prevention; 2) Barriers to Injury Prevention; 3) Use of Digital Technology; 4) The Ideal App; 5) Unintended Consequences of The Ideal App.

Conclusions: The consensus from the participant group views explored was that any digital intervention needs to be evidence based and easily accessible, providing a range of advice for RRI prevention and self-management, which would avoid the need to use too many different apps. Careful consideration needs to be given to the unintended consequences of providing unseen advice which is important in instilling trust in any intervention. The development of any future digital intervention should consider these findings.

Usability testing of digitally enhanced remote rehabilitation feedback for injured dancers and athletes: an innovative protocol.

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Introduction and purpose: During pandemic lockdowns, health professionals had to accelerate telehealth innovation. Rehabilitation adherence and fidelity were especially challenging. We aimed to develop and establish the feasibility of our CAPA_MORF (Computer-augmented-personalised-asynchronous-movement-tracking-overlay-for-remote-feedback) tool as a potential solution. Rapid response funding was secured.

Methods: An innovative iterative-convergent-mixed-methods design was adapted with comprehensive stakeholder engagement of users, developers and therapists, to evaluate and improve digital tool feasibility, usability and acceptability. Twenty injured dancers and athletes aged 18-50 with 3+ years of training experience are being recruited in 4 sequential groups. They perform clinically indicated rehabilitation exercises with bespoke feedback on 2 occasions, alongside Telehab® use. Quantitative outcomes include the System-Usability-Scale and an electronic-health-literacy questionnaire alongside qualitative interviews. This information will be analysed using a matching integration strategy meaning qualitative data explains quantitatively-identified usability problems. Data will iteratively inform digital tool adaptation for subsequent participant groups, until the a-priori defined acceptable usability end point is reached and all major implementation barriers resolved.

Results: An innovative method has been designed suitable to address the evidence-practice gap and translate digital innovations into practice while enabling their improvement. Specific changes to CAPA_MORF presentation included overlay colour, contrast, instructions and set-up amendments. Identified problems were the consistency of the feedback and spinal tracking accuracy.

Conclusion: This study will provide evidence regarding the usability of an innovative digital tool. The developed iterative-convergent-mixed-methods design can be used as guidance for the development of similar complex digital interventions, as preparation for clinical trials.

Risk factors for groin injury in professional men’s football: does asymmetry matter?

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Introduction: Asymmetry between limbs can be identified through musculoskeletal screening. There is no research to date identifying association with asymmetry for risk of hip and groin injury in professional soccer players. Normative data for asymmetry is unknown in this population.
**Aim:** To examine normative values for between-limb asymmetry within professional male soccer players for range of motion and strength. To evaluate the relationship between asymmetry and hip/groin injuries leading to time loss from training and/or match play.

**Materials and Methods:** Retrospective cohort study; Level of evidence, 2. Adult male professional football players in Qatar, underwent musculoskeletal screening with time-loss/exposure monitored through injury surveillance. Asymmetry values for hip range of motion and strength tests were calculated and Cox regression analysis used to assess association for risk of hip/groin injury.

**Results:** No association for asymmetry variables with risk of hip/groin injury except for total rotation range of motion (p 0.040, HR 1.03). Asymmetry ranges between -20 to +20% are normal and exist for all measures.

**Conclusion:** Asymmetry was not associated with risk of hip and groin injury for six out of seven variables. Total rotation range of motion asymmetry was only associated favouring the dominant side.

Identifying the total rotation for both limbs through musculoskeletal screening tools may be relevant however mechanisms/causality remain unknown. The study provides clinical reference values for normative ranges of asymmetry in male professional soccer players; providing context for profiling of players, injury prevention, management and return to play protocols.

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**Prevalence and perception of ankle sprains in college students in Pakistan and the United States.**

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**Introduction:** There is a dearth of knowledge regarding the prevalence, treatment administered and people’s perception of ankle sprains in developing countries such as Pakistan. Therefore, the purpose was to determine the differences in the prevalence, treatments applied following injury and perception of ankle sprains in Pakistan and the United States (US).

**Materials and Methods:** An online epidemiology and literacy survey was administered between January 2019 to April 2019 in both countries. A total of 291 college-aged students (135 Pakistani and 156 US) completed the survey.

**Results:** 49.6% of the US and 48.7% of the Pakistani college students self-reported a history of ankle sprains. In both countries students most commonly reported to doctors (43.48% US, 31.58% Pakistan) and physiotherapists (11.96% US, 10.53% Pakistan). However, Pakistani students (10.53%) also reported to musculoskeletal quacks (bone-setters). Most common treatments used were rest (13.50%), ice (13.4%) and elevation (10.77%) in the US and rest (25%), massage (17.07%) and medications (12.80%) in Pakistan. In terms of health literacy, 95% of the US students think that one ankle sprain can lead to another but only 50% of the Pakistani students thought the same way. 93.6% of the US and 45.3% of Pakistani students think that ankle sprain can result in chronic ankle instability.

**Conclusions:** Although the prevalence of the ankle sprains was similar in both countries (almost half of the college students self-reported) there were huge discrepancies found in health literacy and treatment interventions used.
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Aim: Assess the criterion validity of the sphygmomanometer, relative to the Force Frame Strength Testing System. Determine the test-retest reliability for both hip adduction and abduction strength.

Materials and Methods: 50 asymptomatic, field-sport athletes were tested for maximal isometric hip adduction and abduction strength. Interclass correlation coefficient (ICC2,1) with confidence intervals were calculated to evaluate the reliability of peak strength values. A Pearson product-moment correlation coefficient(r) was calculated to examine the criterion validity of the sphygmomanometer as a measure of force when compared to the ForceFrame.

Results: Intra-rater reliability for bilateral adduction testing using both ForceFrame and sphygmomanometer values revealed good-excellent reliability for both the 0° (Lower CI of ICC2.1 = 0.75 – 0.82) and 45° (Lower CI of ICC2.1 = 0.74 – 0.84) positions. ForceFrame values revealed good-excellent reliability for 0° abduction position and 45° abduction position. A poor relationship (Lower CI of r = 0.42) for 0° adduction position, and no relationship (Lower CI of r = 0.14) for 45° adduction position, were found between adduction squeeze values on ForceFrame and sphygmomanometer.

Conclusion: Excellent reliability in hip adduction squeeze strength testing for both modes. However, there exists a ‘fair’-‘no relationship’ between the Force Frame and sphygmomanometer.

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Patient-reported outcomes and muscle strength after a physiotherapy-led exercise and brace intervention of acute injury of the posterior cruciate ligament.

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Introduction: Posterior Cruciate Ligament (PCL) injuries can be treated surgically or with exercises and a brace. Larger prospective studies reporting outcomes of exercise-related interventions are lacking.

Aim: To investigate changes in patient-reported outcomes of a physiotherapy-led exercise and brace intervention in patients with acute injury of the PCL over a 2-year follow-up period. Furthermore, to investigate changes in isometric knee muscle strength, and to report conversion to surgical reconstruction.

Materials and Methods: Fifty patients were treated with a brace for 12 weeks and underwent a 16-week exercise intervention. Changes in patient-reported outcomes was investigated with the International Knee Documentation Committee Subjective Knee Form (IKDC-SKF), the Tegner Activity Scale and the Knee injury and Osteoarthritis Outcome Score from baseline to 2-year follow-up. Changes in isometric knee flexion and extension strength were measured from 16 weeks after diagnosis to 1-year follow-up. Conversion to surgery was prospectively extracted from medical records. Mean changes were analysed with a mixed effect model with time as a fixed factor.

Results: The IKDC-SKF score improved 28(95% CI 24-33) points from baseline to 2-year follow-up. Isometric knee flexion strength increased 0.15(95%
CI 0.07-0.23)Nm/kg from 16 weeks after diagnosis to 1-year follow-up, corresponding to an increase of 16%. Knee extension strength did not change (0.10(95% CI -0.02-0.21)Nm/kg, p=0.107). Seven patients converted to PCL surgical reconstruction.

**Conclusion:** The physiotherapy-led exercise and support brace intervention demonstrated clinically relevant improvements in patient-reported outcome and knee flexion strength, and the risk of PCL surgical reconstruction was considered low within the first 2 years.

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AlfaCare and the International Federation of Sports Physical Therapy is pleased to announce the recipient of the first annual AlfaCare prize. The winner is Eduardo Tondelli from Argentina. He is an early career member of the national sports organization AKD, the Argentinian Sports Physiotherapy Association. Eduardo has experience in working as a physio in rugby, as well as general practice.

Eduardo is well published and has lectured internationally, both live and online. He is part of the sport physiotherapy faculty of Universidad de Buenos Aires. He currently holds positions as Head Physiotherapist in Rugby Club Los Matreros, Morón, Buenos Aires province, Argentina; Injury surveillance project manager in Buenos Aires Rugby Union. Buenos Aires City, Argentina; Sport Physiotherapist at Club Atlético Huracán. Buenos Aires City, Argentina; and Sport Physiotherapist at Kiné – Deportiva y Funcional (Sport Clinic), Buenos Aires City, Argentina.

According to Eduardo, “My work purpose in the 4th IFSPT congress is to know how colleagues from around the world approach their athletes and how sports societies work in the transmission of knowledge to the community. Also, promote a better image of our AKD in the sports community. I would like the IFSPT Nyborg congress to be the beginning of the path to work together and to be able to participate in future congresses with new studies. On my return to my country, I will expose through an open day to AKD partners how the experience was international and try to generate interest for future conferences.

“My application for the AlfaCare prize award is strengthened since a member that actively participates in the dissemination of scientific content for the association, for having very good handling of interpersonal relationships and communication skills, for handling the English and Portuguese languages, and having a lot of intention and willingness to promote the international growth of the sports physiotherapist association of Argentina.”

Congratulations to Eduardo, and see you in Denmark!
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