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As I begin my second decade as a practicing physical therapist, I would be lying if I said I never felt the proverbial “burnout” that we now hear so much about. Occupational burnout in the healthcare fields has been studied since the late 70’s, when trends of higher burnout compared to other professions were identified. Skip ahead over fifty years and a global pandemic later and I think we are seeing numbers skyrocket. The sports physical therapy profession, specifically, involves lengthy relationships with patients over the course of weeks to many months, and typically has a certain level of pressure involved in restoring an athlete back to competitive level. As healthcare providers, this fuels many if not all of us, and if that were the extent of the pressure, I think burnout would be incredibly low. Now add to this the mounting productivity demands, overwhelming student debt payments, documentation loads, and the attempt at a balance between work and personal life while trying to give your patients your very best, every day. These mental and physical stressors are present in some form to all of us. I certainly don’t have this all figured out, but in my experience, I feel there are two anchors that have helped me avoid hitting “rock bottom” burnout – self-care and mentorship.

When I think about self-care, this is not a spa weekend or reading a self-help book, although both are great and welcomed efforts! I’d view this more as a fluid learning and understanding of what balance you personally need in your current season of life as a healthcare professional. Something as simple as a regular workout routine may be enough to keep you on your game currently, but a few years from now that might look like the desire and need for quality time with family between your last patients of the day and putting your child to bed at night. These two scenarios are different, but one is no more or less important. Making time for what helps to keep you enjoying these trips around the sun is what will make for a physical therapist who can thrive in a chaotic environment.

In September, the American Physical Therapy Association announced its Fit 4 Practice Campaign which will launch mid-October for National Physical Therapy Month. It provides resources and opportunities for clinicians centered around the following four pillars:

1. **Movement**: physical strength and mobility.
2. **Restoration**: sleep and nutrition.
3. **Resiliency**: mental health and stress management.
4. **Practice fitness**: professional development and practice management.

I applaud the APTA for this initiative, and hope it gets more professionals considering the various opportunities around them to care for their physical, mental, and emotional needs. The fourth pillar, practice fitness, takes me to my second anchor noted above – mentorship.

To not just survive but thrive as a sports physical therapist, you need mentors along the way. It has been my observation that there is no shortage of seasoned sports physical therapists willing to help the younger generation. However, the expectation that this assistance and guidance will fall into your lap unsolicited seems to have led to a younger generation of professionals who are frustrated with their trajectory.

I attend many meetings and continuing education courses, and when I look around I see people spending most of their time socializing and mingling with people they already know, predominantly in the same stage of their career. I encourage every young professional or those seeking growth in the world of sports physical therapy to step outside their comfort zone, and simply start with a handshake and a thank you to those who have come before you. Engage in conversations with the people who wrote your textbooks and the research you rely on. But more than anything, be proactive. If you want a mentor, YOU and you alone are responsible for driving that relationship and putting in the time and effort to grow that relationship. Don't get me wrong, your mentor needs to show up, but they are not responsible for seeking you out. That may sound rude or harsh, but in ten, twenty, or thirty years, if you do exactly that, you will look back and realize how significant those choices were, and you too will be on the giving end of mentorship.

If you aren't sure where to start, I'd encourage you to attend meetings where the team approach to sports medicine is the focus. Relationships and support from other therapists, as well as athletic trainers, physicians, and industry representatives, can all play a role in your growth and success as a sports physical therapist. Interacting with orthopedic surgeons and sports medicine physicians should be a regular part of your life. Meetings and courses that incorporate the entire team encourage these interactions and provide a wealth of information to us as physical therapists, both didactically and socially. Attend, shake hands, exchange contacts, and FOLLOW UP! As the saying goes, “the fortune is in the follow up.” If you give Kevin Wilk, Mike Reinold, Kristian Thorborg, me, or any other busy and successful physical therapist your business card and say you’d like us to mentor you…don’t expect a phone call. Reach out, have specific questions, initiate regular conversation, PUT IN THE WORK.

Being a professional is an honor and a blessing, but it is also challenging. If you are seeking happiness in a career as a sports physical therapist, take care of yourself and truly understand what that means in this season of life, and actively seek mentorship. Remember the two things you have control over are your attitude and your effort.

Sincerely,

**Ashley Campbell**
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Thomas Jefferson
Clinical Study & Frontiers in Neurology White Paper
Sports physical therapy has been a recognized specialty since the early 1970s. The International Federation of Sports Physical Therapy (IFSP) has further expanded and promoted this specialty since IFSP was established in 2000. The IFSP’s European Union-funded Sports Physiotherapy for All (SPA) project describes effective professional behaviour and the integration of specific knowledge, skills and attitudes for the context of practice as a sports physical therapist for the first time. As of August 2021, the IFSP includes 34 member countries, and currently 13 of these member organizations have approved educational pathways to allow international sports physical therapist recognition. This has led to more than 300 sports physical therapists globally who now hold the recognition of being an IFSP Registered International Sports Physical Therapist (RISPT) (https://ifspt.org/rispt/). This aligns perfectly with the mission of the IFSP, which is to be the international resource for sports physical therapists, with the vision of promoting sports physical therapy to advance and improve the quality of care of athletes worldwide.

IFSP has created a culture of executive board excellence through good governance. Good governance relies on eight major principles, including participation, consensus, accountability, transparency, responsiveness, effectiveness, equality and inclusivity, and following the rule of law. The IFSP board divides their work into Research, Education, Membership and Communications in separate working groups. For the first time in IFSP history, an annual report was published in 2020 to describe our work and achievements. IFSP also conducted a member survey to make sure we align with the mission and values of the IFSP, and to understand what member benefits our Member Organizations would like IFSP to provide. The main feedback from our member countries was more focus on engagement, knowledge sharing and global networking.

Due to the COVID-19 situation, no face-to-face meeting has been possible since 2019. Our main communications have occurred via official IFSP email communications, social media and Zoom meetings with reports of all official Executive Board meetings. The General Meeting in 2021 was also held online for the first time. In June 2021 we had our first networking session with Member Organizations and invited guests. This was a huge success and a great way to keep more regularly in touch and sharing experiences. So, while COVID-19 has kept us physically apart, it has also improved the opportunity to be in more regular contact due to technological advances and global familiarization with online engagement and knowledge sharing. While we all miss meeting our colleagues physically, the opportunity to meet and participate online have created more equal opportunities for countries which are less financially viable, and also increases the opportunity to better fulfill the wishes of our member countries in relation to global engagement, sharing and networking. During the pandemic IFSP has worked hard to establish resources for members through research dissemination in different languages, especially targeting countries that are non-English speaking.

IFSP has always maintained a good professional and respectful collaboration with World Physiotherapy (WP) (https://world.physio/subgroups/sports). IFSP has initiated an increased focus and collaboration with WP on equality, equity, diversity and inclusion in relation to the physiotherapy profession and IFSP is represented in the congress program committee of the World Physiotherapy Congress 2023, which will be held in Tokyo. Gender bias in sports physical therapy has also been addressed by IFSP, and since 2019, speakers at our flagship event—the World Congress of Sports Physical Therapy (WCSP)—represents genders evenly. A strong point in these conferences is IFSP’s leading role in research dissemination and consensus meetings/statements on sports injury prevention, return to play guidelines,1–3 and promotion of physical activity, as these are all extremely important working areas for sports physical therapists to master in the future.3 Speakers, content and structure of the scientific program for the 2-day WCSP in Denmark will be available on the Congress website by September/October 2021.

Together with the International Journal of Sports Physical Therapy (IJSP), who will also be present and engaged with the WCSP, the focus on clinically relevant research for sports physical therapists has never been bigger. A continued relationship with the IJSP has now been strengthened through collaboration, including international board members, reviewers, and associate editors. Furthermore, the first four IJSP International Perspectives have been published in 2021.4–7 The relationship with IJSP, and IJSP itself, is stronger than ever, and will play a very important role as the main IFSP associated journal going forward including IFSP executive board members with research and publication expertise on the IJSP Editorial board.

IFSP encourage all member organizations and local research environments to work together more closely on future sports physical therapy research, to break down bar-
riers and silos between and within clinical and research environments. We hope to see everyone come together, engage and share knowledge at the next WCSPT, August 26-27, 2022 in Denmark, under the topic of "Translating Science into Action".

ACKNOWLEDGEMENT

As immediate past and present presidents, we wish to acknowledge the contributions of all the individuals who have helped build the IFSP and have brought it to this level of growth and impact.

**Laetitia Dekker-Bakker (Netherlands)** was the founding president and provided leadership for eleven years (2000-2011), as well as supporting the IFSP with wisdom and advice in subsequent years. During her term, she spearheaded the SPA Project and set the stage for the development of the Registration program, along with shouldering the pressures of founding a new global organization. Without her tireless work and guidance, there would be no IFSP.

**Nicola Phillips (United Kingdom)** served the IFSP as a board member for two years and as president for six (2009-2017). During her term, the RISPT program became reality, and the World Congress of Sports Physical Therapy was founded, along with extensive progress in branding, communication and knowledge sharing. Nicola has always been generous with her time before, during and after her term, serving as an ambassador for IFSP and a role model for sports physical therapists globally.

**Anthony Schneiders (New Zealand)** served as member at large, vice president and president during his eight years on the Executive Board (2009-2017). Tony’s accomplishments were seen in the realm of education, research and negotiation within and without the IFSP. Tony traveled many miles to represent IFSP within and outside our member organizations, expanded relationships with WP (then WCPT), and brought awareness to some of our more remote partners in Asia, Africa and Pan-Pacific regions.

Other board members in the past twenty years have contributed immense amounts of time toward the development of the IFSP. The original board under Laetitia Dekker-Bakker included Secretary Jan Gildea-Smith (Australia), Treasurer Mark DeCarlo (US), Members at Large Gul Baltaci (Turkey), Vibeke Bechtold (Denmark), Jose Esteves (Portugal), Jose Antonio Martin Urrialde (Spain), Henning Langberg (Denmark) and Mike Voight (US). Maria Constantionou (Australia), secretary; Gordon Eiland (United States), treasurer; Bente Andersen (Denmark), Mario Bizzini (Switzerland), Craig Smith (South Africa) and Nevin Ergun (Turkey), members at large, all made their mark in the growth of the IFSP.

The most recent executive board has included the work of Colin Paterson (UK), who chaired the Education and Registration committee with great energy and skill and brought in several new member organizations as certified for RISPT (2017-2021). Walt Jenkins (US) served capably as treasurer and John Fitzgerald (Australia), member at large, chaired the Membership Committee (2019-2021). Remaining board members Carlo Ramponi (Italy), who now takes the position of vice president after assisting with membership committee duties, and Bakare Ummukulthoum (Nigeria), who has expanded the IFSP’s awareness on the African continent and well beyond, continue their work with the IFSP.

Last, but certainly not least we want to acknowledge Mary Wilkinson, who has served in the capacity of Marketing and Communications Director, has tirelessly supported IFSP presidents and boards since 2005, filling in where assistance is needed along with her sizable marketing responsibilities.

The IFSP was founded with an impressive and hardworking team and has continued to be fortunate to have talented and passionate individuals to lead. The new executive board is comprised of Luciana de Michelis Mendonça, president (Brazil); Carlo Ramponi, vice president (Italy); Suzanne Gard, treasurer (Switzerland); Chris Napier, secretary (Canada); and Kenneth Watts (UK), Aleksander Killingmo (Norway) and Bakare Ummukulthoum (Nigeria), representatives at large. We look forward to the next four years and how this organization will soar in the future, bringing Sports Physiotherapy for All.

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REFERENCES


Clinical Viewpoint

Making the Case for Modalities: The Need for Critical Thinking in Practice

Phil Page, PhD, PT, ATC, CSCS, FACSM
1 Franciscan University

Keywords: physical therapy, modalities, rehabilitation

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International Journal of Sports Physical Therapy

Physical therapists are playing an important role in the opioid epidemic by providing non-pharmacological pain control. For all the bad coming from this epidemic, there are silver linings. Kasiz et al.1 reported that direct access to physical therapy (PT) reduced the odds for short-term and long-term use of opioids in low back pain patients. The American Physical Therapy Association (APTA) campaign “Choose PT” encourages consumers to utilize PT for pain relief.2 Respondents to a Gallup poll in 2017 believed that PT was the safest and most effective treatment for lower back and neck pain.3 Not only are patients and providers recognizing the benefit of non-pharmacological pain relief, but we are learning more about pain and pain management through neuroscience research (more on that later).

Physical therapy interventions can include therapeutic exercise, manual therapy, patient education, and modalities. Yes, I said "modalities." There's no doubt that there has been a backlash against modalities in recent years as more physical therapists demonize their use, particularly through social media. It seems the word "modalities" has become a taboo word, so much so that they are now referred to as "biophysical agents" in the APTA Guide to Physical Therapist Practice.4 The Guide to Practice offers a number of beneficial effects and indications for modalities (Table 1), which is where the irony begins: how can modalities (aka, biophysical agents) be so "bad" when our own Guide to Practice states so many intended benefit?

Table 1. Intended use for biophysical agents from the APTA Guide to Physical Therapist Practice.4

<table>
<thead>
<tr>
<th>Biophysical Agents Intended Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>• assist muscle force generation and contraction</td>
</tr>
<tr>
<td>• decrease unwanted muscular activity</td>
</tr>
<tr>
<td>• increase the rate of healing of open wounds and soft tissue</td>
</tr>
<tr>
<td>• maintain strength after injury or surgery</td>
</tr>
<tr>
<td>• modulate or decrease pain</td>
</tr>
<tr>
<td>• reduce or eliminate edema</td>
</tr>
<tr>
<td>• improve circulation</td>
</tr>
<tr>
<td>• decrease inflammation, connective tissue extensibility, or restriction associated with musculoskeletal injury or circulatory dysfunction</td>
</tr>
<tr>
<td>• increase joint mobility muscle performance, and neuromuscular performance</td>
</tr>
<tr>
<td>• increase tissue perfusion and remodel scar tissue</td>
</tr>
<tr>
<td>• treat skin conditions</td>
</tr>
</tbody>
</table>

CONFLICTING MESSAGES

In 1995, the APTA House of Delegates took a stand against the exclusive use of biophysical agents/modalities (originally HOD P06-95-29-18; amended in 2018 to HOD P06-18-17-27)4 in response to the potential for overuse of modalities in physical therapy practice. Passive modality treatment became synonymous with the term "physical therapy" in other healthcare professions. Furthermore, the APTA contributed to the "Choosing Wisely" campaign in 2015,5 advocating, "Don't use (superficial or deep) heat to obtain clinically important long term outcomes in musculoskeletal conditions." However, the explanation provided after that statement said, "While there is some evidence of short-term pain relief for heat, the addition of heat should be supported by evidence and used to facilitate an active treatment program." For some reason, that last statement supporting the use of heat for short-term pain relief as an adjunctive in PT was lost by those decrying "modalities as malpractice." Coupled with Medicare's withdrawal of reimbursement for superficial heat and cold around that time, the dominos had fallen against modalities in general.

Ironically, the APTA Guide to Physical Therapist Practice provides similar indications for manual therapy techniques as it does for biophysical agents (Table 2).4 In addition to pain relief, biophysical agents have more intended benefits than manual therapy such as facilitating muscle strength and tissue healing. Recognized as a "passive" treatment, manual therapy is almost always combined with another treatment such as therapeutic exercise or neuromuscular re-education and should be discontinued as the patient progresses in their rehabilitation. In this regard, manual therapy can be thought of as a short-term, passive adjunctive treatment to facilitate exercise...just as modalities should be considered as adjunctive in musculoskeletal rehabilitation. However, the use of manual therapy is not accompanied by the statement used with biophysical agents in the Guide: "The use of biophysical agents in the absence of other interventions should not be considered to be physical therapy unless there is documentation that justifies the necessity of their exclusive use."

The author of a recent article in the New York Times6 characterized modalities such as laser, ultrasound, and electrical stimulation as “voodoo treatments,” suggesting that PT has a "lingering reputation for pseudoscience," further stating that "there is very little if any evidence that ultrasound does anything at all." Once again, modalities played the "punching bag" for PT, further discrediting their
use. The story’s author suggests that physical therapists should use clinical practice guidelines (CPGs) to guide clinical decisions, noting favorable outcomes for exercise (Grade “A” evidence) in knee sprain patients, and less favorable (Grade “D”) evidence for electrotherapy in treating plantar fasciitis patients. By cherry-picking these results, the New York Times author failed to note that electrotherapy has Grade A evidence in the Knee Sprain CPG. Of note, a Grade of D means there is conflicting evidence, not that the evidence is necessarily poor! (Table 3). Fueled by the call for “evidence-based practice,” combined with bashing on social media, it seems modalities have been shunted to the other side of the pendulum of antiquated and shameful treatments.

### CLINICAL PRACTICE GUIDELINES SUPPORT USE AND NON-USE

Clinical practice guidelines have been described as, “systematically developed statements to assist practitioner and patient decisions about appropriate health care for specific clinical circumstances.” While CPGs are highly regarded, they are still susceptible to bias and misinterpretation (as seen in the New York Times article). The authors of the CPG for patellofemoral pain (PFP) provided a “B” grade to support their recommendation against modality use, stating that “Clinicians should not use biophysical agents, including ultrasound, cryotherapy, phonophoresis, iontophoresis, electrical stimulation, and therapeutic laser, for the treatment of patients PFP.” The recommendation was based on one 2011 systematic review of 12 low to moderate-quality studies using different modalities. However, in their explanation for the recommendations, the CPG authors stated, “There was no consistent evidence of any beneficial effect when a therapeutic modality was used alone.” Note that the CPG authors did not include the words “when used alone” from their overall recommendation against biophysical agents. A more recent systematic review agreed that no stand-alone intervention was effective in treating PFP patients; however, there was some evidence that subgroups of PFP patients may benefit from different treatment modalities.

A review of 12 Academy of Orthopedic Physical Therapy (AOPT) CPGs revealed that biophysical agents are both recommended and not recommended for a variety of conditions at various grades of evidence (Table 4). It’s clear that there are more evidence-supported uses for modalities in orthopedic CPGs than against; all CPGs recommended some type of modality. Only 4 (25%) CPGs recommended against the use of modalities; most of the recommendations against the use of modalities in the one CPG for patellofemoral pain. Grade “A” or “B” recommendations for biophysical agents included biofeedback, cryotherapy, electrotherapy, iontophoresis, ultrasound, and mechanical traction. Obviously, there is evidence to support the use of certain modalities in certain patients; therefore, biophysical agents should be considered in specific patient populations.

A 2019 systematic review by Zadro and colleagues titled, “Do physical therapists follow evidence-based guidelines when managing musculoskeletal conditions?” aimed to compare evidence-based treatment recommendations to the percentage of physical therapy treatments reported in the literature. The authors reviewed 94 musculoskeletal evidence-based guidelines and systematic reviews for recom-

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**Table 3. Grades of evidence used in Clinical Practice Guidelines from the Academy of Orthopedic Physical Therapy**

<table>
<thead>
<tr>
<th>Grade of Recommendation</th>
<th>Strength of Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Strong evidence</td>
<td>A preponderance of level I and or level II studies support the recommendation. This must include at least 1 level 1 study.</td>
</tr>
<tr>
<td>B Moderate evidence</td>
<td>A single high-quality randomized controlled trial or a preponderance of level II studies support the recommendation</td>
</tr>
<tr>
<td>C Weak evidence</td>
<td>A single level II study or a preponderance of level III and IV studies, including statements of consensus by content experts, support the recommendation</td>
</tr>
<tr>
<td>D Conflicting evidence</td>
<td>Higher-quality studies conducted on this topic disagree with respect to their conclusions. The recommendation is based on these conflicting studies</td>
</tr>
<tr>
<td>E Theoretical/foundational evidence</td>
<td>A preponderance of evidence from animal or cadaver studies, from conceptual models/principles, or from basic science/bench research support this conclusion</td>
</tr>
<tr>
<td>F Expert opinion</td>
<td>Best practice based on the clinical experience of the guidelines development team</td>
</tr>
</tbody>
</table>

---

**Table 2. Comparison of the intended use of biophysical agents and manual therapy techniques, highlighting similar indications in bold font (From the APTA Guide to Physical Therapist Practice)**

<table>
<thead>
<tr>
<th>Manual Therapy Technique Intended Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>• improve tissue extensibility</td>
</tr>
<tr>
<td>• increase range of motion</td>
</tr>
<tr>
<td>• induce relaxation</td>
</tr>
<tr>
<td>• mobilize or manipulate soft tissue and joints</td>
</tr>
<tr>
<td>• modulate pain</td>
</tr>
<tr>
<td>• reduce soft tissue swelling, inflammation, or restriction</td>
</tr>
</tbody>
</table>

---

*International Journal of Sports Physical Therapy*
Table 4. Summary of grades of evidence with recommendations of modality use in orthopedic physical therapy CPGs.13 (See Table 3 for explanation of grades of evidence.)

<table>
<thead>
<tr>
<th>Biophysical Agent</th>
<th>YES: Recommended for use</th>
<th>NO: Recommended against use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grade</td>
<td>Condition</td>
</tr>
<tr>
<td>Biofeedback</td>
<td>B</td>
<td>Knee cartilage</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>Ankle sprains</td>
</tr>
<tr>
<td>Cryotherapy</td>
<td>B</td>
<td>Knee ACL</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>Knee TKA</td>
</tr>
<tr>
<td>Diathermy</td>
<td>C</td>
<td>Hand CTS</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>Ankle sprains</td>
</tr>
<tr>
<td>Electrotherapy</td>
<td>A</td>
<td>Knee ACL</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>Knee cartilage</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>Hand CTS</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>Shoulder frozen</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>Foot plantar fasciitis</td>
</tr>
<tr>
<td>Heat</td>
<td>C</td>
<td>Hand CTS</td>
</tr>
<tr>
<td>Ionotophoresis</td>
<td>B</td>
<td>Ankle Achilles tendon</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>Foot plantar fasciitis</td>
</tr>
<tr>
<td>Laser</td>
<td>C</td>
<td>Ankle sprains</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>Foot plantar fasciitis</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>Ankle Achilles tendon</td>
</tr>
<tr>
<td>Phonophoresis</td>
<td>C</td>
<td>Hand CTS</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>Foot plantar fasciitis</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>B</td>
<td>Hip OA</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>Knee PFP</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>Knee TKA</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>Shoulder frozen</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>Hand CTS*</td>
</tr>
<tr>
<td>Mechanical Traction</td>
<td>B</td>
<td>Neck pain</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>Back pain</td>
</tr>
</tbody>
</table>

*The CTS CPG noted a grade of C against thermal ultrasound, but a grade of D in favor of non-thermal ultrasound

Recommendations, comparing them to studies using utilization surveys of physical therapists and audits of musculoskeletal PT treatments. The authors reported that a median of 54% of physical therapists chose recommended treatments, while 45% choose treatments not recommended and 81% chose treatments without recommendations. In terms of biophysical agents, there appears to be a gap between musculoskeletal treatment recommendations and clinical practice. Only 28% (8/11) of recommendations were appropriately followed by at least 50% of physical therapists.

A NEW LOOK AT THE EVIDENCE

Modalities appear to be one of the most-researched interventions in physical therapy. A quick, informal search¹ in PubMed in August 2021 resulted in 196,756 results for electrotherapy.

¹ Note that these results only represent the number of studies published and do not represent quality or efficacy. PubMed search terms in August 2021 included, Search 1: “((physical therapy) OR (physiotherapy)) AND (electrotherapy) OR (electrical stimulation)”; Search 2: terms, “((physical therapy) OR (physiotherapy)) AND (ultrasound); Search 3: “((physical therapy) OR (physiotherapy)) AND (exercise) OR (therapeutic ultrasound)”.

International Journal of Sports Physical Therapy
Table 5. Evidence-based recommendations for biophysical agents across different musculoskeletal conditions and the percentage of physical therapists reporting use. Over half of physical therapists reportedly do not follow recommendations for 8 out of 11 situations (72%), noted by shading.

<table>
<thead>
<tr>
<th>Body Part</th>
<th>Treatment</th>
<th>Recommended?</th>
<th>Percentage reporting use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Back Pain</td>
<td>Ultrasound / electrotherapy</td>
<td>No</td>
<td>67%</td>
</tr>
<tr>
<td></td>
<td>Heat</td>
<td>Yes</td>
<td>39%</td>
</tr>
<tr>
<td>Neck</td>
<td>Heat/Cold</td>
<td>No</td>
<td>53%</td>
</tr>
<tr>
<td></td>
<td>Ultrasound / electrotherapy</td>
<td>No</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>Laser</td>
<td>Yes</td>
<td>6%</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Electrotherapy</td>
<td>No</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>Laser</td>
<td>Yes</td>
<td>36%</td>
</tr>
<tr>
<td>Knee</td>
<td>Heat/Cold</td>
<td>Yes</td>
<td>62%</td>
</tr>
<tr>
<td></td>
<td>Ultrasound / electrotherapy</td>
<td>No</td>
<td>43%</td>
</tr>
<tr>
<td>Plantar Fasciitis</td>
<td>Laser</td>
<td>Yes</td>
<td>43%</td>
</tr>
<tr>
<td></td>
<td>Ultrasound / electrotherapy</td>
<td>Yes</td>
<td>43%</td>
</tr>
</tbody>
</table>

terapy and 27,116 for ultrasound, as opposed to 158,786 results for exercise and 26,192 for manual therapy. While beyond the scope of this paper, there appears to be ample evidence to support the use of modalities for short-term pain relief and to promote a healing environment.

Several textbooks provide excellent summaries of the mechanisms behind modalities. Biophysical agents provide acute, short-term pain relief through direct and indirect mechanisms. Direct mechanisms include modulation of inflammatory mediators, slowed nerve conduction, pain signal blockage, and endogenous analgesia. In addition to pain relief, modalities offer direct therapeutic benefits through muscle stimulation and wound healing. Modalities are also thought to reduce pain indirectly through spasm reduction or through tissue healing, as evidenced by a supportive environment for wound healing increased blood flow. Unfortunately, much of the direct evidence on tissue healing with modalities is from experimental animal models; as, human subjects are not keen to volunteer for experimental crush injuries or ligament transections.

OUTCOMES RESEARCH

Some modality research outcomes focus on longer-term results; however, the natural process of healing of time may trump all factors. A common argument against modalities is the lack of impact on long-term outcomes; however, modalities are commonly recommended as an adjunct (during certain phases of rehabilitation) and offer short-term pain relief. Improvement in short-term goals has been associated with better outcomes in low back pain patients. Just as pain medications are recommended for short-term relief, modalities can provide acute, non-pharmaceutical pain relief. Continued use of multiple modalities beyond one to two weeks may not be necessary but might be considered in situations of sub-acute pain and exacerbations during a multi-modal rehabilitation program.

It is interesting to note that patient satisfaction is not always associated with better outcomes. A meta-analysis of patient satisfaction determinants reported that outpatient musculoskeletal patients seem equivocal to receiving passive treatments such as manual therapy or modalities, as compared to active exercise intervention, although some preferred exercise. The authors further noted that "an individualized approach to decision-making about treatment represented the best strategy to increase patient satisfaction." Providing modalities solely based on improving patient satisfaction may not warranted; rather, clinicians should include patients in the decision-making process when deciding if modalities are indicated to address specific impairments and limitations.

Cost effectiveness research helps identify value of an intervention in healthcare systems by comparing outcomes and costs. A study from the United Kingdom found that modalities provided similar cost-benefit to manual therapy in a review of studies on patients with knee OA. In fact, they found TENS treatments to be the most cost-effective modality studied in knee OA patients. While some systematic reviews suggest electrotherapy modalities benefit some groups of patients, clinicians should consider the cost of these modalities in their clinical practice in respect to the types of patients they treat.

NEUROSCIENCE RESEARCH

Researchers and clinicians are helping us better-understand both mechanisms of pain and effective interventions. This evolving research expands on existing knowledge and offers...
new insights for potential non-pharmacological treatments. Emerging research from human and animal studies in pain science may provide information on other mechanisms and dose-responses for effective use of biophysical agents.

Relative to modalities, neuroscience research on pain control suggests other potential mechanisms for pain control. Thermal and electrical modalities are often thought to provide pain relief through the Gate Control Theory, where ascending pain signals in the peripheral nervous system are blocked at the spinal cord level. More recently, scientists have noted the influence of central nervous system descending signals in modulating pain. Researchers have shown painful stimuli can inhibit pain at a distant site through an endogenous mechanism in animal studies, known as “diffuse noxious inhibitory control” (DNIC) of pain.24 This is also a proposed pain relief mechanism of the “hurts so good” treatments such as roller massage and foam rolling.25

The DNIC mechanism is thought to play a role in chronic central sensitization of pain in patients with chronic pain such as knee osteoarthritis26 and fibromyalgia.27 Electroacupuncture has been studied in a mouse model,28 suggesting DNIC plays a role in knee osteoarthritis pain relief. In 2019, Peng et al.29 reported that acupuncture-like TENS influences pain through the descending pain inhibitory system from the prefrontal cortex in humans. Acupuncture-like TENS is considered a "noxious" stimulus rather than the more-comfortable conventional TENS and is often used to prevent nervous system adaptation particularly in chronic pain. The authors suggested that conventional TENS and acupuncture-like TENS mediate their analgesic effects through different mechanisms.

Biophysical agents are applied directly through the skin. Interestingly, the role of the skin in pain relief has little research. Fortunately, research in the integumentary and fascial systems and their role in pain modulation is slowly growing. Specialized receptors in the skin, transient receptor proteins (TRP) have been known to play a role in our sensation of temperature and may be activated by various substances in nature. For example, the TRP receptor for menthol (TRP-M8) is sensitive to both cold and menthol. More recently, researchers have discovered a potential role for TRP channels in pain modulation.30 The TRP-M8 receptor has been shown to provide analgesia in rats with chronic neuropathies via the glutamate system in the spinal cord.31,32 Furthermore, Andersen et al.33 investigated the role of TRP-M8 in humans, providing in-vivo support for the Gate Control theory in pain and inflammation.

EMBRACING THE PLACEBO EFFECT

Some may feel that modalities offer little more than placebo effect. However, as discussed previously, evidence supports some level of therapeutic effect for biophysical agents. The placebo effect is only part of the overall effectiveness of an intervention (Figure 1). Several factors of a treatment contribute to overall pain relief. Natural healing provides a physiological effect on pain, while treatment provides both a therapeutic and placebo effect of varying degrees. Two treatments may have similar efficacy, but one may provide more therapeutic and less placebo effects (or vice versa).

Figure 1. Internal contributions of natural healing, therapeutic effect, and placebo effect on overall pain relief. Some biophysical agents such as electrical stimulation may facilitate the natural healing process as well. Side effects may also play a role in the decision to use a specific treatment. As we learn more through pain research, the placebo effect has gained a new appreciation as a non-pharmacological pain relief mechanism with no side effects.

Beyond the therapeutic, placebo, and natural healing effects, other factors may play an important role in the overall effectiveness of a treatment. Better adherence and compliance are generally thought to positive treatment outcomes. Contextual factors and social determinants of health (SDH) such as socioeconomic status and education level may also influence outcomes.34 A therapeutic alliance (therapist-patient relationship) may enhance outcomes,35 although a strong relationship has not been established.36 Other factors such as the healing phase, previous injury, and tissue health may influence outcomes in addition to the presence of co-morbidities such as diabetes or risky behaviors such as smoking.

DOSE RESPONSE

Clinical trials often proceed through 3 phases of research. "Pre-clinical" studies are mechanistic bench studies (usually in animals) to evaluate the mechanism of action of a medication or treatment. Phase 1 clinical trials are first small groups of study participants to participate in the treatment. Phase 2 studies look at the dose-response to determine the appropriate amount of medication for a desired response (such as pain relief in humans), and Phase 3 trials are outcome studies in larger groups of patients, often involving placebos. Phase 2 studies are often lacking prior to outcomes research in non-pharmacological studies. Instead, most studies on these interventions evaluate outcomes prior to establishing a dose-response, which leads us to question ineffective treatment outcomes: was the appropriate dose of the treatment given for the desired outcome?

Many physical therapy interventions are limited by lack of a specific dose-response. The relationship of therapeutic dose (time, intensity, duration) and the titrated result on the desired response (pain, movement, swelling) remain unknown for many interventions and patient populations.
Even the most recommended interventions such as manual therapy, therapeutic exercise and balance training lack specific dose-response parameters across patient populations. While the traditional "3 sets of 10" of an exercise is rooted in a physiological dose response to strengthening in healthy subjects, this dosage has not been well-evaluated in patient populations.

If a particular dose of an intervention such as ultrasound is being studied for efficacy, other questions arise from the research methodology. Devices should be calibrated prior to a study to ensure the prescribed dose is actually being administered; damage to ultrasound heads can go undetected, thus resulting in a lower or inaccurate dose. Furthermore, the technique of application can also hinder the appropriate dose from being delivered. “Textbook” application of ultrasound should be slow (4 cm/second) and within a small area (twice the size of the sound head) to effectively deliver the energy to the tissue.15,13,16,37 Yet many have witnessed a clinical application of ultrasound rarely stays within these parameters, thus affecting the intended dosage.

Some researchers have evaluated the dose-response of modalities as an adjunctive treatment. The "Stretching Window" was described by the late Dr. David Draper as the period following modality application to prepare tissues for active treatments such as stretching or mobilization.57 (Figure 2). Draper suggested that a 5°C increase in tissue temperature created by ultrasound would be effective for an average of 3.3 minutes after treatment. Adjunctive modalities provide a specific timeframe to acutely reduce pain or prepare tissue for active treatment. The length of this window varies depending on the modality, tissue type and depth of tissue.38

CONCERNING TRENDS

Modalities aren’t the only intervention that has become demonized in PT; take isokinetics for example. In the 1970s and 80s, isokinetic testing and exercise were mainstays in outpatient orthopedic PT clinics. Despite evidence of its benefit, isokinetic devices became nearly extinct in the 1990s as reimbursement codes were removed and the cry for more "functional closed chain" exercises began (We’ll save the discussion on today’s epidemic of quadriceps weakness and ACL failure rates today for another time).

At the same time that isokinetics were waning, a new treatment was emerging: manual therapy. Manual therapy was heralded as a hands-on therapy applied to the patient with mechanisms best explained through physiological benefits to relieve pain and promote healing (sound familiar? See Table 2). Manual therapy quickly became the gold-standard in treating many orthopedic conditions, as is evidenced by their inclusion in nearly all AOPT CPGs with high grades of evidence.13

A concerning trend parallels the downfall of modalities and isokinetic exercise: "The Demonization of Manual Therapy," as recently published by Dr. Chad Cook.39 Some popular and effective interventions such as ultrasound become overutilized, while scientific evidence begins to cast doubt on the mechanism or efficacy of such treatments, which may lead to removal of reimbursement... oftentimes the deadly blow to an intervention. There's no doubt that interventions in physical therapy wax and wane in popularity as newer treatments emerge. The trend in the rise and fall of popularity of interventions was originally described as "Scott’s Parabola,"40 and was recently modified for physical therapy in an editorial in JISPT.41 Clinicians sometimes abandon effective treatments for various reasons as new, less proven treatments become popular. Interestingly, this cycle seems to continue as a "roller coaster," where forgotten treatments regain their clinical popularity (sometimes slightly modified), such as rigid tape, electrical stimulation, or mechanical percussion.

The "Tomato Effect" has been used to explain this phenomenon as well. The Tomato Effect occurs "when an efficacious treatment for a certain disease is ignored or rejected because it does not 'make sense' in the light of accepted theories of disease mechanisms and drug actions."42 Luckily, the Tomato Effect can be reversed as new evidence emerges that is consistent with accepted theories. Modalities are poised to see such a reversal as we have discussed previously with insights into clinical outcomes, pain neuro-

Figure 2. Recommendations for ultrasound dose parameters to heat tissues prior to stretching or mobilization as an adjunctive treatment, known as the "stretching window"38

<table>
<thead>
<tr>
<th>Tissue Type</th>
<th>Superficial Tissue (&lt;2.5 cm)</th>
<th>Deep Tissue (2.5-5 cm)</th>
<th>Place tissue on stretch near end of treatment before manual therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle</td>
<td>3 MHz 1W/cm² 100% duty 6 min</td>
<td>1 MHz 1.5 W/cm² 100% duty 14 min</td>
<td>Therapeutic ‘window’ after US: 3 min. for muscle</td>
</tr>
<tr>
<td>Tendon</td>
<td>3 MHz 0.8-1.0 W/cm² 100% duty 4-5 min</td>
<td>1 MHz 1.0 W/cm² 100% duty 6 min</td>
<td>5 min. for tendon/mobilization</td>
</tr>
</tbody>
</table>

AREA = 2π x sound head size
RATE = 4 cm/second

Tissue viscoelasticity is enhanced with heat. Apply therapeutic ultrasound prior to manual therapy techniques or stretching to create optimal tissue temperature. Tissue depth and type dictates dose parameters.

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2 As an example, blood flow restriction therapy has been used since the 1960’s in Japan, and even in the United States in the 1990’s as an adjunct for exercise training particularly in the elderly. It wasn’t until the late 2010’s that blood flow restriction became a popular treatment in physical therapy, although it had been used for nearly 50 years prior.
science, dose-response, and the placebo effect.

IT’S TIME FOR US TO ‘RE-THINK’ MODALITIES IN PHYSICAL THERAPY

“Evidence-based” clinicians may re-evaluate their attitudes toward modalities, particularly since they are still included in the APTA Guide to Physical Therapist Practice, required in accredited DPT programs, and included as questions on the National PT Examination (NPTE). This requires critical appraisal skills to evaluate new research in context with existing evidence while considering limitations. While CPGs are excellent guides to assist evidence-based decision making, they are still limited to a small number of patient populations and should not be used to generalize decisions about other populations. Evidence-based practice does not rely on evidence alone; empirical experiences and patient values are integrated with the best evidence when determining which intervention is appropriate for each individual patient. Prescribing therapeutic modalities is a skilled intervention to correctly choose, dose, and apply as part of an individualized and integrated treatment approach.

The physiological benefits of modalities are well-established in bench studies and reported in several textbooks; however, these results don’t always translate into human outcomes. There are clinical studies of varying quality reporting both for and against modality use in certain situations (as mentioned previously using electrotherapy as an example in CPGs). It’s obvious that “one size does not fit all” when it comes to modalities; the recommendation for a specific modality remains specific to the population.

There is no argument that modalities have been overused and abused for financial gain by some, but the message should be loud and clear: Modalities are beneficial but should not be used as a stand-alone intervention. It’s time to move on from stereotyping modalities as useless equipment and respect biophysical agents for all the benefits they provide, particularly as short-term non-pharmacological pain relief. It’s time to stop bashing modality use on social media and recognize that there are legitimate applications of ultrasound, laser, and cryotherapy that are supported with high-level clinical practice guidelines. Are we using modalities as intended and indicated, or are we denying patients a beneficial modality? Don’t throw the baby out with the bathwater. Re-think the evidence as new research evolves. Recognize legitimate use of modalities to reduce pain and support a healing environment when used as an adjunct to active treatment, particularly as an alternative to pharmacological management.

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REFERENCES


40. Scott JW. Scott's parabola. BMJ. 2001;325(7327):1477. doi:10.1136/bmj.325.7327.1477


Systematic Review/Meta-Analysis

Systematic Review and Meta-Analysis of the Y-Balance Test Lower Quarter: Reliability, Discriminant Validity, and Predictive Validity

Phillip Plisky¹, Katherine Schwartkopf-Phifer², Bethany Huebner¹, Mary Beth Garner¹, Garrett Bullock¹,²

¹ Physical Therapy, University of Evansville; ProRehab-PC, ² Physical Therapy, University of Evansville; Rehabilitation & Performance Institute, ³ Physical Therapy, University of Evansville, ⁴ Department of Orthopaedic Surgery, Wake Forest School of Medicine; Centre for Sport, Exercise and Osteoarthritis Research Versus Arthritis, University of Oxford

Keywords: y-balance test lower quarter, dynamic balance, single leg balance, star excursion balance test

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Background
Deficits in dynamic neuromuscular control have been associated with post-injury sequelae and increased injury risk. The Y-Balance Test Lower Quarter (YBT-LQ) has emerged as a tool to identify these deficits.

Purpose
To review the reliability of the YBT-LQ, determine if performance on the YBT-LQ varies among populations (i.e., sex, sport/activity, and competition level), and to determine the injury risk identification validity of the YBT-LQ based on asymmetry, individual reach direction performance, or composite score.

Study Design
Systematic Review

Methods
A comprehensive search was performed of 10 online databases from inception to October 30, 2019. Only studies that tested dynamic single leg balance using the YBT-LQ were included. Studies were excluded if the Y-Balance Test kit was not utilized during testing or if there was a major deviation from the Y-Balance test procedure. For methodological quality assessment, the modified Downs and Black scale and the Newcastle-Ottawa Scale were used.

Results
Fifty-seven studies (four in multiple categories) were included with nine studies assessing reliability, 36 assessing population differences, and 16 assessing injury prediction were included. Intra-rater reliability ranged from 0.85-0.91. Sex differences were observed in the posteromedial direction (males: 109.6 [95%CI 107.4-111.8]; females: 102.3 [95%CI 97.2-107.4; p = 0.01]) and posterolateral direction (males: 107.0 [95%CI 105.0-109.1]; females: 102.0 [95%CI 97.8-106.2]). However, no difference was observed between sexes in the anterior reach direction (males: 71.9 [95%CI 69.5-74.5]; females: 70.8 [95%CI 65.7-75.9]; p=0.708). Differences in composite score were noted between soccer (97.6; 95%CI 95.9-100.2) and basketball (92.8; 95%CI 90.4-95.3; p <0.01), and baseball (97.4; 95%CI 94.6-100.2) and basketball (92.8; 95%CI 90.4-95.3; p=0.02). Given the heterogeneity of injury prediction studies, a meta-analysis of these data was not possible.

Three of the 13 studies reported a relationship between anterior reach asymmetry reach and injury risk, three of 10 studies for posteromedial and posterolateral reach asymmetry, 

Corresponding author:
Garrett S. Bullock PT, DPT, DPhil
Department of Orthopaedic Surgery
Wake Forest School of Medicine
Winston-Salem, NC
gbullock@wakehealth.edu
and one of 13 studies reported relationship with composite reach asymmetry.

Conclusions
There was moderate to high quality evidence demonstrating that the YBT-LQ is a reliable dynamic neuromuscular control test. Significant differences in sex and sport were observed. If general cut points (i.e., not population specific) are used, the YBT-LQ may not be predictive of injury. Clinical population specific requirements (e.g., age, sex, sport/activity) should be considered when interpreting YBT-LQ performance, particularly when used to identify risk factors for injury.

Level of Evidence
1b

INTRODUCTION

Despite increased evidence on injury prevention and identification, injuries ranging from minor to career-limiting continue to rise.1,2 Deficits in lower extremity dynamic neuromuscular control have been implicated as an injury risk factor and have been observed after lower extremity injury.3–6 Interventions to improve lower extremity dynamic neuromuscular control have been utilized as a component in multiple injury prevention programs. Specifically, researchers have observed that athletes who participated in an injury prevention program displayed improved lower extremity dynamic neuromuscular control.7,8 One study observed that the intervention group who was most compliant demonstrated the greatest lower extremity dynamic neuromuscular control improvement, and sustained lower extremity injuries at decreased rates.8 Additionally, health care practitioners frequently utilize dynamic neuromuscular control as an outcome measure for return to sport criterion. Thus, there is a need for a lower extremity dynamic neuromuscular control test that identifies athletes at increased injury risk, captures changes that may occur with intervention, and evaluates return to sport readiness (i.e., ensure motor control deficits that occur after injury have normalized). In order to be useful in a sports setting the test would need to be valid and easy to use.

The Star Excursion Balance Test (SEBT) and Y-Balance Test Lower Quarter (YBT-LQ) have been studied and used extensively for the determination of physical readiness and injury risk identification, return to sport testing, and pre-post intervention measurement.6,9 The SEBT, through a systematic review, has been found to be reliable, valid, and responsive to specific dynamic neuromuscular control training for injured and healthy athletic populations.6 The advantage of the SEBT and YBT-LQ is that they test neuromuscular control at the limits of stability, which may allow for identification and magnification of subtle deficits and asymmetry.6

The YBT-LQ was developed from the SEBT in order to improve the reliability and field expediency of the SEBT.9 The YBT-LQ was simplified to use only the most reliable three reach directions (compared to eight reach directions with the SEBT). While both tests require dynamic neuromuscular control at the limits of stability, there are differences between the tests. The YBT-LQ uses a standardized approach via a testing kit and revised protocol to improve the reliability and testing speed. Protocol revisions include: heel of stance foot is allowed to raise, no touch down is allowed with reaching limb, and kit incorporates a standard height off the ground is used.9

While the efficiency of the test may have been improved, these differences in test procedures can alter performance, leading researchers to conclude that the SEBT and YBT-LQ are not interchangeable.10,11 Coughlan et al.10 compared the performance on the SEBT and YBT-LQ, and found that healthy males reached farther on the SEBT in the anterior direction, but had similar reach distances in the posterior directions.10 Fullam et al.11 examined the kinematic differences between the SEBT and YBT-LQ. It was confirmed that healthy males reached farther in the anterior direction, and from a kinematic perspective, the YBT-LQ anterior reach had greater hip flexion.11 These differences may be due to procedural differences or the use of a standardized YBT-LQ test kit. In addition to the differences in results between the YBT-LQ and SEBT, researchers have found that there may be differences in performance based on sex, sport and competition level in both tests.3,4 Differences have been reported between subject performance on the YBT-LQ based on country of origin,12 as well as, competition level.13,14 However, it is uncertain whether these findings are isolated to these populations or represent a true difference in performance among populations.

While a systematic review has been performed on the reliability and discriminant validity of the SEBT, the YBT-LQ has not undergone a similar rigorous analysis regarding its effectiveness regarding injury risk identification.6 In the SEBT systematic review, the YBT-LQ was described as reliable, but only one study was available; thus, there is a need to investigate and summarize the YBT-LQ literature.6 The purpose of this systematic review and meta-analysis was to review the reliability of the YBT-LQ, determine if performance on the YBT-LQ varies among populations (i.e., sex, sport/activity, and competition level), and to determine the injury risk identification validity of the YBT-LQ based on asymmetry, individual reach direction performance, or composite score.

METHODS

STUDY DESIGN

A systematic review was performed on the reliability, validity, and population differences of the YBT-LQ. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were utilized to conduct and report this review.15 This review was prospectively registered with
Prospero CRD42018090102.

SEARCH STRATEGY

A comprehensive computerized search was performed, employing online databases (MEDLINE, CINAHL, Cochrane, Embase, SPORTDiscus, Health Source-Consumer Edition, Health Source: Nursing/Academic Edition, SocINDEX, and Social Sciences), from inception to October 30, 2019. Medical subject headings (MeSH) and keywords were utilized for “dynamic balance,” “Y-Balance Test,” “Star Excursion Balance Test,” and “single leg balance.” The full search strategy entailed “y balance test”[All Fields] OR “star excursion balance test”[All Fields] OR YBT[All Fields] OR SEBT[All Fields]. References were tracked in Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia).

ELIGIBILITY CRITERIA

Studies examining the YBT-LQ were included if they met the following criteria: 1) tested dynamic single leg balance using the YBT-LQ; 2) full-text articles were written in English. Study exclusion criteria consisted of 1) studies that did not use the Y-Balance Test kit during testing; 2) major deviation from the Y-Balance Test procedure (e.g., stance foot heel kept down); 3) the Y-Balance Test Upper Quarter procedure was utilized instead of the YBT-LQ; 4) conference abstracts or non-peer-reviewed papers.

STUDY SELECTION

Four reviewers (GB, MG, BH, KS) were split into pairs, and each pair independently assessed half of the selected studies. Title and abstracts were first screened using inclusion and exclusion criteria. Four reviewers independently, who were all physical therapists and specialized in sports medicine, executed full-text review following title and abstract screening. Any conflicts were first discussed within the four reviewers. If a consensus could not be reached, another reviewer (PJ), who is a physical therapist, athletic trainer, PhD, with over twenty years’ experience in sports medicine, was utilized to determine final study eligibility. Following full-text review, a hand search was performed for any studies missed within the initial search.

DATA EXTRACTION

Data were extracted into a customized Excel spreadsheet (Version 2013, Microsoft, Redmond, Washington, United States) in three domains: reliability, population differences, and injury prediction. Two reviewers verified data for each domain. Disagreements concerning data domain placement were resolved by a third reviewer (PJ). Data elements included study characteristics (e.g., publication data, study design, and population), YBT-LQ methodology, and results (number of injuries, reach distance, reach asymmetry, and reliability).

QUALITY ASSESSMENT

All three domains (reliability, population differences, and injury prediction) were each analyzed by two independent reviewers (GB, MG, BH, KS). A third reviewer (PJ) resolved any quality assessment disagreements. The Oxford Centre for Evidence-Based Medicine (OCEBM) levels of evidence (Level I to IV)16 was used to discern study design. The YBT-LQ methodology was specifically assessed for uniformity.6 The YBT-LQ protocol factors that were assessed included the use of shoes during testing, the use of the average or maximum reach for each reach direction, hand placement during testing, number of practice trials, and number of data collection trials.6 The modified Downs and Black tool was utilized for methodological assessment for studies within the reliability and population differences domains.17,18 The modified Downs and Black tool has been shown to be reliable and valid.17 This methodological tool was scored on a scale of 0 to 15. The scoring system has a stratified ranking, with a score of 12 or greater deemed high quality, a score of 10 to 11 deemed moderate quality, and a score at or below 9 deemed low quality.18 The Newcastle-Ottawa Scale (NOS) was utilized for methodological assessment for studies within the injury prediction domain. The NOS incorporates a ‘star system’ for three broad perspectives: the selection of the study groups (four questions); the comparability of the groups (one question); and the ascertainment of outcome of interest (three questions). Multiple questions can have more than one star, which may result in the number of stars totaling greater than total number of questions.19

STATISTICAL ANALYSES

Percentage agreement and Cohen Kappa statistics were calculated to provide absolute agreement between raters in SPSS 23 (SPSS Inc, IBM, Chicago, Illinois). The extracted data were aggregated into three domains: reliability, population differences, and injury prediction. Reliability data were summarized in a narrative fashion. The population differences domain data were analyzed by pooling the study means through a random effects inverse variance approach, originally described by DerSimonian and Laird.20 Studies that reported more than one individual cohort were each calculated as individual studies. Heterogeneity was assessed with the Cochrane Q and I 2 with high heterogeneity designated by a Q p-value <0.10 and I 2 >50%. Meta-analysis was used to combine and summarize the data. In outcomes related meta-analysis, high heterogeneity indicates that there is large variation in study outcomes between studies and that results should not be pooled or combined. In this meta-analysis, high heterogeneity was observed indicating that there indeed may be differences in performance on the YBT-LQ among populations (i.e., age, sex, sport, activity, occupation, and injury status). Through an abundance of caution, a random effects model was used assuming that even within populations, results fall in a normal distribution. Data subdivisions were first grouped by sex for each YBT-LQ reach and composite score then analyzed through a series of z-tests (p<0.05). Due to the differences found between sexes, and the paucity of female studies, only males were assessed for further subdivisions. Additionally, competition level was not able to be compared as there were no greater than two subgroups at each compe-
tition level. Male sports differences (for all three YBT-LQ reaches and composite scores) were analyzed through one-way ANOVA with Tukey-Kramer Q tests to localize pairwise differences based on pooled study means and variances (p<0.05). All meta-analyses were performed in R version 3.5.1 (R Core Team (2013). R: A language and environment for statistical computing (R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/), using the meta package. Given the heterogeneity in study design and data reporting, injury prediction data were summarized in a narrative fashion.

RESULTS

STUDY SELECTION

A total of 982 titles were identified through the initial database and hand searches. After removal of duplicate articles, 732 abstracts were reviewed for relevance. Substantial agreement was demonstrated in title and abstract screening (k=0.976, p<0.01). Full text eligibility assessment of the remaining 411 articles resulted in 57 articles with 4 in multiple categories (Figure 1). Nine studies assessed reliability, 36 studies examined differences in the performance on the YBT-LQ in different populations or reported mean performance on the YBT-LQ in a specific population, and 16 studies examined injury prediction (see Table 1). Substantial agreement was also observed for full text review (k=0.84, p<0.01).

QUALITY ASSESSMENT

The NOS was used to assess quality of the included cohort studies (n=16). For the remaining 41 articles, the Downs and Black tool was used to assess reliability. Nine studies assessed reliability of YBT-LQ (see Table 1). Intraclass correlation coefficients (ICCs) for intrarater reliability ranged from 0.57-0.82 in adolescent populations, and 0.85-0.91 in adult populations. Inter-rater reliability ICCs ranged from 0.81-1.00. Test-retest reliability was assessed in five studies with ICCs ranging from 0.65-0.93.

SEX DIFFERENCES

When sex was considered alone, differences were observed in the posteroomedial direction (Male: 109.695% CI 107.4-111.8; Female: 102.95% CI 97.2-107.4; p < 0.01) and posterolateral direction (Male: 107.095% CI 105.0-109.1; Female: 102.095% CI 97.8-106.2; p=0.036). However, no difference was observed between sexes in the anterior reach direction (Male: 71.995% CI 69.5-74.5; Female: 70.895% CI 65.7-75.9; p=0.708) or in composite score (Male: 95.895% CI 94.5-97.2; Female: 95.395% CI 92.9-97.8; p=0.75) (Figure 2). However, there were significant differences based on sex, competition level, and sport throughout Figure 2. To illustrate, male Rwandan high school soccer players have a mean composite reach of 105.6 (95% CI 102.99-108.21), while male professional basketball players have a mean composite reach of 92.0 (95% CI 90.16-95.84). These scores also differ from female collegiate athletes, where a mean composite reach of 100.0 (95% CI 98.87-101.15) was observed.

COMPETITION LEVEL DIFFERENCES

When competition level was considered alone (middle school, high school, college, professional), no differences were observed for the anterior (p = 0.05), posteroomedial (p = 0.69), posterolateral (p = 0.62), or composite score (p = 0.15). However, there were significant differences between soccer and basketball athletes (Soccer: 76.095% CI 73.6-78.4; Basketball: 70.595% CI 67.7-73.2; p < 0.01). In the posteroomedial reach direction, a significant difference was observed between soccer and basketball athletes (Soccer: 114.895% CI 111.6-118.3; Basketball: 105.695% CI 101.9-109.4; p < 0.01), and baseball and basketball athletes (Baseball: 113.895% CI 109.5-118.1; Basketball 105.695% CI 101.9-109.4; p < 0.01). In the...
Table 1: Study demographics, design, and risk of bias

<table>
<thead>
<tr>
<th>Author</th>
<th>Level of Evidence (Study Design)</th>
<th>Study Domain</th>
<th>Sport</th>
<th>Competition Level</th>
<th># of subjects M:F</th>
<th>Risk of Bias (Downs and Black)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avery et al. 2017</td>
<td>4 (Case series)</td>
<td>Reliability and Population differences</td>
<td>Ice Hockey</td>
<td>Youth</td>
<td>36:0</td>
<td>12/15</td>
</tr>
<tr>
<td>Benis et al. 2016</td>
<td>1 (Randomized controlled trial)</td>
<td>Reliability and Population differences</td>
<td>Basketball</td>
<td>Elite</td>
<td>0.28</td>
<td>13/15</td>
</tr>
<tr>
<td>Bonato et al. 2017</td>
<td>1 (Randomized controlled trial)</td>
<td>Population differences</td>
<td>Basketball</td>
<td>Elite</td>
<td>0.160</td>
<td>13/15</td>
</tr>
<tr>
<td>Booyesen et al. 2015</td>
<td>4 (Case series)</td>
<td>Population differences</td>
<td>Soccer</td>
<td>University &amp; Elite</td>
<td>50:0</td>
<td>12/15</td>
</tr>
<tr>
<td>Bullock et al. 2016</td>
<td>4 (Case series)</td>
<td>Population differences</td>
<td>Basketball</td>
<td>Middle School High School Collegiate Professional</td>
<td>88:0</td>
<td>105:0</td>
</tr>
<tr>
<td>Butler et al. 2012</td>
<td>4 (Case series)</td>
<td>Population differences</td>
<td>Soccer</td>
<td>High School Collegiate Professional</td>
<td>38:0</td>
<td>37:0</td>
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<tr>
<td>Butler et al. 2013</td>
<td>4 (Case series)</td>
<td>Population differences</td>
<td>Soccer</td>
<td>Adolescent</td>
<td>26:0</td>
<td>12/15</td>
</tr>
<tr>
<td>Butler et al. 2016</td>
<td>4 (Case series)</td>
<td>Population differences</td>
<td>Baseball</td>
<td>High School Collegiate Professional</td>
<td>88:0</td>
<td>78:0</td>
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<tr>
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<td>1 (Randomized control trial)</td>
<td>Population differences</td>
<td>Soccer</td>
<td>Adolescent Elite</td>
<td>26:0</td>
<td>12/15</td>
</tr>
<tr>
<td>Chimera et al. 2015</td>
<td>3 (Case control)</td>
<td>Population differences</td>
<td>Basketball Basketball Cheer &amp; Dance Cross Country Cross Country Football Golf Soccer Swimming &amp; Diving Tennis Tennis Track &amp; Field Track &amp; Field Volleyball Division I Collegiate</td>
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<td>9:0 0:2</td>
<td>0:4 13:0</td>
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<tr>
<td>Chimera et al. 2016</td>
<td>4 (Case series)</td>
<td>Population differences</td>
<td>Rowing</td>
<td>Adolescent Varsity Adolescent Novice</td>
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<td>0:31 0:21</td>
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<td>Engquist et al. 2015</td>
<td>4 (Case series)</td>
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<td>-</td>
<td>Division I Collegiate General College students</td>
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<td>31:72</td>
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<td>-</td>
<td>-</td>
<td>97:91</td>
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<td>Gorman et al. 2012</td>
<td>3 (Case control)</td>
<td>Population differences</td>
<td>Single Sport Multi-Sport</td>
<td>High School</td>
<td>68:24</td>
<td>12/15</td>
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<td>Greenberg et al. 2012</td>
<td>2</td>
<td>Reliability</td>
<td>Athletes</td>
<td>Adolescent</td>
<td>0:21</td>
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<td>Reference</td>
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<td>Study Type</td>
<td>Population Differences</td>
<td>Sport/Sport Category</td>
<td>Control Group</td>
<td>Effect Size (95% CI)</td>
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<td>Johnston et al. 2019</td>
<td>2 (Prospective cohort)</td>
<td>Population differences</td>
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<td>Under 20 Senior</td>
<td>50:0 211:0</td>
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<td>Population differences</td>
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<td>Middle High School College Professional</td>
<td>53:0 129:0 207:0 29:0</td>
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<td>Lacey et al. 2019</td>
<td>4 (Observational repeated measures)</td>
<td>Reliability</td>
<td>Gaelic Football, Hurling, Camogie, Soccer, Rugby</td>
<td>Local sports clubs</td>
<td>11:8</td>
<td>10/15</td>
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<td>Linek et al. 2017</td>
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<td>Lisman et al. 2018</td>
<td>4 (Cross-sectional)</td>
<td>Population differences</td>
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<td>12/15</td>
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<td>Linek et al. 2019</td>
<td>2b (Cross-sectional)</td>
<td>Population differences</td>
<td>Soccer</td>
<td>Elite Adolescents</td>
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<td>Lopez-Valenciano et al. 2019</td>
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<td>Muehlbauer et al. 2019</td>
<td>4 (Cross-sectional)</td>
<td>Population differences</td>
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<td>Sub-Elite</td>
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<td>O’Malley et al. 2016</td>
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<td>Plisky et al. 2009</td>
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<td>Population differences</td>
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<td>Elementary/Middle School</td>
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<td>12/15</td>
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<td>Ryu et al. 2019</td>
<td>3 (Case control)</td>
<td>Population differences</td>
<td>Baseball</td>
<td>Professional</td>
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<td>10/15</td>
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<td>Schafer et al. 2013</td>
<td>2 (Randomized control trial)</td>
<td>Reliability</td>
<td>Service Members</td>
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<td>10/15</td>
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<td>Gaelic Football</td>
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<td>Slater et al. 2018</td>
<td>4 (Descriptive)</td>
<td>Population differences</td>
<td>Ice Skating</td>
<td>Senior Level</td>
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<td>10/15</td>
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<tr>
<td>Smith (Laura) et al. 2018</td>
<td>2b (Cross-sectional)</td>
<td>Reliability</td>
<td>Football</td>
<td>High School</td>
<td>30:0 12:34 8:0</td>
<td>12/15</td>
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<td>Level of Evidence (Study Design)</td>
<td>Study Domain</td>
<td>Sport</td>
<td>Competition Level</td>
<td># of subjects</td>
<td>M:F</td>
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<td>Smith (Joseph) et al. 2018</td>
<td>2b (Cross-sectional)</td>
<td>Population differences</td>
<td>Basketball Soccer</td>
<td>High School</td>
<td>94:91</td>
<td>13/15</td>
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<td>Teyhen et al. 2016</td>
<td>3 (Case control)</td>
<td>Population differences</td>
<td>Military</td>
<td>Army</td>
<td>1380:86</td>
<td>13/15</td>
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<tr>
<td>Smith (Joseph) et al. 2018</td>
<td>2b (Cross-sectional)</td>
<td>Population differences</td>
<td>Basketball Soccer</td>
<td>High School</td>
<td>94:91</td>
<td>13/15</td>
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<td>Teyhen et al. 2016</td>
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<td>Military</td>
<td>Army</td>
<td>1380:86</td>
<td>13/15</td>
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<table>
<thead>
<tr>
<th>Author</th>
<th>Level of Evidence (Study Design)</th>
<th>Study Domain</th>
<th>Sport</th>
<th>Competition Level</th>
<th># of subjects</th>
<th>M:F</th>
<th>Risk of Bias (Newcastle)</th>
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<tr>
<td>Brumitt et al. 2018</td>
<td>2 (Prospective cohort)</td>
<td>Predictive</td>
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<td>Collegiate</td>
<td>169:0</td>
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<tr>
<td>Butler et al. 2013</td>
<td>2 (Prospective cohort)</td>
<td>Predictive</td>
<td>Football</td>
<td>Collegiate</td>
<td>59:0</td>
<td>9</td>
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<tr>
<td>de la Motte et al. 2019</td>
<td>2 (Prospective cohort)</td>
<td>Predictive</td>
<td>Military</td>
<td>-</td>
<td>1433:281</td>
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<td>Gonell et al. 2015</td>
<td>2 (Prospective cohort)</td>
<td>Predictive</td>
<td>Soccer</td>
<td>Professional</td>
<td>34:0:40:0</td>
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<tr>
<td>Gonzalez et al. 2018</td>
<td>2 (Prospective cohort)</td>
<td>Predictive</td>
<td>Rowing</td>
<td>Division I</td>
<td>0:31</td>
<td>11</td>
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<tr>
<td>Hartley et al. 2017</td>
<td>2 (Prospective cohort)</td>
<td>Predictive</td>
<td>Baseball, Basketball, Lacrosse Soccer, Softball, Volleyball</td>
<td>Division II/NAIA</td>
<td>54:0 67:35 161:0 19:0 62:48 0:30 10:0 0:30 11:24</td>
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<td>Johnston et al. 2019</td>
<td>2 (Prospective cohort)</td>
<td>Predictive</td>
<td>Rugby</td>
<td>Elite</td>
<td>109:0</td>
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<td>Lai et al. 2017</td>
<td>3 (Case control)</td>
<td>Predictive</td>
<td>-</td>
<td>Division I</td>
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<tr>
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<td>Predictive</td>
<td>Football, Lacrosse, Baseball</td>
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<td>Ruffe et al</td>
<td>2 (Prospective cohort)</td>
<td>Predictive</td>
<td>Cross Country</td>
<td>High School</td>
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<tr>
<td>Siupsinskas et al. 2019</td>
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<td>Smith et al. 2015</td>
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<td>Predictive</td>
<td>Basketball, Cross Country, Track &amp; Field, Tennis, Lacrosse, Golf, Volleyball, Soccer, Swimming &amp; Diving</td>
<td>Division I</td>
<td>9:2 13:17 7:3 5:5 68:0 0.3 0:8 0:27 0:17</td>
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</tbody>
</table>
posterior lateral reach direction, a significant difference was observed between soccer and basketball athletes (soccer: 111.8, 95% CI 108.5-115.0; basketball: 102.095% CI 101.3-104.4; p < 0.01), and baseball and basketball athletes (baseball: 107.7% CI 105.7-106.1; basketball: 102.095% CI 101.3-104.4; p < 0.01). For composite score, there was a significant difference between soccer and basketball athletes (soccer: 97.695% CI 95.9-99.3; basketball: 92.895% CI 90.4-95.3; p < 0.01) and baseball and basketball athletes (baseball: 97.495% CI 94.6-100.2; basketball: 92.895% CI 90.4-95.3; p = 0.02).

INJURY PREDICTION

A total of 16 studies3,31,34,36,39,48,50,57,64,68–74 investigated the association between YBT-LQ performance and injury risk: 12 investigated anterior reach asymmetry, 10 investigated asymmetries in the posterior-medial and posterolateral directions, five studied individual reach directions, and 13 utilized composite scores. Populations studied include collegiate athletes3,36,39,50,57,68,70 (n=1,493), elite female basketball players73 (n=169), male high school athletes72 (n=156), professional and amateur soccer athletes34 (n=74), rugby players71 (n=109), high school cross country runners64 (n=148), military personnel51,48,69 (n=1919), and firefighters74 (n=59).

ANTERIOR REACH ASYMMETRY

Twelve studies34,36,39,48,50,57,64,68,72–74 examined the injury prediction ability of the YBT-LQ anterior reach asymmetry (Subjects: n=3,986). Five of these studies34,50,57,64,68 examined anterior reach asymmetry using a cut off of ≥4 cm; three34,57,64 reported raw numbers of subjects falling above and below this cut off score. Due to the high level of methodological and reporting discrepancies in the available data, a meta-analysis was not able to be completed.

Smith et al.68 utilized the 4 cm threshold and found a relationship with future injury risk, reporting an OR of 2.20 (95% CI 1.09-4.46). The remaining seven studies varied in interpretation of anterior reach performance. Five studies39,48,69,72,74 utilized anterior asymmetry cut off values varying from 2-5cm; of these, Valuerin et al.74 found an asymmetry of ≥2cm was predictive of ankle sprains. Siupsinskas et al.73 reported only limb difference scores and did not find an association to injury in elite female basketball players. Hartley et al.36 created a reach distance cut off of 54.5 %LL for the anterior reach and found a significant difference between injured and uninjured collegiate athletes. Populations and definition of injury and asymmetry varied between studies, however, the three studies identifying a relationship between injury risk and anterior reach all included collegiate or professional athletes.

POSTEROMEDIAL AND POSTEROLATERAL ASYMMETRY

Ten studies3,34,36,39,57,64,68,72–74 examined the relationship between posteromedial and/or posterolateral reach asymmetry and future injury risk. Gonell et al.34 reported an OR of 3.86 (95%CI 1.46-10.95) for male soccer players with a posteromedial asymmetry of 4cm or greater. No relationship was observed with posterolateral asymmetry. Four studies57,64,68,72 used the same 4cm or greater asymmetry threshold for both the posteromedial and posterolateral directions, and found no relationship to future non-contact injuries in collegiate basketball players, high school cross country runners, collegiate athletes, or musculoskeletal injuries in male high school athletes, respectively. Hartley et al.36 also reported a significant difference in posteromedial reach asymmetry, with injured female athletes having a significantly reduced asymmetry compared to uninjured counterparts. Lai et al.39 reported asymmetries of 9cm in the posteromedial reach direction and 5cm in the posterolateral direction resulted in a sensitivity of 17.1% and 54.9% (respectively), while specificity was reported as 89.9% and 54.6% (respectively). Valuerin et al.74 and Siupsinskas et al.73 reported varying values for asymmetry in reach directions or limb differences, though no relationships to future injury risk were noted. Finally, Butler et al.3 did not observe significant differences in reach asymmetry between injured and uninjured football players.

INDIVIDUAL REACH DIRECTIONS DISTANCE

Five studies34,36,50,69,71 described the relationship between injury and individual reach directions. Four of these studies34,36,50,69 reported normalized reach distances for all reach directions, with no significant difference noted between injured and uninjured subjects.

Johnston et al.71 examined the relationship between the anterior reach and future concussions. Using an inertial sensor, rugby players with increased sample entropy when reaching in the anterior direction were found to be 3 times more likely to sustain a concussion. No association between postero medial and postero lateral reaches to concussion
COMPOSITE

One of 13 studies found a relationship between composite score and future injury. Butler et al. reported an odds ratio of 3.5 (95% CI 2.4-5.3) when using a cutoff of 89.6% (SN=100%, SP=71.7%) in football players. Wright et al. utilized different composite cutoffs for athletic teams, ranging from 89-94%, all yielding non-significant likelihood ratios (ranges 0.55-1.32 and 0.50-1.70, respectively). Nine studies did not report significant relationships between composite scores and future injury.

Three studies examined the relationship between composite score asymmetry and future injury. Gonell et al. and Ruft et al. both utilized 12cm or greater threshold for asymmetry and no relationship to injury was noted. De la Motte et al. found no significant differences in composite asymmetry between injured and uninjured military personnel (p=0.50).

DISCUSSION

Testing is an important function for researchers, health care providers, and performance professionals. Many decisions.
hinge on test results, and it is essential to have validated tests in this process. While commonly used, the YBT-LQ has not been rigorously studied via systematic review and meta-analysis. This systematic review observed that the YBT-LQ is a highly reliable test. Dynamic balance differences were observed between sex, sport, and competition level, and asymmetry in the anterior reach demonstrated increased risk of lower extremity injury.

**RELIABILITY**

The YBT-LQ demonstrated high reliability over time and between raters. The high YBT-LQ reliability is comparable to the SEBT, which highlights the ability of the YBT-LQ to accurately measure dynamic neuromuscular control. Higher variability in single session performance on the YBT-LQ in children may be due to the greater variability of balance performance seen in children.

**DIFFERENCE IN YBT-LQ BY SEX, SPORT, AND COMPETITION LEVEL**

When sex was considered alone, differences were observed in the posteromedial and posterolateral directions, but no...
differences were observed between sexes in the anterior reach direction or in composite score. While it may appear that there was not a difference between sexes in composite score, it is important to note that there was large variability in each sex, sport, and age/competition level in YBT-LQ performance. This was confirmed by the high heterogeneity observed indicating that there indeed may be differences in performance on the YBT-LQ among populations (i.e., age, sex, sport, activity, occupation, and injury status). This overall heterogeneity helped confirm that sex, sport, and competition level differences may exist. Thus, when the pooled means were analyzed, no differences were noted. Composite reach scores varied by as much as 15 %LL depending on the sex, sport, and competition level. These differences may point to the differences seen in injury rate and type by sex.76

**SPORT DIFFERENCES**

There were significant differences observed between baseball and basketball in the posteromedial, posterolateral reach directions, and overall composite reach, with baseball demonstrating greater reach distances normalized to limb length. There were also differences observed between soccer and basketball in the anterior, posteromedial, postero-lateral reach directions, and overall composite reach, with

<table>
<thead>
<tr>
<th>Study</th>
<th>TE</th>
<th>seTE</th>
<th>95%-CI Weight</th>
</tr>
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<tbody>
<tr>
<td>High School</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kryskav</td>
<td>106.53</td>
<td>1.1507</td>
<td>&gt; 106.53 [104.27; 108.79]</td>
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<tr>
<td>Smith 2018</td>
<td>92.40</td>
<td>0.8910</td>
<td>&gt; 92.40 [90.65; 94.15]</td>
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<tr>
<td>Butler (Rwanda) 2013</td>
<td>82.30</td>
<td>1.2193</td>
<td>82.30 [81.52; 83.08]</td>
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<tr>
<td>Muehlbauer 2019</td>
<td>81.45</td>
<td>1.8548</td>
<td>81.45 [77.81; 85.09]</td>
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<tr>
<td>Muehlbauer 2019</td>
<td>77.20</td>
<td>1.2875</td>
<td>77.20 [74.68; 79.72]</td>
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<tr>
<td>Butler (US) 2013</td>
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<td>1.2944</td>
<td>76.50 [73.96; 79.04]</td>
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<tr>
<td>Butler 2012</td>
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<td>1.0822</td>
<td>76.20 [75.56; 76.85]</td>
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<tr>
<td>Bullock 2016</td>
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<td>76.00 [74.85; 77.15]</td>
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<td>Butler 2016</td>
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<td>0.8102</td>
<td>75.90 [74.31; 77.49]</td>
</tr>
<tr>
<td>Muehlbauer 2019</td>
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<td>1.9777</td>
<td>73.05 [69.17; 76.93]</td>
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<tr>
<td>Linke 2019</td>
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<td>1.2664</td>
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<td>Ruffe 2019</td>
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<td>63.85 [62.03; 65.67]</td>
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<tr>
<td>Lisman 2018</td>
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<td>0.8043</td>
<td>63.40 [61.82; 64.98]</td>
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<td>Miller 2017</td>
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<td>0.0925</td>
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<tr>
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<td>58.90</td>
<td>0.6667</td>
<td>58.90 [57.60; 60.20]</td>
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<tr>
<td>Random effects model</td>
<td></td>
<td></td>
<td>75.62 [71.71; 79.54]</td>
</tr>
<tr>
<td>Heterogeneity: $I^2 = 100%$, $p = 0$</td>
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</tr>
</tbody>
</table>

| Middle School |       |      |               |
| Muehlbauer 2019 | 79.80 | 2.8218| 79.80 [74.27; 85.33] | 2.8% |
| Bullock 2016 | 73.70 | 0.8400| 73.70 [72.05; 75.35] | 3.0% |
| Kryskav    | 72.27 | 1.1332| 72.27 [70.05; 74.49] | 3.0% |
| Lisman 2018 | 64.10 | 1.0399| 64.10 [62.06; 66.14] | 3.0% |
| Random effects model | | | 72.28 [64.61; 79.94] | 11.5% |
| Heterogeneity: $I^2 = 96\%$, $p < 0.01$ | | | | |

| College |       |      |               |
| Engquist 2015 | 75.80 | 0.0959| 75.80 [75.61; 75.99] | 3.0% |
| Butler 2012 | 72.80 | 0.1644| 72.80 [72.48; 73.12] | 3.0% |
| Kryskav    | 71.81 | 0.6436| 71.81 [70.55; 73.07] | 3.0% |
| Butler 2016 | 71.60 | 0.7586| 71.60 [70.11; 73.09] | 3.0% |
| Bullock 2016 | 68.00 | 0.6738| 68.00 [66.68; 69.32] | 3.0% |
| O’Malley 2016 | 65.80 | 0.8719| 65.80 [64.09; 67.51] | 3.0% |
| Random effects model | | | 70.98 [64.84; 77.13] | 18.0% |
| Heterogeneity: $I^2 = 99\%$, $p < 0.01$ | | | | |

| Professional |       |      |               |
| Butler 2016 | 73.20 | 0.6535| 73.20 [71.92; 74.48] | 3.0% |
| Butler 2012 | 72.20 | 0.1960| 72.20 [71.82; 72.58] | 3.0% |
| Slater (Singles) 2018 | 69.49 | 1.6271| 69.49 [66.30; 72.68] | 2.9% |
| Kryskav    | 69.33 | 2.0037| 69.33 [65.40; 73.26] | 2.8% |
| Slater (Dance) 2018 | 66.56 | 2.0025| 66.56 [62.64; 70.49] | 2.8% |
| Slater (Pairs) 2018 | 65.45 | 2.3275| 65.45 [60.89; 70.12] | 2.7% |
| Ryu 2019 | 63.15 | 0.9783| 63.15 [61.23; 65.07] | 3.0% |
| Bullock 2016 | 63.00 | 1.3275| 63.00 [60.40; 65.60] | 2.9% |
| Johnston 2019 | 57.20 | 0.3855| 57.20 [56.84; 57.98] | 3.0% |
| Random effects model | | | 66.61 [61.52; 71.70] | 26.2% |
| Heterogeneity: $I^2 = 99\%$, $p < 0.01$ | | | | |

**Random effects model** | | | 72.04 [69.57; 74.51] | 100.0% |
| Heterogeneity: $I^2 = 100\%$, $p = 0$ | | | | |
| Residual heterogeneity: $I^2 = 100\%$, $p = 0$ | | | | |
soccer demonstrating greater reach distances normalized to limb length. This may be due to sport specific adaptations in dynamic balance based on the demands and environment of the sport. For example, while both sports spend time running, soccer spends more time in unilateral stance at the limit of stability (e.g., kicking the ball) compared to basketball. While these differences may be due to sport specific adaptations, or limb dominance, specifically greater dynamic balance strategies on the stance leg during the kicking motion, it is also worth noting that dynamic neuromuscular control differences could be due to disparate anthropometric body types in athletes. For example, basketball players may in general have longer femurs than soccer players, which may make single limb squatting (i.e., anterior reach) biomechanically more difficult for basketball players.

**POPULATION DIFFERENCES SUMMARY**

There were significant differences across populations by sex and sport in YBT-LQ reach distance. There were not enough studies to analyze all the possible sex, sport, competition level permutations; however, it was clear that differences exist. For example, when male Rwandan high school soccer players were compared to male high school soccer players from the United States, the posteromedial and posterolat-
eral reach distances were not different.\textsuperscript{12} However, there was a significant difference in anterior reach and composite score. This shows YBT-LQ performance can potentially be affected by environment factors (e.g., in Rwanda there is less frequent wearing of athletic shoes and more frequent deep squatting for activities of daily living compared to the United States).\textsuperscript{12}

It is interesting to note, that not only sex, sport, and environment might influence YBT-LQ performance, but also biological maturation. Researchers have found that YBT-LQ reach distance was significantly associated with the total Balance Error Scoring System score as YBT-LQ anterior and posteromedial reach distances.\textsuperscript{78}

\textbf{INJURY PREDICTION VALIDITY OF THE YBT-LQ}

Since there were sport and gender differences in YBT-LQ, predictive studies could only be analyzed if they used a population-specific cut point or examined homogeneous populations (e.g., male collegiate football players). Cut points for asymmetry and composite score varied between studies. Due to these differences, composite score was found to be predictive of future injury in one study.\textsuperscript{3} More research is needed to develop these population-specific cut points to more accurately determine future injury risk.

Lehr et al.\textsuperscript{5} used population specific cut points across...
multiple sports. The researchers found that accurate injury risk identification was possible when multiple risk factors, including the YBT-LQ, were combined. The authors used age, sex, and sport specific risk cut points to place athletes in risk categories. These cut points were based on previously published injury prediction studies and normative databases.\(^5\) Thus, it is important to include age, sex, and sport cut points for injury risk identification. This study was not included in the meta-analysis since the researchers included multiple risk factors and the YBT-LQ was not able to be isolated as a risk factor. Further, Teyhen et al.\(^{79}\) found using a multifactorial model in soldiers that included YBT-LQ: Anterior Reach ≤ 72% limb length as one of the risk factors in the model. This study further illustrates the point that YBT cut points are population specific but also that the YBT should be used as part of a multifactorial model rather than a single risk factor in isolation.

Six studies\(^{34,36,39,48,50,68}\) examined reach asymmetry as a predictor of injury. Four of the studies found a positive relationship between injury risk and reach asymmetry. However, there was variability in the definition of "asymmetry" with a wide cut point range and different risk reporting methods (e.g., odds ratios, likelihood ratio, sensitivity, and specificity). Thus, there may be an association with reach asymmetry and injury risk, but this was difficult to quantify given the variability of data reporting and analysis. Given that sport and sex differences were observed, it is likely that tolerance for asymmetry and direction of asymmetry may differ by sport or population. While asymmetry is an absolute value that is relative to the individual, it also may need population specific cut points, like composite score. A meta-analysis was not performed and definitive conclusions could not be drawn.

**LIMITATIONS**

While 57 articles were included in this review, there were not enough studies (even when combined) to provide enough power to compare populations by the different combinations of sex, sport, and competition levels. A meta-analysis on the YBT-LQ predictive ability was not completed because only two studies were found that used homogeneous methodology and reporting measures. YBT-LQ reach asymmetry as a predictive factor was not analyzed due to the highly variable reported risk cut points. Two studies\(^{9,40}\) were low quality, while the rest were moderate and high quality. Furthermore, some of the studies had high heterogeneity in the specific YBT-LQ methodology (hands free versus hands on hip, maximum versus average reach, etc.). Due to the study risk of bias stratification, and the methodological heterogeneity, these findings need to be taken with some caution. The YBT-LQ is a controlled dynamic balance test. As many sport injuries are sustained at high velocities and forces, the YBT-LQ does not mimic some sport mechanisms of injury, which decreases the transferability of these results to the sport setting. Finally, this systematic review investigated athletic and active populations; thus, these findings cannot be generalized to all adult populations (inactive adults, geriatrics, etc.).

**RECOMMENDATIONS FOR FUTURE RESEARCH**

From this meta-analysis, it is clear that populations when stratified by sex and sport perform significantly differently on the YBT-LQ. This has two large implications. First, future research needs to establish normative data for a wide range of populations that utilize this test. Second, injury predictive studies need to use population specific (e.g., age, sex, sport/activity) cut points for composite score and reach asymmetry. For asymmetry, these cut points should be greater than the standard error of measure (3.2cm)\(^9\), so that meaningful asymmetry, beyond the error of measure, can be identified. Further, given the findings of Lehr et al.\(^5\) and Teyhen et al.\(^{79}\) it may be most appropriate to combine the YBT-LQ asymmetry and composite score specific to age, sex, and sport, along with other testing to accurately determine injury risk. Interestingly, country of origin seemed to impact performance; thus, cut points may need to specify beyond the aforementioned factors to include geographical location. Future research should use adequately powered and homogenous age, sex, and sport/activity specific analysis to determine if composite score is related to injury risk.

**CONCLUSION**

The YBT-LQ is a reliable tool for capturing dynamic single leg neuromuscular control at the limits of stability. Performance on the YBT-LQ differs based on age, sex, and sport, therefore clinicians should consider these factors when interpreting results to ensure accurate clinical decision-making. The relationship between the YBT-LQ and future injury risk remains unclear; future studies should utilize population specific cut points and homogenous samples to determine utility in injury prediction.

**DATA SHARING STATEMENT**

This study is registered with PROSPERO, and the protocol can be found at https://www.crd.york.ac.uk/prospero/ with the identifier Prospero CRD42018090102.

**CONFLICTS OF INTEREST**

Funding for payment of a graduate research assistant was made possible through the Ridgeway 488 Student Research Award from the University of Evansville.

Dr Phlip Plisky developed the Y-Balance Test Protocol and Test Kit and receives royalties from the sale of the Y-Balance Test kit.

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REFERENCES


The Neuromuscular Effects of the Copenhagen Adductor Exercise: A Systematic Review

Morgan Schaber¹, Zachary Guiser¹, Logan Brauer¹, Rebecca Jackson¹, John Banyasz¹, Ryan Miletti¹, Amy Hassen-Miller²

¹ Physical Therapy, Walsh University, ² Physical Therapy, Walsh University (OH)

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Background
Groin strains are one of the most common time-loss injuries in athletes. The Copenhagen Adductor Exercise (CAE) eccentrically strengthens the adductors and may function to prevent adductor strains, similar to the eccentric mechanism in which the Nordic Hamstrings exercise acts to prevent hamstring strains.

Objective
The purpose of this study was to systematically review the literature on the CAE and its effects on adductor muscle strength and muscle activity in athletes.

Study Design
Systematic Review

Methods
A systematic search of the literature was performed in the following databases: Pubmed; Medline (EBSCO); Sportdiscus; Scopus; Web of Science; CINAHL; Proquest; Cochrane Library; Physiotherapy Evidence Database (PEDro). Inclusion criteria consisted of 1) implements CAE, 2) includes athletes of any age participating in at least one sport, 3) study type is a cohort study or randomized control trial. Studies were excluded if they were not written in English or did not measure strength as an outcome. Data were extracted on eccentric hip adductor strength (EHAD), eccentric hip abductor strength (EHAB), EHAD:EHAB ratio, and electromyography (EMG) activity of the adductor muscles. Quality assessment was performed on all included studies using Quality Assessment Tool for Quantitative Studies.

Results
Five articles were identified for inclusion, four of which received a strong rating, and one a moderate rating on the Quality Assessment Tool for Quantitative Studies. The CAE significantly increased EHAD in four of the four studies that examined it; significantly increased EHAB and EHAD:EHAB in three of the three studies that examined them, and increased the EMG activity of the adductors in the dominant leg 108%.

Conclusion
Overall, the CAE increases EHAD, EHAB, EHAD:EHAB, and EMG activity in the hip adductors in male soccer players. The increase in strength may reduce adductor muscle injuries, although more research needs to be done in this area to identify a clear
relationship between the CAE and groin injury prevention.

**Level of Evidence**

1b

**INTRODUCTION**

Lower extremity muscle strains and injuries are commonplace in sports, especially those requiring the movement patterns of cutting, kicking, sprinting, and jumping.\(^1\) The hip adductors are able to produce torque in all three planes of motion.\(^2\) Furthermore, within the sagittal plane the adductor muscles are able to aid in production of both hip flexion and hip extension, depending on the starting position of the limb.\(^3\) The versatility of the hip adductors may help explain their relative susceptibility to injury and high injury recurrence rates. The prevalence of sports-related groin strains seems to be most common in hockey and soccer, however it is not limited to just these sports.\(^1,4\)

Studies following collegiate athletes in the NCAA report that adductor tears are one of the most prevalent injuries,\(^4\) and that most are a result of non-contact mechanisms.\(^1\) In sub-elite soccer, adductor injury to the dominant leg is the most prevalent injury.\(^5\) In the NHL, groin injury is also the most common injury, and has a high recurrence rate of 23.5%.\(^6\)

Research performed on sub-elite soccer players has shown that having an adductor-related groin injury doubles the injury time compared to injuries not involving the adductor.\(^5\) Although recovery time is often described as being dependent on injury severity, research on sub-elite soccer players demonstrates that timelines may be more protracted than previously thought. Holmich et al found that 76% of groin injuries took greater than eight days to return to play. Of that 76% percent of injuries, 33% took greater than 28 days to recover, which illustrates the often prolonged nature of recovery.\(^5\)

While some research has shown that many adductor injuries require less than 1 week of time lost from play, the combination of high recurrence rates and number of games played in a week can lead to a significant number of games missed.\(^1,4\) In the NHL, it is estimated that the impact of groin/abdominal injury on each team is a game loss of 25 player games per year.\(^6\) An epidemiological study of professional soccer players has reported similar numbers, with an average 14.0 +/- 24.3 days missed following adductor injury and an 18% reinjury rate.\(^7\)

One of the most prevalent factors related to groin injuries is diminished adductor strength. High quality studies have reported an increased number of groin injuries occurring in individuals with decreased adductor strength.\(^8\)-\(^12\) Additionally, a significant increased risk of groin injury is present when an athlete has had a previous groin injury as far as 20 months previously.\(^5\)

Researchers have assessed the relationship of hip adductor strength to hip abductor strength and imbalances between agonist/antagonist muscle groups.\(^9,11,13\) Sports that involve side-to-side cutting, striding, sudden change of direction and quick acceleration and deceleration are at a heightened risk of hip/groin injuries with a decreased level of hip adduction strength relative to the hip abductors.\(^9,11,13\)

With adductor weakness being prognostic of groin strains, it logically follows that exercise programs designed to strengthen the hip adductors may prevent groin strains. However, there is conflicting evidence for this.\(^13\)-\(^15\) Studies without significant results reported poor compliance levels.\(^16,17\) When the adductor strengthening was performed with high compliance, injury rates decreased significantly.\(^15\) Even studies with statistically non-significant but clinically relevant results showed up to 31% reduction of adductor strains.\(^14\) This suggests that preventative effect is significant with compliance. This is further supported by the strong evidence for adductor strengthening in returning to play following a groin injury in research by Holmich et al.\(^18\)

Therefore, the purpose of this study was to systematically review the literature on the CAE and its effects on adductor muscle strength and muscle activity in athletes.

**METHODS**

**REGISTRATION AND PROTOCOL**

This study was registered in the International Prospective Register of Systematic Reviews (PROSPERO) database under the ID: 178579.

**ELIGIBILITY CRITERIA**

The following criteria were required for inclusion: 1) implements CAE, 2) includes athletes of any age participating in at least one sport, 3) study type is a cohort study or randomized control trial. Studies were excluded if they were not written in English or did not measure strength as an outcome. It is important to note that in the current research the term “football” refers to European football commonly known as soccer in the US. The term soccer will be used to describe European football throughout this manuscript. The CAE is defined as an exercise in which the participant assumes a side plank position, with superior lower extremity held by a partner. The participant lowers the free lower extremity to the ground, producing pelvic on femoral abduction on the supported extremity, then raises it to return to the start position, producing pelvic on femoral concentric adduction on the supported extremity.\(^17\) (**Figure 1**) Based on this exercise, the adductor strengthening program was developed and studied.\(^19\)

**SEARCH STRATEGY, DATABASES UTILIZED, AND STUDY SELECTION**

The search strategy for each database is provided in Appendix 1. The following databases were searched: Pubmed; Medline (EBSCO); Sportdiscus; Scopus; Web of Science; CINAHL; Proquest; Cochrane Library; Physiotherapy Evidence Database (PEDro). All studies identified in the search were obtained and duplicates removed. Two researchers in-
dependently reviewed titles and abstracts for inclusion criteria. Inclusion criteria consisted of 1) implements CAE, 2) includes athletes of any age participating in at least one sport, 3) study type is a cohort study or randomized control trial. Studies were excluded if they were not written in English or did not measure strength as an outcome. Full text articles identified through the title and abstract search were screened by two researchers; consensus was reached after any disagreement. The initial search was conducted April, 2020. Follow up searches were completed September 2020 and February 2021.

DATA EXTRACTION AND ANALYSIS

Each article was individually reviewed by two reviewers; consensus was reached following any initial disagreement. Author and date, study type, sample size, age, sport, intervention, independent variable, control, and outcome measures were extracted. The following outcome measures were extracted from the articles: eccentric hip adductor strength (EHAD), eccentric hip abductor strength (EHAB), EHAD:EHAB ratio, delayed onset muscle soreness (DOMS), electromyography (EMG) activity, knee flexor strength, sprint speed, and Rate of Perceived Exertion (RPE). Data analyzed in this systematic review were EHAD strength, EHAB strength, EHAD:EHAB ratio, and EMG activity.

QUALITY ASSESSMENT

Quality assessment was performed independently by three reviewers. Each reviewer assessed the articles with the Quality Assessment Tool for Quantitative Studies, which was developed by the Effective Public Health Practice project.20 The studies were assessed independently prior to discussion and consensus regarding strength of the study. The Quality Assessment Tool rates studies based on selection bias, study design, confounders, blinding, data collection methods, withdrawals and drop-outs, intervention integrity, and analysis, culminating in a global rating of strong, moderate or weak based on the culmination of category ratings.

RESULTS

STUDY SELECTION

The results of the search criteria produced 8,880 titles, which were reviewed for applicability. After title assessment and abstracts were screened, 53 were deemed appropriate for full-text review. The agreement between the two authors for the full text review was $k = .89$ (almost perfect agreement) for which full text articles were selected for inclusion. Discrepancies were decided through discussion and a consensus was reached. Five full-text articles were selected after full evaluation and included in the systematic review. (Figure 2)

QUALITY ASSESSMENT

The Quality Assessment Tool for Qualitative Studies has been shown to have fair inter-rater agreement for individual domains and excellent agreement for the final grade.20 Four of the studies were rated as strong, while one of the studies was rated as moderate using the tool. The agreement between authors for the quality assessment "Global Rating" was $k = 1.0$. Details can be found in Table 1.

STUDY CHARACTERISTICS

Three studies were randomized controlled trials and two were cohort studies. All five studies were performed on male...
Table 1. Quality Assessment Analysis

<table>
<thead>
<tr>
<th>Study</th>
<th>Selection Bias</th>
<th>Study Design</th>
<th>Confounders</th>
<th>Blinding</th>
<th>Data Collection Methods</th>
<th>Withdrawals and Dropouts</th>
<th>Global Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harøy, J et al., 2017³⁹</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
<td>Moderate</td>
<td>Strong</td>
</tr>
<tr>
<td>Ishoi, L et al., 2016²¹</td>
<td>Moderate</td>
<td>Strong</td>
<td>Strong</td>
<td>Moderate</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
</tr>
<tr>
<td>Polglass, G et al., 2019²²</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Strong</td>
<td>Moderate</td>
<td>Strong</td>
<td>Moderate</td>
<td>Strong</td>
</tr>
<tr>
<td>Kohavi, B et al., 2018²³</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
<td>Moderate</td>
<td>Strong</td>
<td>Moderate</td>
<td>Strong</td>
</tr>
<tr>
<td>Serner, A et al., 2014⁻⁷¹</td>
<td>Strong</td>
<td>Weak</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

Methodological quality is rated (guidance provided) for the following areas: selection bias, study design, confounders, blinding, data collection methods, withdrawals and dropouts, intervention integrity, and analysis.

Strong - no weak ratings given
Moderate - one weak rating
Weak - two or more weak ratings

soccer players. Number of participants and mean age can be found in Table 2. Four studies had hip adduction strength as the primary outcome measure (measured in a side-lying break test according to Thorborg’s protocol²⁴ using a handheld dynamometer), while one study had EMG activity as the primary outcome measure. All five studies used the CAE, but one study used a modified progression to build up to the CAE. Study and intervention details can be found in Table 2.

EMG activity was measured through bipolar disposable silver/silver chloride surface electrodes placed parallel to muscle fibers with two centimeters between electrodes to avoid unstable recordings. To confirm correct placement of electrodes, a manual muscle test was performed while monitoring EMG. EMG activity was measured in the adductor longus,²⁵,²⁶ gluteus medius,²⁵–²⁸ rectus abdominis,²⁹ and external abdominal oblique.³⁰,³¹

STRENGTH ASSESSMENT

Four of the studies included maximal eccentric hip adduction strength (EHAD) as an outcome measure. All studies found a significant increase in EHAD in the groups using the CAE. Three of the four studies also included EHAB and EHAD:EHAB ratio, and all studies found significant increases in these additional variables for the groups using the CAE. Results can be found in Table 3.

Harøy et al randomized 45 male soccer players into two groups: one group performed the FIFA 11+ warm up program (which includes the Nordic hamstring exercise); the other group performed the FIFA 11+ but replaced the Nordic hamstring exercise with CAE. Both groups performed the intervention three times a week for eight weeks. Significant EHAD strength was found in the group performing the CAE.¹⁶ (Table 3)

Ishoi et al conducted a cluster randomized trial where they recruited two soccer teams to participate in an eight week training program twice a week. One team was designated as the control and was assigned to continue training as usual. The other team was assigned as the intervention group and participated in a progressive training program using the CAE in addition to usual training. The CAE group demonstrated significant increases in EHAD, EHAB and EHAD:EHAB.²¹ (Table 3)

Kohavi et al randomized 42 soccer players into a CAE, sliding hip (SH), or a control group. The SH exercise is described as, “(t)he athlete stand(s) with both legs on a plastic sliding pad, with trunk, hips, and knees straight, and hands placed in front of the chest on a stable supporting bar. Both legs are abducted, and the center of gravity moves downward as much as controllably possible. After reaching the maximal distance and keeping the same position for two seconds, the legs are adducted, sliding back to the starting position.” The CAE and SH group performed their respective exercises two sessions a week for eight weeks. The control group performed a time matched protocol of hip mobility exercises. Both the CAE and SH groups experienced significant increases in EHAD, EHAB and EHAD:EHAB.²³ (Table 3)
<table>
<thead>
<tr>
<th>Study</th>
<th>Intervention Details</th>
<th>Study Design</th>
<th>Participants (n)</th>
<th>Age (Years)</th>
<th>Gender</th>
<th>Sport</th>
<th>Outcome Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haroy, J et al., 2017</td>
<td>CA performed on both sides compared to Nordic Hamstring. Intervention performed 3x per week for 8 weeks with 1 set per side, progressing from 3-5 reps to 12-15 reps from beginner to advanced athletes.</td>
<td>RCT</td>
<td>33</td>
<td>16.9 ± 1.0</td>
<td>100 %</td>
<td>Male</td>
<td>Soccer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Intervention Group- 16.7 ± 0.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Control Group - 16.9 ± 1.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ishoi, L et al., 2016</td>
<td>CA performed both sides compared to control group with no intervention. Intervention performed 2x per week for 8 weeks, progressing from 2 sets of 6 reps per side each session to 3 sets of 15 reps per side each session.</td>
<td>Cluster RCT</td>
<td>20</td>
<td>17.4 (17-18)*</td>
<td>100 %</td>
<td>Male</td>
<td>Soccer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Intervention - 17.3 (17-18)*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polglass, G et al., 2019</td>
<td>Modified Progressive CA (MPCA) with no comparison group. MPCA consisted of 6 levels, ranging from an assisted isometric adduction to a full CA exercise. Intervention was performed 2x per week for 8 weeks, progressing from 2 sets of 6 reps per side to 3 sets of 10 reps per side.</td>
<td>Cohort</td>
<td>17</td>
<td>27.4 (20-35)*</td>
<td>100 %</td>
<td>Male</td>
<td>Soccer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>27.4 (20-35)*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kohavi, B et al., 2018</td>
<td>CA compared to sliding hip (SH) exercises and control group with active mobilization. Intervention performed 2x per week for 8 weeks, progressing from 2 sets of 6 reps per side to 4 sets of 9 reps per side.</td>
<td>Prospective RCT</td>
<td>42</td>
<td>17.5 ± 1.1</td>
<td>100 %</td>
<td>Male</td>
<td>Soccer</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>17.5 ± 1.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Serner, A et al., 2014</td>
<td>Examined the EMG activity of 6 different adductor exercises.</td>
<td>Cohort</td>
<td>35</td>
<td>21.4 ± 3.3</td>
<td>100 %</td>
<td>Male</td>
<td>Soccer</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>21.4 ± 3.3</td>
<td></td>
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</tr>
</tbody>
</table>

* = age range; EHAD = eccentric hip adduction strength; EHAB = eccentric hip abduction strength; EMG = electromyography
<table>
<thead>
<tr>
<th>Study</th>
<th>Leg(s)</th>
<th>EHAD Strength</th>
<th>EHAB Strength</th>
<th>EHAD:EHAB Ratio</th>
<th>EMG</th>
<th>Gluteus Medius (% MVIC)</th>
<th>External Abdominal Oblique (% MVIC)</th>
<th>Rectus Abdominis (% MVIC)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Harøy, J et al., 2017</strong></td>
<td>Cumulative</td>
<td>8.0% increase</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Nondominant</td>
<td>(3.25 ± 0.62 to 3.51 ± 0.63 Nm/kg; (p &lt; 0.001); (d = 0.60)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Dominant</td>
<td>(3.29 ± 0.57 to 3.53 ± 0.58 Nm/kg; (p = 0.02)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Ishoi, L et al., 2016</strong></td>
<td>Cumulative</td>
<td>35.7% increase</td>
<td>20.3% increase</td>
<td>12.3% increase</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>(2.71±0.48 to 3.67 ± 0.38 Nm/kg; (p &lt; 0.001); (d = 2.2); 95% CI (25.83%, 45.39%</td>
<td>(2.27 ± 0.41 to 2.74 ± 0.41 Nm/kg; (p &lt; 0.001); (d = 1.1); 95% CI (12.78%, 28.19%)</td>
<td>(1.22 ± 0.28 to 1.37 ± 0.23); (p = 0.019) (d = 0.6); 95% CI (2.46%, 21.31%)</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td></td>
<td>Left</td>
<td>(3.46 ±0.49) to 4.32 ±0.86; (p &lt; 0.01)</td>
<td>(3.08 ±0.55) to 3.5 (±0.67); (p &lt; 0.01)</td>
<td>(1.12 ±0.51 to 1.24 (±0.75); (p &lt; 0.01)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Polglass, G et al., 2019</strong></td>
<td>Right</td>
<td>25% increase</td>
<td>13% increase</td>
<td>10% increase</td>
<td>-</td>
<td>-</td>
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<tr>
<td></td>
<td>Left</td>
<td>24% increase</td>
<td>10% increase</td>
<td>12% increase</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Kohavi, B et al., 2018</strong></td>
<td>Right</td>
<td>(0.84 ±0.38 to 4.11 ±0.76 Nm/kg; (p &lt; 0.001); (d = 2.11)</td>
<td>(2.57 ± 0.36 to 3 ± 0.36 Nm/kg; (p &lt; 0.01); (d = 1.18)</td>
<td>(1.12 ± 0.18 to 1.38 ± 0.26); (p &lt; 0.001); (d = 0.84)</td>
<td>-</td>
<td>-</td>
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<tr>
<td></td>
<td>Left</td>
<td>(2.76 ±0.46 to 4.13 ±0.91 Nm/kg; (p &lt; 0.001); (d = 1.9)</td>
<td>(2.59 ± 0.28 to 2.96 ± 0.28 Nm/kg; (p = 0.01); (d = 1.32)</td>
<td>(1.07 ± 0.21 to 1.4 ± 0.35); (p = 0.001); (d = 1.14)</td>
<td>-</td>
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<tr>
<td><strong>Serner, A et al.</strong></td>
<td>Dominant</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>20 ± 3</td>
<td>29 ± 3</td>
<td>19 ± 3</td>
<td>-</td>
</tr>
<tr>
<td>Study</td>
<td>Strength</td>
<td>EMG</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Leg(s)</td>
<td>EHAD Strength</td>
<td>EHAB Strength</td>
<td>EHAD:EHAB Ratio</td>
<td>Adductor Longus (% MVIC)</td>
<td>Gluteus Medius (% MVIC)</td>
<td>External Abdominal Oblique (% MVIC)</td>
<td>Rectus Abdominis (% MVIC)</td>
</tr>
<tr>
<td>201417</td>
<td>Non-Dominant</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>48 ± 3</td>
<td>36 ± 3</td>
<td>40 ± 3</td>
</tr>
</tbody>
</table>

EHAD = eccentric hip adduction strength; EHAB = eccentric hip abduction strength; MVIC = maximal voluntary isometric contraction; EMG = electromyography; CA = Copenhagen adductor exercise. Bolded p-values indicate statistically significant differences.
Polglass et al performed a cohort study to investigate a progressive CAE program with the aim of limiting muscle soreness while increasing strength. Twenty-five soccer players completed the eight week program with sessions twice a week. While there was no control group, researchers used the participants rate of perceived exertion (RPE), delayed onset muscle soreness (DOMS), and performance of the exercise to determine if the participant was able to progress to the next level in the program. The players completed the program with decreased delayed onset of muscle soreness and increased EHAD, EHAB, and EHAD:EHAB.\(^{22}\) (Table 3)

**EMG ASSESSMENT**

The study by Serner et al focused on EMG measurement of adductor longus, abdominal, and gluteal activation during eight hip adduction exercises. There were six traditional exercises which included isometric adduction with a ball between ankles, isometric adduction with a ball between knees, side-lying hip adduction, sliding hip abduction/adduction, hip adduction with an elastic band, and hip adductor machine. Two new exercises were included: CAE and supine bilateral hip adduction. The study used 40 male soccer players as the participants. When looking at EMG activity in the adductor longus, gluteus medius, external abdominal oblique, and rectus abdominis, there was a significant difference found between the three exercises (CAE, isometric adduction with ball between knees, and hip adduction with an elastic band) with the highest nEMG of the adductor longus (peak normalized EMG signal, the value was normalized using an isometric maximal voluntary contraction as a reference) activity and the three exercises with the lowest nEMG activity (isometric adduction with ball between ankles, side-lying hip adduction, supine hip adduction) of the adductor magnus. There were three exercises performed during this study that had significantly higher activation in the adductor longus muscle in the dominant leg versus the non-dominant leg. These exercises were the CAE, hip adduction with an elastic band, and side-lying hip adduction. The differences in peak nEMG of the adductor longus muscle were measured and the CAE along with isometric adduction with a ball between the knees produced a nEMG of 108%.\(^{17}\) This is capable of producing a strengthening stimulus, as strength gains of active muscle are expected when EMG is greater than 40%.\(^{32}\)

**DISCUSSION**

The purpose of this study was to systematically review the literature on the CAE and its effects on adductor muscle strength and muscle activity in athletes. After reviewing the five studies that met the inclusion criteria, the CAE significantly increased EHAD in all the studies examining EHAD, and significantly increased EHAB and EHAD:EHAB ratio in all the studies examining EHAD:EHAB ratio. The CAE also produced peak EMG of the adductor longus of 108% on the dominant leg, which was higher than other exercises which target the adductor longus. The lack of equipment needed to perform the exercise combined with the results of this systematic review suggest that the CAE is a pragmatic and viable intervention to increase adductor strength.

Research on the CAE that was used for this systematic review is subject to limitations. The small sample sizes in the included articles presents a limiting factor. Methodological procedures that introduced potential bias were 1) the fair to good ICC measurement for EMG activity in two adductor longus isometric exercises, although these were not considered to significantly influence the findings,\(^{17}\) 2) using the Bonferroni correction which may increase the risk of a Type 2 error,\(^{17}\) and 3) the absence of a control group in some studies which prevents definitive conclusions. Furthermore, RCTs with cluster randomization were included which increases the potential for Type 1 error due to inability to control for confounding factors. Lack of blinding to intervention type and the limited documentation of reliability and validation of the NordBord testing that may introduce potential bias are additional limitations.\(^{16}\)

Several studies allowed players to continue their generalized strength program and therefore researchers were unable to control for all variables. Additionally, the studies excluded subjects with previous groin strain rates. Lastly, some of the research lacks reproducibility due to the nature of the EMG testing and utilization of a mean of tests in some research.

This systematic review illustrates that strength increases are associated with the CAE, however, only recently have research studies have investigated the effect of this exercise in terms of adductor injury reduction. Haroy et al randomized 35 semi-professional football (soccer) teams into an intervention group performing an adductor strengthening program based on the CAE, and a control group instructed to train as normal. After 6-8 week preseason, the average weekly prevalence of groin problems during the season in the control group was 21.3% compared to 15.5% in the intervention group (11.7% after removal of players not meeting the per-protocol criteria). Further analysis revealed a significant (41%) lower risk of reporting groin injury in the intervention group.\(^{19}\) The same study found the average weekly prevalence of substantial groin problems in the control group was 8.0% compared to 5.7% in the intervention group (4.5% after removal of players not meeting per-protocol criteria). These values equate to an 18% lower risk of reporting substantial groin problems; however, this was not determined to be significant.\(^{19}\)

The effects of the CAE on injury rates remains an area in need of further research. Ishoi et al graded the evidence on various lower extremity injuries and treatments and found that mixed groin prevention programs and adductor specific groin programs showed trivial and insignificant risk reduction, and the FIFA 11+ program showed a small but insignificant risk reduction.\(^{33}\) Additionally, the dosage required to achieve these strength increases while still maintaining adherence to the program presents opportunities for future research, and has been initiated by Ishoi et al who recently researched training volume and the clinical application of the CAE.\(^{34}\) Haroy et al found that while football (soccer) players agreed that groin injuries are prevalent in the sport, and that preventative measures should be taken, only 46% reported that they followed the CAE program as instructed, and only 51% reported that they would continue the program after the study.\(^{35}\) Another more recent study by van
der Horst et al shows less adherence, with almost 70% of athletes never completing the exercise and only 4% completing it as prescribed.56 These statistics show the need to find a program that will promote adherence while maintaining the proper dosage needed for strength increases, and possibly be linked to reduced injury rates.

While there is a lack of extensive research of the CAE, the Nordic Hamstring exercise, which consists of an eccentric activation of the hamstrings, similar to the eccentric activation of the adductors during the CAE, has been researched extensively. While reviewing 40 articles that examined the effectiveness of exercise on hamstring injury prevention, Raya-Gonzalez et al noted that three studies asserted that eccentric based protocols were effective, and 17 reported that the Nordic Hamstring Exercise was effective.37 Mjolsnes et al reported an 11% increase in eccentric hamstring strength after a 10-week Nordic Hamstring exercise program, compared to no increase in the control group completing hamstring curls.38 Furthermore, de Oliveira et al examined eccentric knee extensor and biceps femoris muscle fascicle length in female soccer players following implementation of the Nordic Hamstrings exercise, two measures also consistent with hamstrings injuries. The study by de Oliveira found that over two-thirds of participants demonstrated a significant increase in eccentric knee extensor strength and nearly half of participants demonstrated fascicle length increases.39

There is evidence that the increase in eccentric hamstring strength developed by the Nordic Hamstring exercise has been accompanied by a decrease in hamstring injuries. Van Dyk, N et al found a 0.49 reduction in risk ratio (95% CI 0.32-0.74; p=0.0008) in programs including the Nordic Hamstring exercise.40 Al Attar, WSA et al reported a significant reduction of hamstring injury risk ratio of 0.490, equating to up to 51% reduction in hamstring strains when using the Nordic Hamstring exercise compared to no hamstring injury prevention exercise.41 Van der Horst et al conducted an RCT examining the effects of the Nordic Hamstring Exercise on injury rates in 40 football (soccer) teams. The study concluded that after 25 sessions during a 15-week training period, injury incidence rates were significantly different between intervention and control groups. The intervention group demonstrated a 0.25 (per 1,000 hours) injury incidence rates while the control group demonstrated a 0.8 injury incidence rate. However, no significant data was found on the severity of the injuries.42 Ishoi et al graded the current evidence on the Nordic Hamstring Exercise and the effects on injury rates and found that the FIFA 11+ program coupled with the Nordic Hamstring Exercise resulted in a significant 45-65% decreased risk of hamstrings injury in elite football (soccer) players. However, while 66% of elite football teams reported using the Nordic Hamstrings Exercise, over 80% of these teams were not compliant in the 10-week protocol, which is likely why hamstrings injuries continue to be prevalent in football players.43 The research above cannot be directly applied to the adductor musculature due to the anatomical and kinesiological differences between muscle groups.

Additionally, this review is subject to limitations. First, there is limited research available on the CAE, therefore, only five studies are included in this systematic review. Also, the research on the CAE is not robust; only three RCTs have been conducted meeting the inclusion criteria for this systematic review. The other two studies included in the review are cohort studies. Also, the Quality Assessment Tool has only been shown to have "fair" inter-rater agreement. Lastly, all the studies included looked only at male football (soccer) players, thus reducing generalizability of the results to athletes in other sports, albeit providing an excellent data set on this population.

CONCLUSION

The results of this systematic review indicate that the CAE can increase adductor strength, EHAD:EHAB strength ratio, and produce EMG activity level capable of producing a strengthening stimulus in the adductors. The research examined only included male soccer players, which provides excellent data on this subgroup, while decreasing generalizability to the other populations. More research needs to be conducted to examine the relationship between the CAE and adductor injury prevention.

CONFLICTS OF INTEREST

Authors have no conflicts of interest to disclose.

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REFERENCES


34. Ishai L, Thorborg K. Copenhagen adduction exercise can increase eccentric strength and mitigate the risk of groin problems: But how much is enough! *Br J Sports Med.* 2021. doi:10.1136/bjsports-2020-103564


Systematic Review/Meta-Analysis

A Systematic Review of Center of Mass as a Measure of Dynamic Postural Control Following Concussion

Sarah Patejak¹, Joshua Forrest¹, Emily Harting¹, Mable Sisk¹, Eric Schussler²

¹ The James A. Haley Veteran's Hospital, ² School of Rehabilitation Sciences, Physical Therapy, Old Dominion University, ³ Wardell Orthopedics, ⁴ Sentara Healthcare, Great Bridge Sports and Orthopedic Therapy Center

Keywords: movement system, gait, dynamic stability, concussion, center of mass

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Background
The incidence of sports-related concussion in the US is between 1.6-3.8 million annually. Identification of ongoing impairment post-concussion continues to be challenging, as research indicates many patients are cleared for return to activity while still suffering subclinical impairment of function. Purpose: To identify and review the current literature on the use of center of mass (COM) during gait as a potential indicator variable after concussive injury. Study Design: Systematic Review

Methods
A Pubmed search was undertaken utilizing search terms involving gait performance and concussion. Study inclusion criteria included: (1) COM used as a variable in data analysis, (2) study population included individuals diagnosed with concussion, (3) postural control was evaluated throughout the recovery process. Articles were excluded if they were systematic reviews, unedited manuscripts, meta-analyses, or were more than 15 years old.

Results
Search of the PubMed database identified six articles which matched the determined criteria. The average STROBE score was 26.5/34 (range from 23-30). The areas that had the poorest scoring were bias, study size, statistical methods, participants, descriptive data, and main results. Results of the review indicate that COM displacement was higher in concussion groups with a sufficiently taxing task, such as a dual task paradigm.

Conclusion
Center of mass measures during gait may be an indicator of ongoing concussive injury involvement after clinical indications have subsided.

Level of Evidence
2a

INTRODUCTION
The incidence of sports-related concussion, also known as mild traumatic brain injury (mTBI), in the US is between 1.6-3.8 million annually.¹ "Sport related concussion is a traumatic brain injury induced by biomechanical forces"² and is an area of interest in research for diagnosis, deficits, intervention, and recovery. Typically, relative rest is recommended until symptoms have resolved, which typically takes around seven days and occurs in about 90% of individuals.³ Symptoms and presentation vary extensively between patients, and can include impairments in cognitive function, motor tasks such as balance and coordination, visual acuity, and reaction time, among many others.

Originally, concussion diagnosis was based on a graded scale based on symptom severity at initial presentation.⁴
Currently, there is no definitive objective diagnostic test or biomarker clinicians can rely on for an immediate diagnosis. Because a concussion injury is highly variable, both in symptoms and duration, classification is difficult. Time to full recovery is the current standard for measuring injury severity. At this time, a battery of subjective and objective measures are used both at initial presentation and at subsequent re-examinations, all evaluating different aspects of impaired function. However, the specific variables each of these tools utilize to make their determinations of an individual’s level of function may not be appropriate for the tasks they are intended to evaluate. This could potentially lead to participation in activities that carry a risk of reinjury prior to full functional recovery.

Any collection of concussion symptoms that persists for longer than two weeks and impacts an individual’s daily function is considered diagnostic criteria for Post-Concussion Syndrome (PCS). There is currently no way to definitively predict the development of PCS, as biomechanics of the impact and the severity of the impact have not been shown to be related to the onset of PCS. Risk factors for PCS include retrograde amnesia, difficult concentrating, disorientation, insomnia, loss of balance, sensitivity to noise and visual disturbances after injury. There are a variety of accepted diagnostic outcome measures that are used for identifying concussion and PCS that have evolved as new research has elucidated the complexities of the conditions.

Center of mass (COM) as a measure to determine dynamic postural stability has been examined for efficacy as a diagnostic tool and as an outcome measure for use in concussion rehabilitation. Statically, COM is the point where the mass of the body is centered and is usually located just below the umbilicus in quiet standing. During gait, COM shifts in a predictable pattern toward the foot that is stepping and also at a predictable velocity determined by the gait speed of the individual. Previous studies have examined whole-body COM motion during ambulation with kinematic measurements to examine recovery of gait balance control after sustaining a concussion. Previous research has also identified significant changes in COM sway and velocity during gait with the addition of a dual-task paradigm via a cognitive component up to 28 days post-injury with little attention paid to the remainder of recovery time.

Due to the diverse presentation of concussion and PCS, there is no evident consensus for clearance of an individual to return to their prior level of function and activity. It is imperative to avoid clearing an individual too soon, especially in the athletic population, to decrease the risk of sustaining a second head injury. In addition, returning prior to full recovery has been indicated to slow the general rate of symptom resolution and prolong the presence of problematic deficits. In order to more definitively determine when discharge from monitored care is appropriate and safe, objective measures must be evaluated for their ability to detect meaningful differences. The purpose of this systematic review is to identify and review the current literature on the use of center of mass (COM) during gait as a potential indicator variable after concussive injury.

METHODS

EVIDENCE ACQUISITION

The PubMed database was searched for relevant, peer-reviewed articles published in English from the inception of the database until November 19, 2019. The search strategy included two concepts (gait, and concussion) and a combination of associated key words and MeSH terms tailored to the database (APPENDIX 1). All located articles were hand-searched by two study authors (EH and SP) to confirm the presence of assessment related to balance, posture, or postural control in combination with gait and concussion. Reference lists of all relevant articles were hand-searched for additional relevant articles by four study authors (JF, EH, SP, & MS).

Four study authors (JF, EH, SP, & MS) independently screened all articles for study inclusion criteria: (1) COM used as a variable in data analysis, (2) study population included individuals diagnosed with concussion, (3) postural control was evaluated throughout the recovery process. Articles were excluded if they were systematic reviews, unedited manuscripts, meta-analyses, or were more than 15 years old. Articles that studied postural control but did not use COM as a measurable variable were also excluded. Author consensus for inclusion was achieved through discussion.

Four authors (JF, EH, SP, & MS) independently reviewed the methods and standards of quality of six articles using the STROBE quality assessment tool, and the Downs and Black bias assessment. The STROBE tool is validated for content and initial construct validity and inter-rater reliability for cohort studies through asking 34 questions of selection bias, study design, confounders, blinding, data collection methods, withdrawals and dropouts, intervention integrity, and analysis. The max rating is a 54 with higher scores indicating higher quality. The Downs and Black scale is validated for use in assessing the bias of cohort studies by asking 27 focused questions, with scoring of 0 for no, or 1 for yes. Higher scores indicate a lower risk of bias.

Four authors (JF, EH, SP, & MS) performed data extraction: study design, purpose, healthy/control subjects (#, demographics), injured/case subjects (#, demographics), inclusion and exclusion criteria, setting, dependent variables, independent variables, intervention, procedures, equipment/collection parameters, statistical analysis performed, summary of results, threats to internal validity, threats to external validity, and conclusions. All data used in the review was captured using these parameters. Four authors (JF, EH, SP, & MS) completed an assessment of the level of evidence and strength of recommendation (SORT) for each accepted study.

RESULTS

Search of the PubMed database yielded 259 articles. After screening for duplicates this number dropped to 107 records. Title and abstract screening yielded 22 articles for full-text review. Author agreement for inclusion/exclusion prior to full-text review and after full-text review was satisfactory. Ultimately, six articles 5, 4, 6, 11, 14, 15 met the inclu-
sion criteria and quality and bias standard and were accepted for inclusion into this systematic review. Analysis was completed on the final six articles (Figure 1). All studies included are cohort studies with a SORT, level 2\(^\text{16}\) and level 4 evidence as noted with the Downs and Black bias assessment.\(^\text{13}\)

Of the six included articles, the average quality\(^\text{12}\) score was 26.5/34 (range from 23-30). The areas that had the poorest scoring were bias, study size, statistical methods, participants, descriptive data, and main results. There was one similar author group, but it was found that they had similar assessment windows and outcome measures with use of different population groups.\(^\text{6,15}\)

All six of the articles (100%) were cohort studies,\(^\text{1,3,4,6,11}\) two articles (33.3%) performed prospective testing occurring five separate times,\(^\text{6,15}\) and four articles (66.6%) were longitudinal with testing times ranging between five to seven separate sessions.\(^\text{6,11,14,15}\) All articles assessed COM during gait. Participants ranged in age from 14 to 27 years, and most were high school or collegiate athletes.\(^\text{3,4,6,11,14,15}\) None of the studies reported results based on sex, and four had no further delineations beyond concussion diagnosis compared to controls.\(^\text{3,4,6,14}\) One study compared adolescent and young adult age groups.\(^\text{15}\) One article delineated concussed and non-concussed athletes, and further divided these groups into high- and low-velocity impact groups.\(^\text{11}\) One study delineated groups of high school athletes and their recovery before return to activity (RTA) and after RTA.\(^\text{6}\) A diagnosis of concussion was made using the American Academy of Neurology’s definition for two studies,\(^\text{3,11}\) the McCrory et al.\(^\text{15}\) definition for three studies,\(^\text{4,6,15}\) and was not specified in one study.\(^\text{14}\) Diagnoses were made exclusively by physicians in two studies,\(^\text{4,14}\) and by either a physician or a certified athletic trainer in the other four.\(^\text{3,6,11,15}\) Details of study design and quality reporting scores are summarized in Table 1.

Participants were initially assessed within 48 to 72 hours in four of the studies,\(^\text{3,6,11,15}\) while two of the studies did not state when initial assessment occurred.\(^\text{4,14}\) Reassessment did not occur in one study.\(^\text{4}\) Two studies followed participants for one month with weekly testing dates.\(^\text{3,11}\) Two studies followed participants for two months with follow-up sessions at one week, two weeks, one month, and two months.\(^\text{6,15}\) One study followed participants with weekly testing for six weeks and a one-year post-injury follow up.\(^\text{14}\) Four studies did not specify if practice trials were allowed,\(^\text{6,11,14,15}\) while two allowed unlimited practice before data points were collected.\(^\text{3,4}\) The experimental protocol, assessment time points, and study results are summarized in Table 2.
Table 1. Study Design and Participant Characteristics of Articles Included in the Systematic Review

<table>
<thead>
<tr>
<th>Study</th>
<th>Study Design</th>
<th>Inclusion Criteria</th>
<th>Exclusion Criteria</th>
<th>Concussed Participants</th>
<th>Non-concussed Participants</th>
<th>STROBE Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fino, et al. (2016)</td>
<td>Longitudinal exam of the local dynamic stability (LDS) of recently concussed and matched control athletes</td>
<td>mTBI group: diagnosis of mTBI based on VHA/DoD criteria with persisting symptoms &gt;3 after injury; Between 21-50 years old; minimal cognitive impairment; score of between 0-8 on Short Blessed test for cognitive function; may/may not had loss of consciousness after initial injury Control group: between 21-50 years old; no hx of mTBI brain injury</td>
<td>Have had/currently have any other injury, medical, substance or neurological illness that could potentially explain balance deficits (i.e. - CNS disease, stroke, moderate TBI, lower extremity amputation); meet criteria for moderate to severe substance use disorder within the past month (DSM-V); display behavior that would significantly interfere with validity of data collection or safety during study; be in significant pain during eval (5/10 subjectively); pregnant female; history of peripheral vestibular pathology or ocular motor deficits; significant hearing loss unable to abstain from use of medications for 24 hours prior to testing (meds might impair balance)</td>
<td>5 concussed Varsity athletes</td>
<td>4 matched varsity athletes; recruited from teammates of concussed subjects - matched by sport position, skill level, and height</td>
<td>30/17</td>
</tr>
<tr>
<td>Parker, et al. (2008)</td>
<td>Longitudinal cohort study</td>
<td>All concussed subjects had sustained a Grade 2 concussion according to the American Academy of Neurology Practice Parameter. Concussed participants were initially identified by medical personnel including certified athletic trainers and attending medical doctors in the university intercollegiate athletic program and the student health center and were referred for testing as soon as possible following the injury. None of the NORM subjects self-reported a history of neurological diseases, visual impairment not correctable with lenses, musculoskeletal impairments, or persistent symptoms of vertigo, lightheadedness, unsteadiness, falling or a history of concussion within the last year.</td>
<td>Not reported</td>
<td>28 Grade 2 concussed individuals (14 athletes and 14 non-athletes)</td>
<td>28 uninjured matched controls (14 athletes and 14 non-athletes); The control subjects were matched to concussed subjects by gender, age, height, weight, and physical activity</td>
<td>27/14</td>
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<tr>
<td>Catena, et al. (2009)</td>
<td>Longitudinal cohort study</td>
<td>Student health center/athletic team physicians/trainers of university campus examined participants for mTBIs including those diagnosed with grade II concussions defined by American Academy of Neurology Practice Parameters</td>
<td>Concussion symptoms lasting longer than 15 minutes but no loss of consciousness, pre-existing abnormalities of gait, or cognition, no prior concussions in the previous year.</td>
<td>30 university subjects with grade 2 mTBI.</td>
<td>30 control subjects matched by gender, age, mass, height, level of</td>
<td>23/16</td>
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<tr>
<td>Study</td>
<td>Study Design</td>
<td>Inclusion Criteria</td>
<td>Exclusion Criteria</td>
<td>Concussed Participants</td>
<td>Non-concussed Participants</td>
<td>STROBE Scores</td>
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<tr>
<td>Howell, et al (2015)</td>
<td>Prospective longitudinal cohort study</td>
<td>Individuals sustaining a concussion were diagnosed and identified for potential inclusion in the study by a physician or athletic trainer as described by: direct blow to head, face, neck, or elsewhere with force transmitted to head resulting in impaired neurological function.</td>
<td>Lower extremity deficiency/injury that may affect normal gait, history of cognitive deficiencies (memory loss, decreased concentration), history of 3+ previous concussions, loss of consciousness from the concussion &gt; 1 min., history of ADHD, previously documented concussion in the past year.</td>
<td>19 local high school students.</td>
<td>19 control subjects matched by sex, height, mass, age, and sport.</td>
<td>28/17</td>
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<tr>
<td>Doherty, et al (2017)</td>
<td>Cohort study</td>
<td>Convenience recruiting of patients at a clinic in Ireland who had sustained a concussion within 1 month, dx by physician consistent with latest international consensus on definition</td>
<td>Any lower extremity injury that may affect gait, hx of cognitive deficiencies, hx of 3+ previous concussions (chronic mTBI), loss of consciousness following concussion &gt; 1 min, previously documented concussion in the past year.</td>
<td>15 concussion patients (4 females, 11 males)</td>
<td>15 age and sex-matched controls</td>
<td>25/12</td>
</tr>
<tr>
<td>Howell, et al (2015)</td>
<td>Cohort Study</td>
<td>High school and college students who sustained a concussion were diagnosed and identified for potential inclusion in the study by a certified athletic trainer or physician. The definition of concussion was consistent with that described by McCrory et al: an injury caused by a direct blow to the head, face, neck, or elsewhere on the body with an impulsive force transmitted to the head, resulting in a graded set of clinical symptoms.</td>
<td>Exclusion criteria for all prospective subjects included the following: (1) lower extremity deficiency or injury that may affect normal gait patterns; (2) history of cognitive deficiencies, such as permanent memory loss or concentration abnormalities; (3) history of 3 or more previous concussions; (4) loss of consciousness from the concussion lasting longer than 1 minute; (5) history of attention-deficit hyperactivity disorder; or (6) a previously documented concussion within the past year. Consistent with previous work, potential subjects with 3 or more previous concussions were not included in the study to ensure, to the extent possible, that those with chronic mild traumatic brain injury were not a part of the study. Additionally, those who experienced a loss of consciousness for greater than 1 minute were excluded because of the role that this sign plays in concussion management modification.</td>
<td>A total of 38 subjects with concussion, 19 young adults (mean 6 SD age, 20.3 6 2.4 years) and 19 adolescents (mean 6 SD age, 15.1 6 1.1 years) [19 young adults (mean +/- SD age, 20.3 +/- 2.4 years) and 19</td>
<td>38 individually matched control subjects: Matched for sex, age, height, mass, activity participation</td>
<td>26/12</td>
</tr>
<tr>
<td>Study</td>
<td>Study Design</td>
<td>Inclusion Criteria</td>
<td>Exclusion Criteria</td>
<td>Concussed Participants</td>
<td>Non-concussed Participants</td>
<td>STROBE&lt;sup&gt;10&lt;/sup&gt; (0-34)/Downs &amp; Black (0-27) Scores</td>
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<td>adolescents (mean +/- SD age, 15.1 +/- 1.1 years)</td>
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</tbody>
</table>

Abbreviations: mTBI: mild traumatic brain injury, VHA/DoD: Veterans Health Affairs/Department of Defense, CNS: central nervous system, TBI: Traumatic brain injury

*International Journal of Sports Physical Therapy*
Table 2. Center of Mass (COM) Assessment Protocol and Results

<table>
<thead>
<tr>
<th>Study</th>
<th>Gait COM Protocol</th>
<th>Assessment Time Points</th>
<th>Study Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fino, et al&lt;sup&gt;6&lt;/sup&gt; (2016)</td>
<td>2 six-axis IMUs aligned in the mediolateral, vertical, and anterior posterior directions with data sampled at 128 Hz during single task and dual task gait. 18m walkway</td>
<td>Assessed weekly for six weeks and a one-year follow-up assessment.</td>
<td>Single Task: no differences in stability or variability between groups; no significant main effects of group, week or task found for stride time, variability, λ&lt;sub&gt;s&lt;/sub&gt;-Trunk, or λ&lt;sub&gt;s&lt;/sub&gt;-Head. Dual Task: gait speed was slower than single task gait speed, with increased speed over time.</td>
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<tr>
<td>Parker, et al&lt;sup&gt;10&lt;/sup&gt; (2008)</td>
<td>External markers and estimated joint centers were used to calculate 3-dimensional motion for individual body segments and locations of segmental COM. Two COM variables were examined: (1) the COM displacement in the medial-lateral direction and (2) the maximum separation between COM and COP of the supporting foot in the anterior direction. The relationship between the whole-body COM and the base of support (shown to be a sensitive measure of gait imbalance). 10m walkway</td>
<td>Assessed 48 hours after injury concussed, day 2 (non-concussed), day 5 (all), day 14 (all), and day 28 (all)</td>
<td>Gait imbalance during the divided attention condition was marked by greater sway and sway velocity of the whole-body COM that was maintained for up to 28 days following injury.</td>
</tr>
<tr>
<td>Catena, et al&lt;sup&gt;2&lt;/sup&gt; (2009)</td>
<td>29 retroreflective markers attached to anatomical landmarks while 3D marker trajectories were taken with eight camera motion tracking system at 60Hz, then filtered with low-pass fourth order Butterworth filter at cutoff frequency of 8 Hz. Marker position data was used to locate segmental COM of a thirteen-link model: head, trunk, two upper arms, two lower legs, pelvis, two thighs, two shanks, two feet.</td>
<td>Assessed 48 hours, on the 6th day, 14th day, and 28th day post-injury.</td>
<td>Concussed individuals significantly reduced peak anteroposterior velocity during dual task walking on day 2. Peak mediolateral velocity was significantly reduced by day 14 during short obstacle crossing.</td>
</tr>
<tr>
<td>Howell, et al&lt;sup&gt;7&lt;/sup&gt; (2015)</td>
<td>29 retroreflective markers placed on bony landmarks of the patient with whole body motion analysis performed using a 10-camera motion analysis system at a sampling rate of 60 Hz capturing and reconstructing 3D trajectory of each marker. Marker trajectory data was low-pass filtered using the fourth-order Butterworth filter with cutoff frequency set to 8 Hz. whole body COM positions were calculated as the weighted sum of all 13 body segments to represent the whole body. 15m walkway</td>
<td>Assessed within 72 hours of injury and 1 week, 2 weeks, 1 month, and 2 months post-injury.</td>
<td>Concussion group: Significant differences were found in group-time interaction between dual-task walking for mediolateral displacement of COM and COM mediolateral velocity. Significant worsening of COM control after return to activity was also illustrated during dual-task walking. Overall mean return to activity mediolateral displacement was significantly greater than controls for same time point measurements when dual-tasking gait. The percent change value of mediolateral velocity during dual-task walking was significantly greater. Peak COM anterior velocity was also decreased in percent change value between pre- and post-return to activity while dual-tasking gait There was a significant group-time interaction pre- and post-return to activity in clinical symptom scores. Pre-Return timepoints between tests 2 and 1 changed significantly more than that of controls which showed little to no change for either testing interval. Additionally, mean pre- and post-return to activity changes were significantly different than controls for clinical symptoms.</td>
</tr>
</tbody>
</table>

Abbreviations: IMU: inertial measurement unit, COP: Center of Pressure, λ<sub>s</sub>: Lyapunov exponents
POSTURAL CONTROL PARADIGMS

STUDY OUTCOME VARIABLES

All studies used flat surfaces for experimental walkways that ranged from 10 to 18m in length in four studies,\textsuperscript{3,6,11,14} though the length was not specified in the other two protocols.\textsuperscript{3,6} All six studies utilized self-selected walking speeds for dynamic tasks, and all subjects were tested in the barefoot condition.\textsuperscript{5,6,11,14,15} Two studies used accelerometers to capture motion data,\textsuperscript{4,14} another two used force plates embedded within the experimental walkways,\textsuperscript{3,4} and four studies utilized reflective markers and multiple camera motion analysis to collect changes in COM excursion, velocity, and acceleration.\textsuperscript{3,6,11,15} Only one study used obstacles negotiation as a separate condition.\textsuperscript{3}

Five of the six studies (83.3\%) added a cognitive component to assess dual-tasking ability of subjects during gait.\textsuperscript{3,6,11,14,15} In two studies, participants were given a random number and asked to serially subtract by 7’s,\textsuperscript{5,11,14} one of the studies utilized backwards spelling and recitation of the months of the year in reverse,\textsuperscript{11} and another utilized question-and-answer verbal response.\textsuperscript{3} Two studies performed the Stroop cognitive assessment during walking trials, where subjects are asked to compare whether an auditory and a visual cue given simultaneously are the same or different.\textsuperscript{6,11} Instructions were given verbally for all studies.

SINGLE-TASK DYNAMIC VARIABLES

All six studies examined dynamic variables related to COM, specifically excursion of the COM during gait and peak velocity. These were evaluated along two straight anatomical planes: the anterior-posterior (AP) and medio-lateral (ML). In six articles, these were assessed using computer analysis of the data gathered from various technology (force plates,\textsuperscript{3,4} accelerometers,\textsuperscript{4,14} and/or motion capture systems\textsuperscript{3,6,11,15}). Five studies described COM excursion in whole-body terms \textsuperscript{3,4,6,11,15}, while one study split the COM into head and trunk segments.\textsuperscript{14} Three studies showed greater ML sway, or COM excursion, in concussed individuals versus controls during single-task walking.\textsuperscript{3,6,15} This difference was also reflected in the one study that included an obstacle negotiation condition.\textsuperscript{3} One study split the groups into athletes and non-athletes, and found that ML sway was significantly greater for athletes, regardless of presence of concussion.\textsuperscript{11} Peak COM velocities were slower in concussed groups versus controls in the ML plane in three studies\textsuperscript{6,15} and in the AP plane in three studies.\textsuperscript{3,4,11} No significant differences were found between concussion subgroups or control groups for any single-task dynamic variables across all studies.

DUAL-TASK DYNAMIC VARIABLES

A cognitive component was added to dynamic tasks in five of the six studies reviewed,\textsuperscript{3,4,6,11,15} as described previously. Only two of the studies reported accuracy on the specific cognitive task;\textsuperscript{6,15} while the others simply used a cognitive task to create a dual-task condition.\textsuperscript{3,4,11,14} One of the studies showed decreased performance on the cognitive task in the adolescent versus young adult groups throughout all testing days,\textsuperscript{15} while another saw no significant differences between groups in cognitive task performance.\textsuperscript{6} During dual-task trials, three studies showed significantly slowed gait speed as measured by total COM displacement over time.\textsuperscript{6,14,15}

Four of the six studies compared single- and dual-task conditions.\textsuperscript{3,6,11,14} ML sway of the COM also increased significantly from the single-task condition in two of the studies across both concussed and non-concussed groups.\textsuperscript{3,11} In the study that compared athletes to nonathletes, athletes still displayed greater ML COM sway during the dual-task condition, regardless of concussion status, though the concussed athlete group displayed the greatest ML sway over all other testing conditions.\textsuperscript{11} ML COM velocity was significantly decreased between single- and dual-task conditions in two studies,\textsuperscript{3,11} and increased in one study.\textsuperscript{6} Two studies showed significantly decreased peak COM AP velocity during dual-task walking.\textsuperscript{6,11}

NEUROPSYCHOLOGICAL TESTS AND POST-CONCUSSION SYMPTOM SCALES

In total, three of six articles\textsuperscript{4,6,15} referenced use of neuropsychological tests or post-concussion symptom scales and a secondary outcome measure of interest. There were two articles that note neuropsychological test and post-concussion symptom scales as a part of their data collection. Howell et al\textsuperscript{6} used cognitive assessment via Attentional Network Test (ANT) and a Task Switching Test (TST) for initial assessment, yielding a significant interaction pre- and post-return to activity in the clinical symptom scores. Participants in the concussed group showed significant differences in pre- and post-return to activity scores.\textsuperscript{6} Two articles\textsuperscript{4,15} cited use of the SCAT3 symptom checklist and reported that adolescents had greater symptom severity compared to the control group.\textsuperscript{15} Doherty et al.\textsuperscript{4} had reports of poorer perceived health in the concussed group compared to the control group with use of the SCAT3 symptom scale. The remaining three articles\textsuperscript{3,11,14} did not assess or report neuropsychological and post-concussion symptom scales as a part of their studies.

DISCUSSION

Based on this review, COM appears to be an accurate measure of dynamic postural control in the post-concussion population (< 1 year) under both single- and dual-task conditions. Despite the accuracy and usefulness of the measure in the laboratory setting, the clinical utility of COM is limited due to the substantial technology required to detect subtle post-concussive motor control deficits. Knowledge of COM as a valuable stand-alone measure does have a practical clinical function; however, when compared to the precision of technology-driven assessments, the subjective nature of current balance outcome measures remains a weakness in concussion management. This is of particular importance when considering that the subtle motor impairments that occur post-concussion appear to persist even when symptoms have seemingly resolved.\textsuperscript{17}
There is no gold standard outcome measure to clinically assess dynamic balance and postural control, nor have normative values been established for ML or AP sway in the post-concussion population. In addition, there is no standard battery of outcome measures in use in the research setting. At present, strong recommendations for the use of post-concussion balance/postural control outcome exams remain in question. A recent clinical practice guideline expressly made no recommendations of functional outcome measures and states "there is insufficient evidence to support a clear set of motor function measures for individuals who have experienced a concussive event." The TBI Evidence Database to Guide Effectiveness (EDGE), has recommended three functional balance measures for clinical use in the TBI population: the Balance Error Scoring System (BESS), the Berg Balance Scale (BBS), and the Community Balance and Mobility Scale (CBMS). All have been validated in the concussion population and are considered clinically useful in the outpatient setting; however, their use in research to establish normative values of postural control variables such as COM is largely absent.

In addition to balance, gait velocity may be considered a useful measure in post-concussion recovery assessment. Gait velocity can be measured simply with markings on the floor and a stopwatch, and there are well-known values for safe ambulation speed; however, the reviewed studies did not report any normative values for gait speed in post-concussion subjects when compared to the COM variables. Despite the clinical utility of gait velocity, this measure is often imprecise and unable to capture the subtle deficits that often remain after more obvious post-concussion symptoms have resolved. Current research is advancing the study of COM velocity to determine standardized values for single-task gait, single- vs. dual-task static and dynamic conditions, and sport-specific criteria (running, cutting) for clinical application. In addition to research, technology such as force plates, pressure-sensitive walkways, and motion capture offer a more precise method of COM variable calculation and assessment than visual estimation of sway or deviation counting such as in the BESS test. For COM assessment to become clinically useful, normative values will need to be established for the measure in all planes of motion, and technology will need to be readily available in patient care settings to help establish appropriate and meaningful concussion treatment protocols. Gait velocity as a measure of concussion recovery may be a useful measure due to the applicability to both return-to-sport activities and ability to complete activities of daily living (ADLs).

More research for standardized COM values in this population would be beneficial to determine what significant differences in COM sway/displacement in different planes and how those differences relate to function. Measurement of ML (increased post-concussion) and AP (decreased post-concussion) displacement of the COM is not clinically feasible unless clinicians have easy access to technology, are already trained in how to capture and analyze data, and are able to interpret the results. Lower-tech versions of clinical measures related to the sway of the COM that are currently used in clinical practice generally relate to static postural control tasks and do not incorporate dynamic conditions as might be encountered on the playing field or in daily living. These include assessments such as those mentioned earlier (BESS, BBS, CMBS), as well as Functional Gait Analysis (FGA), Clinical Test of Sensory Interaction in Balance (CTSIB), miniBESS test, and Romberg (and its variations), which have been validated for multiple population types. To advance the clinical utility of COM sway as an outcome measure, future research should focus on what functional activities are negatively affected by decreased control of postural sway, and what norms and cutoff scores determine dysfunction. In current clinical practice, the authors recommend including dynamic balance activities that challenge ML control of the COM, though future research is needed to determine whether this deficit translates to dysfunction or risk of reinjury.

One study compared athletes and non-athletes, and significant differences were found in ML sway variables suggesting that repeated sub-concussive blows due to certain types of athletic participation may produce a measurable consequence for controlling the whole body COM during gait. However, this assumption cannot be confirmed based on the studies reviewed. While this is an intriguing line of thinking, more research would be needed to determine the true factors contributing to COM displacement changes in athletes compared to non-athletes, both in the presence of concussion and those who have sustained repeated sub-concussive impacts which are typical in athletics. Without the results of such research, COM may not be a useful measure in determining presence of dynamic gait deficits in athletes who have sustained concussion, since they may display significant deficits either way. This line of research could be expanded to help establish norms for COM differences in athletic versus non-athletic populations, enhancing the generalizability of a clinical concussion treatment protocol.

The addition of a cognitive component to a dynamic task exposes persistent postural control deficits in subjects with subacute (post-28 days) to chronic concussion in both ML- and AP-COM directions. There is currently no validated clinical outcome measure for the assessment of dynamic postural control when comparing single- and dual-task conditions for the concussed population. While neuropsychological testing is considered the standard for diagnosis and reassessment of concussion, and static balance assessment tools are commonly used in clinical practice to show progress, neither of these incorporate dynamic movements with cognitive tasks. As a result, neuropsychological testing and static balance assessments may not capture lingering motor impairments. Returning to both daily function and sport requires the ability to balance while moving the body through space and completing various cognitive tasks, such as attention-switching, responding to environmental and verbal cues, and reacting to visual and verbal stimuli. The subtleties of concussion injuries often appear in these more complex tasks where COM variables prove to be most valuable. While no standardized COM assessment currently exists in routine clinical practice, adding a cognitive component to dynamic tasks could offer an adequate option to elucidate subtle impairments. More research needs to be conducted to determine at what point in the recovery timelines the addition of the dual-task
condition would present an appropriate challenge. At present, subjective rating of symptom exacerbation following dynamic dual-task activities should keep patients safe and appropriately challenged without neglecting this aspect of their recovery.

A limited population of participants were available for analysis with all relevant studies reviewing athletes versus non-athletes, or concussed athletes versus healthy controls and a limited total age range. The lack of diversity in age and population can be attributed to a sample of convenience offered by the athletic and younger population with higher concussion incidence and easier access to study enrollment than the general population (student proximity to university labs).3,4,6,11,14,15 Despite the apparent limitation of the study population type/age, this narrow population does allow for increased internal validity for the athletic and adolescent/young adult population. Results of the reviewed studies demonstrate similar responses across trials using similar methods of assessment for COM and velocity. Bias assessment revealed good results with STROBE scores ranging 26.5±3.5 of 34 indicating decreased risk of systematic error. In order to better serve the field of study, additional research should be done to identify effects on a greater range of subjects types/ages that would better exemplify the general population using a standardized protocol. At this time there is a lack of external validity of review search results due to the homogenous sample pool offered in current studies.

CONCLUSIONS

The results of this systematic review indicate COM may be a strong indicator of ongoing impairment after a concussion. Multiple COM measures were found to be abnormal in athletes following concussion long after their clearance to return to play. This result is often dependent on the utilization of a dual task condition or distraction from the gait task in order to increase the difficulty of the gait task and allow the deviations to present. While limits in technology available to the clinician may restrict regular evaluation of COM during gait after concussion, these barriers may be lowering.

CONFLICT OF INTEREST

None of the authors have a conflict of interest to report.

Submitted: December 10, 2020 CDT, Accepted: June 15, 2021 CDT
REFERENCES


APPENDIX 1: SEARCH STRATEGY

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International Journal of Sports Physical Therapy
Systematic Review/Meta-Analysis

Prevalence and Incidence of Injury during Olympic-style Shooting Events: A Systematic Review

Mica R. Harr¹ ², Cody J. Mansfield¹, Bailey Urbach¹, Matt Briggs¹ ³, James Onate¹ ³, Laura C. Boucher¹ ³

¹ Neuroscience, The Ohio State University; ² School of Health and Rehabilitation Sciences, The Ohio State University; Sports Medicine; ³ The Ohio State University Wexner Medical Center; Sports Medicine Research Institute, The Ohio State University Wexner Medical Center; Department of Orthopedics, The Ohio State University Wexner Medical Center; ⁴ School of Health and Rehabilitation Sciences, The Ohio State University; Sports Medicine Research Institute, The Ohio State University Wexner Medical Center

Keywords: shooting sports, biathlon, low back pain, athletic injuries

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Background
Shooting sports are included in collegiate and Olympic events. However, there is minimal evidence examining injury prevalence and incidence for these athletes.

Hypothesis/Purpose
The purpose of this study was to systematically review the literature to examine the available evidence regarding the incidence, prevalence, and types of injuries that affect athletes in Olympic-style shooting events.

Study Design
Systematic review.

Methods
The electronic databases PubMed, Cochrane Library, Cinahl, MEDLINE, and SPORTDiscus were searched utilizing terms related to shooting and injuries. Studies were included if they reported prevalence or incidence of injury in collegiate or Olympic shooting events, and were excluded if inclusion criteria were not met, full text was unavailable, or not in English. Two reviewers independently screened articles in two phases: 1) screening of titles/abstracts 2) full text review. A third reviewer resolved conflicts.

Results
Nineteen studies were ultimately included. The sports identified were biathlon, rifle, pistol, and shotgun. Shooting events in both winter and summer Olympics had low percentages of injuries compared to other sports. Winter shooting events had a higher percentage of injuries (6.9%) compared to summer (2.3%). In summer, females demonstrated a higher percentage of injuries (6.9%) compared to males (1.7%). In winter, males had a higher percentage of injuries (8.6%) versus females (5.1%).

Conclusion
Injury incidence and prevalence was low for athletes in shooting sports in the Olympics. Injury rate was higher in the winter Olympic shooting events likely from increased physiological demand. With injury surveillance focusing on acute injuries rather than chronic, the number of injuries may be underestimated. Females had higher injury rates than males in the summer Olympics while the opposite was observed in the winter.
Olympics, likely from sex differences and differences in physiological demand for each event.

**Level of Evidence**
Level 3

**INTRODUCTION**

Popularity of Olympic-style shooting events has grown since the first Olympics in 1896. The sport has been present in the summer Olympics since 1896 and in the winter Olympics since 1924. Women started competing in the summer Olympics in 1968 and in the winter Olympics since 1992. According to the International Shooting Sport Federation (ISSF), the 2016 summer Olympics, in Rio de Janeiro, Brazil had 390 athletes in summer Olympic-style shooting events. The 2018 winter Olympics in PyeongChang, China had 230 athletes in shooting events. Despite the growing popularity of the sport and representation at the summer and winter Olympics and other events, the types and prevalence of injuries in competitions is unknown.

Injury surveillance studies have found the prevalence of injury for athletes of shooting events in the Olympics to be as low as 0.78% or as high as 6.90%. These studies defined the included injuries as acute, and may not capture the chronic musculoskeletal injuries that commonly affect athletes that compete in shooting events. By only focusing on acute injuries, this could underestimate the needs of these athletes and limit the amount of resources allocated. Summer Olympic shooting events include rifle, pistol, and shotgun. Winter Olympic events include the biathlon as it is a combination of target rifle shooting and cross-country skiing. The different physiological demands from each sport and the use of different types of firearms may lead to injuries in specific body parts (i.e. neck, shoulder, low back).

Across the events, pistol shooters tend to have more wrist injuries, shotgun shooters tend to have more shoulder injuries, and both rifle and biathlon typically have more low back injuries. The purpose of this study was to systematically review the literature to examine the available evidence regarding the incidence, prevalence, and types of injuries that affect athletes in Olympic-style shooting events. The authors hypothesized that 1) injury rates for Olympic-style shooting events would be low due to the emphasis of acute injury tracking in the literature, since these athletes typically endure chronic musculoskeletal injuries 2) injury rates would be higher in biathlon winter Olympic style shooting events than summer Olympic shooting events due to the increase physiological demand, and 3) athletes who use a rifle or shotgun would have higher injury rates than athletes participating in events with handheld firearms due to the differences in shooting position.

**METHODS**

**STUDY DESIGN**

This systematic review was performed with the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The systematic review was registered in PROSPERO (CRD42020152019).

**INFORMATION SOURCES**

An electronic search of five databases (PubMed, Cochrane Library, Cinahl, MEDLINE, and SPORTDiscus) was performed from inception to February 3rd, 2020. These databases were selected in order to find shooting studies related to sports medicine and to carry out the search strategy.

**SEARCHES**

Each database was searched using key terms related to firearms, Olympic-style shooting events, and sports medicine (Appendix). These terms were developed based on Medical Subject Headings (MeSH) in PubMed.
Table 1. PICO Question

<table>
<thead>
<tr>
<th>P</th>
<th>Any individual participating in an Olympic-style shooting event, including, but not limited to summer and winter Olympics, and NCAA competition.</th>
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<tr>
<td>I</td>
<td>Not applicable, assessing for injury rate, incidence, definition of injury used by researchers and prevalence.</td>
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<tr>
<td>C</td>
<td>Compare data between different shooting athletic events (Olympic vs NCAA vs other) and sex differences (male vs female).</td>
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<tr>
<td>O</td>
<td>Data of interest: injury rate, incidence, prevalence, and how injury was defined by researchers.</td>
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ELIGIBILITY CRITERIA

The research question was developed from the PICO question (Table 1). From the PICO question, eligibility criteria for included studies was determined. Studies were included if they met the following criteria: (1) reported injury rate, prevalence, or incidence of injury in Olympic-style shooting events (Olympics, World Cup, etc.) (2) English language, and (3) had full text available. Studies were excluded based on the following criteria: (1) non-Olympic style shooting event, (2) case report, (3) clinical commentary, (4) systematic review (5) expert opinion (6) non-peer reviewed study. Although systematic reviews were excluded, if they were of interest, the references were screened for inclusion.

STUDY SELECTION

The studies were identified and uploaded to Covidence, a systematic review tool created by a non-profit company in Australia to organize the study screening process. Two independent reviewers (MH, BU) independently screened the titles and abstracts using the aforementioned inclusion and exclusion criteria. A third reviewer (CM) resolved conflicts. This process was repeated for studies that qualified for full text review with two independent reviewers (MH, BU). A third reviewer (CM) resolved conflicts.

QUALITY ASSESSMENT OF STUDIES

The internal validity of the studies was assessed by one author (BU) and confirmed by another (MH) using the NIH Study Quality Assessment Tool for Cohort and Cross-Sectional Studies. Based on the quality appraisal of included studies, the risk of bias was considered and a rating was assigned to each study according to the number of questions that had a ‘Yes’ response: Poor (1-5), Fair (6-8), or Good (9-14) (Table 2).
Table 2. NIH Quality Assessment Tool for Internal Validity of Cohort and Cross-Sectional Studies

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Y = Yes, N = No, NR = Not Reported, NA = Not Applicable. Poor = high risk of bias (1-3 Y), Fair = moderate risk of bias (4-8 Y), Good = low risk of bias (9-14 Y).

Q1. Was the research question or objective in this paper clearly stated?.
Q2. Was the study population clearly specified and defined?.
Q3. Was the participation rate of eligible persons at least 50%?.
Q4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?.
Q5. Was a sample size justification, power description, or variance and effect estimates provided?.
Q6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?.
Q7. Was the timeframe sufficiently so that one could reasonably expect to see an association between exposure and outcome if it existed?.
Q8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?
Q9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?.
Q10. Was loss to follow-up after baseline 20% or less?.
Q11. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?
Q12. Were the outcome assessors blinded to the exposure status of participants?.
Q13. Was the exposure(s) assessed more than once over time?.
Q14. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?.
Table 3. Johanna Briggs Institute Critical Appraisal Tool for Risk of Bias of Analytical Cross-Sectional Studies

<table>
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</table>

Y = Yes. N = No. U = Unclear. Poor = high risk of bias (1-3 Y). Fair = moderate risk of bias (4-5 Y). Good = low risk of bias (6-8 Y).

Q1. Were the criteria for inclusion in the sample clearly defined? Q2. Were the study subjects and the setting described in detail? Q3. Was the exposure measured in a valid and reliable way? Q4. Were objective, standard criteria used for measurement of the condition? Q5. Were confounding factors identified? Q6. Were strategies to deal with confounding factors stated? Q7. Were the outcomes measured in a valid and reliable way? Q8. Was appropriate statistical analysis used?

RISK OF BIAS ASSESSMENT

The Johanna Briggs Institute (JBI) critical appraisal tool, developed by the University of Adelaide in South Australia, was used to assess risk of bias for each study type by one author (MH) analytical cross-sectional studies and confirmed by another author (BU).<sup>29,30</sup> A rating was assigned according to the number of questions that had a 'Yes' response: Poor (1-3), Fair (4-5), or Good (6-8) (<table 5>).<sup>30,31</sup> A 'Good' rating indicated a low risk of bias, 'Fair' a moderate risk of bias, and 'Poor' a high risk of bias. This process was repeated for cohort studies. A rating was assigned using the JBI tool specific for cohort studies according to the number of questions that had a 'Yes' response: Poor (1-4), Fair (5-7), or Good (8-11) (<table 4>).<sup>30,31</sup>

DATA EXTRACTION

Extraction of pertinent information from each study included in the review was performed by the primary author (MH) and confirmed by another author (CM). Pertinent information included: author, year, setting (Olympics, World Cup, etc.), number of participants, age, sex, incidence of injuries, and prevalence of injuries. A custom designed table was created with the pertinent information that was extracted (<table 5>).

DATA ANALYSIS

A descriptive analysis of the extracted data was performed. Data from all studies were compiled into a table to compare injury incidence and prevalence data from different years (<table 5>). Data were formed into a chart to visually appraise some of the prevalence data (<figure 4>).

International Journal of Sports Physical Therapy
### Table 4. Johanna Briggs Institute Critical Appraisal Tool for Risk of Bias of Cohort Studies

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Y = Yes, N = No, U = Unclear, NA = Not Applicable. Poor = high risk of bias (1-4 Y). Fair = moderate risk of bias (5-7 Y). Good = low risk of bias (8-11 Y).

Q1. Were the two groups similar and recruited from the same population?, Q2. Were the exposures measured similarly to assign people to both exposed and unexposed groups?, Q3. Was the exposure measured in a valid and reliable way?, Q4. Were confounding factors identified?, Q5. Were strategies to deal with confounding factors stated?, Q6. Were the groups/participants free of the outcome at the moment of exposure?, Q7. Were the outcomes measured in a valid and reliable way?, Q8. Was the follow up time reported and sufficient to be long enough for outcomes to occur?, Q9. Was follow up complete, and if not, were the reasons to loss to follow up described and explored?, Q10. Were strategies to address incomplete follow up utilized?, Q11. Was appropriate statistical analysis used?
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<th>Number of Injured Athletes in Shooting Events</th>
<th>Incidence of Injuries in Shooting Events</th>
<th>Prevalence of Injuries in Shooting Events</th>
<th>Athletes in Shooting Events by Sex, n (%)</th>
<th>Injured Athletes in Shooting Events by Sex, n (%)</th>
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<td>2010-2011 Turkish Shooting Sports Championship</td>
<td>n=729 shooting athletes</td>
<td>n=729 shooting</td>
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<td>34 (79.1%) male, 9 (20.9%) female</td>
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<td>2008-2009 Biathlon World Cup event</td>
<td>n=116 biathlon athletes</td>
<td>n=116 biathlon</td>
<td>47</td>
<td>40.50%</td>
<td></td>
<td>(44%) male, (56%) female</td>
<td>(39.7%) male, (54.4%) female</td>
</tr>
<tr>
<td>Derman et al., 2016</td>
<td>2014 Winter Paralympics</td>
<td>n=547 athletes</td>
<td>n=149 biathlon/cross-country skiing</td>
<td>15</td>
<td>10.00%</td>
<td></td>
<td>95 (63.8%) male, 54 (36.2%) female</td>
<td>n/a</td>
</tr>
<tr>
<td>Wilber et al., 2000</td>
<td>1998 US Winter Olympic Team</td>
<td>n=170 athletes</td>
<td>n=34 biathlon</td>
<td>0</td>
<td>0%</td>
<td></td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Kujala et al., 1995</td>
<td>1920-1965 Finland top athletes</td>
<td>n=117 athletes</td>
<td>n=29 biathlon</td>
<td>n/a</td>
<td>3%</td>
<td></td>
<td>29 (100%) male</td>
<td>n/a</td>
</tr>
<tr>
<td>Noormohammadpour et al., 2016</td>
<td>2014 National Sports Olympiad of Female University Students</td>
<td>n=1059 athletes</td>
<td>n=91 shooting</td>
<td>n/a</td>
<td>29.70%</td>
<td></td>
<td>91 (100%) female</td>
<td>n/a</td>
</tr>
<tr>
<td>Volski et al., 1986</td>
<td>1983 International Shooting Championships</td>
<td>n=80 shooting athletes</td>
<td>n=52 rifle, n=25 pistol, n=3 non-designated</td>
<td>n/a</td>
<td>63%</td>
<td></td>
<td>59 (74%) male, 21 (286%) female</td>
<td>n/a</td>
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<tr>
<td>Osteras et al., 2013</td>
<td>2007 Females with Norwegian Biathlon Federation license</td>
<td>n=148 biathlon athletes</td>
<td>n=148 biathlon</td>
<td>85</td>
<td>57.40%</td>
<td></td>
<td>148 (100%) female</td>
<td>n/a</td>
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<tr>
<td>Junge et al., 2009</td>
<td>2008 Summer Olympics</td>
<td>n=10977 Olympic</td>
<td>n=386 shooting</td>
<td>3</td>
<td>0.78%</td>
<td></td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Author and Year</td>
<td>Setting</td>
<td>Total Participants</td>
<td>Number of Athletes in Shooting Events</td>
<td>Number of Injured Athletes in Shooting Events</td>
<td>Incidence of Injuries in Shooting Events</td>
<td>Prevalence of Injuries in Shooting Events</td>
<td>Athletes in Shooting Events by Sex, n (%)</td>
<td>Injured Athletes in Shooting Events by Sex, n (%)</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------------------------------------------</td>
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<td>---------------------------------------------</td>
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<td>------------------------------------------</td>
<td>------------------------------------------</td>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>Engebretsen et al., 2010</td>
<td>2010 Winter Olympics</td>
<td>n=2567 Olympic athletes</td>
<td>n=202 biathlon</td>
<td>3</td>
<td>3/202</td>
<td>1.50%</td>
<td>104 (51.5%) male, 98 (48.5%) female</td>
<td>2 (1.9%) male, 1 (1.0%) female</td>
</tr>
<tr>
<td>Engebretsen et al., 2013</td>
<td>2012 Summer Olympics</td>
<td>n=10568 Olympic athletes</td>
<td>n=390 shooting</td>
<td>15</td>
<td>15/390</td>
<td>3.80%</td>
<td>231 (59.2%) male, 159 (40.8%) female</td>
<td>4 (1.7%) male, 11 (6.9%) female</td>
</tr>
<tr>
<td>Palmer-Green and Elliot, 2015</td>
<td>2014 Winter Olympics GB Team</td>
<td>n=56 athletes</td>
<td>n=2 biathlon</td>
<td>0</td>
<td>0</td>
<td>0%</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Soligard et al., 2016</td>
<td>2014 Winter Olympics</td>
<td>n=2788 Olympic athletes</td>
<td>n=204 biathlon</td>
<td>14</td>
<td>14/204</td>
<td>6.90%</td>
<td>105 (51.5%) male, 99 (48.5%) female</td>
<td>9 (8.6%) male, 5 (5.1%) female</td>
</tr>
<tr>
<td>Soligard et al., 2017</td>
<td>2016 Summer Olympics</td>
<td>n=11274 Olympic athletes</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>0-3%</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Soligard et al., 2019</td>
<td>2018 Winter Olympics</td>
<td>n=27914 Olympic athletes</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>2%</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Laoruengthana et al., 2009</td>
<td>2008 Tailand National “Phisanulok” Games</td>
<td>n=12199 athletes</td>
<td>n=771 shooting</td>
<td>0</td>
<td>0</td>
<td>0%</td>
<td>469 (60.8%) male, 302 (39.2%) female</td>
<td>n/a</td>
</tr>
<tr>
<td>Engebretsen et al., 2015</td>
<td>2008 &amp; 2010 Olympics</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

Combined data from Junge et al., 2009 and Engebretsen et al., 2010
RESULTS

Results of the systematic review yielded nineteen studies (Table 5). Of these studies, nine were on the Olympics, with three summer Olympics (Beijing 2008; London 2012; Rio de Janeiro 2016) and four winter Olympics (Nagano 1998; Vancouver 2010; Sochi 2014; PyeongChang 2018). Other studies included injury data from the Finland top athletes (1920-1965), International Shooting Championships (1983), Czech Internationals (1998), Females with Norwegian Biathlon Federation license (2007), Thailand National “Phitsanulok” Games (2008), Biathlon World Cup event (2008-2009), Turkish Shooting Sports Championship (2010-2011), National Sports Olympiad of Female University Students (2014), and Brandenburg, Germany sport schools (2015). In eleven of the studies, injury was defined as acute with pre-existing injuries not being recorded.5–7,13,16,22–27 Overall the prevalence and incidence of injury for athletes in shooting events was low, as most prevalence data was equal to or below 10% and five studies were at 0%; 6,7,15,16–18,22–26

QUALITY ASSESSMENT

The NIH Quality Assessment Tool showed that ten of the nineteen studies had ‘Good’ overall quality, five had ‘Fair’ overall quality, and four had ‘Poor’ overall quality (Table 2). All studies clearly stated the research question/objective, clearly specified and defined study population, and selected/recruited subjects from same/similar populations with inclusion/exclusion criteria specified and applied. Four studies did not clearly define injury exposure measures or ensure they were valid, reliable, and implemented consistently. Nine studies assessed exposures more than once.

RISK OF BIAS

The JBI critical appraisal tool for analytical cross-sectional studies showed that six of the eight cross-sectional studies had ‘Good’ overall quality while two had ‘Poor’ overall quality (Table 3). Six cross-sectional studies clearly defined the criteria for inclusion in the sample and described the setting and subjects in detail. All the cross-sectional studies identified confounding factors, but only four stated strategies to deal with them. There was only one cross-sectional study that did not use an appropriate statistical analysis.

The JBI critical appraisal tool for cohort studies showed that ten of the eleven cohort studies had ‘Good’ overall quality and one had ‘Fair’ overall quality (Table 4). All of the cohort studies had groups that were similar and recruited from the same population, measured exposures similarly, had all the participants free of the outcome prior to the study, had sufficient follow up time for outcomes to occur, and completed the follow up. Only one cohort study did not use appropriate statistical analysis.

SUMMER OLYMPICS

Since one study did not record an exact number of injuries sustained by athletes in shooting events, the average prevalence of injuries in the summer Olympics (2008, 2012, 2016) is between 1.53–2.53% with shooting having the lowest injury prevalence compared to all other sports.6,23,25,28 The prevalence of injuries by year was 0.78% (2008), 3.80% (2012), and between 0-5% (2016) (Figure 4).6,23,25,28 In the 2008 Olympics, 100% of the injuries occurred during training.9 One injury mentioned was a coracoid process fracture in a shotgun trap shooter.28 In the 2012 Olympics, one injury occurred during competition while the others resulted from overuse during training.25 In the 2016 Olympics, one severe injury was mentioned, with severe referring to the need for absence for longer than a week.25 Although it is unrecorded for the 2008 and 2016 Olympics, there was a higher percentage of females injured than males in 2012 (6.9%),6,25,25,28

WINTER OLYMPICS

The average prevalence of injuries in the winter Olympics (2010, 2014, 2018) was 3.47% with the percentage of injuries being one of the lowest out of all sports.7,22,26,28 The prevalence of injuries by year was 1.50% (2010), 6.90% (2014), 2.00% (2018) (Figure 4).7,22,26,28 In the 2018 Olympics, the prevalence of injury dropped.26 There was a higher percentage of males injured than females in the 2010 (1.9%) and 2014 (8.6%) Olympics.7,22,28

Three studies contained data that pertained to the Sochi 2014 Olympics. One was a systematic surveillance of injuries and illnesses, another was a surveillance of the Great Britain team at the winter Olympics, and a third was a prospective cohort study on the 2014 Paralympic games.7,16,24 There was a high percentage of biathlon injuries compared to other years, though none of these injuries occurred within the Great Britain team.7,24 With an incidence of 6.86%, four of the injuries occurred during competition and the rest occurred during training.7 Most of these injuries were from overuse with two requiring over a week of time loss from competition.7 In the 2014 Paralympics, the prevalence of injuries was 10% with the biathlon data being combined with cross-country skiing.16

NON-OLYMPIC EVENTS

A high prevalence of low back pain in shooters at the 1983 International Shooting Championships was seen with 78% of shooters reporting low back pain during competition and 63% reporting pain lingering after competition.20 In another study, there was a high number of participants at

Figure 4. Prevalence of Shooting Injuries by Olympic Year

Prevalence and Incidence of Injury during Olympic-style Shooting Events: A Systematic Review
the 2008 Thailand National "Phitsanulok" Games with 771 shooters but zero injuries were reported. At the 2008-2009 Biathlon World Cup Event, there was a high prevalence of injuries at 40.50%. Running was the primary cause of injury with most occurring during training. Low back injuries were the most frequent with other common injuries being knee and shoulder injuries. There was a higher overall number of injuries in females (39 vs 29), a higher number of lower back injuries (10 vs 4), and a higher number of knee injuries (7 vs 3).

At the 2010-2011 Turkish Shooting Sports Championship, there was a prevalence of injuries at 12.80%. Most injuries were due to overuse with common injuries occurring in training being strains and muscles tears in the shoulder, calf-thigh, and hand-wrist. Common competition injuries were sprains, muscle tears, tendinitis, and sprains in the shoulder and foot-ankle. Rifle events showed a high risk of low back and shoulder injuries while pistol showed a high risk of hand injuries.

A study that was performed on Czech International shooters showed a high prevalence of low back pain at 58%. Rifle shooters had a high incidence of spinal deviation/scoliosis while pistol shooters had the highest number of weak abdominal muscles. Other findings included neck pain, shoulder pain, thoracic back pain, and tightened muscles. Osteras et al. reported a high prevalence of injuries at 57.40% for females with Norwegian Biathlon Federation licenses. Knee injuries were the most frequent. The prevalence of low back pain was 10.8%. A study on National Sports Olympiad of Female University Students showed a relatively low prevalence of low back pain in shooters compared to other sports with a point prevalence of 9.9% and a life-time prevalence of 50.5%. Muller et al. researched adolescent athletes in Brandenburg, Germany sport schools and found a high back pain incidence in shooting and a prevalence of greater than or equal to 10%. An interesting finding from a study that assessed Finland’s top athletes from the years 1920-1965 was a low incidence of knee osteoarthritis in shooters with a prevalence of 3%.

SEX DIFFERENCES

There was a higher number of male shooters than females in each study that included both sexes. Females suffered a higher average percentage of injuries in the summer Olympics (males 1.7% vs females 6.9%) while males had a higher average percentage of injuries in the winter Olympics (males 5.25% vs females 3.05%). The incidence of injuries during the 2008-2009 Biathlon World Cup demonstrated the opposite with a higher percentage of injuries in females (males 39.7% vs females 54.4%). Zeman et al. reported females having more occurrences of weak abdominal muscles than males, thought to be due to a lack of strengthening.

DISCUSSION

The purpose of this systematic review was to provide a collective understanding of the current literature and evidence of the incidence and prevalence data in Olympic-style shooting events. The first hypothesis that injury rate for Olympic-style shooting events will be low due to the emphasis of acute injury tracking in the literature, since these athletes likely endure more chronic musculoskeletal injuries was accepted. Injury rate for Olympic-style shooting events were low within studies that emphasized acute injury tracking. Fourteen of the nineteen studies had included data from a wide range of sports, while the remaining five studies had data that was just from shooting and biathlon events. Studies that analyzed injury rate of a wide variety of sports had more acute injuries, resulting in a relatively low percentage of injuries from shooting sports in comparison to other sports. The six studies that collected data on only shooting athletes at non-Olympic events had either no incidences of injury at all or had a high incidence rate from including incidences of pain within the injury rate in order to capture the full extent of physical demand the athletes go through. The majority of injuries that these athletes endured were likely not captured due to their chronicity. Athletes in shooting events tend to experience more chronic injuries than acute due to holding positions for long periods of time rather than undergoing sudden movements. More studies that seek to capture chronic injuries rates in injury surveillance are needed in order to better understand the extent of injuries that athletes in shooting events endure. If injury surveillance data only captures acute injuries for these athletes, then medical associations and event planners are likely underestimating the needs of these athletes. This could result in a lack of appropriate medical care and a lack of resource allocation.

There was an overall lack of specificity in recording data for separate shooting events. Most studies combined all the events into one category of "shooting." This does not capture the accurate injury rates since each event has different mechanisms of injury due to the differences in physical demands. These differences lead to distinct common injuries within each category. For example, shotgun events tend to have more shoulder injuries due to the contact of the firearm to the shoulder and the recoil while pistol does not have this contact and handles recoil differently. To effectively understand the medical needs of these athletes, data should be separated by event to show which events need more medical care and what specific injuries are more common to appropriately provide treatment.

The second hypothesis that injury rate would be higher in biathlon winter Olympic style shooting events than summer Olympic shooting events due to the increase physiological demand was accepted. The average injury rate was higher in biathlon winter Olympic shooting events than summer Olympic shooting events. This may be due to the added physiological demands as biathletes combine cross-country skiing with competition shooting. The summer Olympics had approximately the same percentages of injury rate each year, while the winter Olympics had a little more variance between years, having varied between 1% and 6.9%.

The third hypothesis of this review was that athletes who use a rifle or shotgun will have higher injury rates than athletes participating in events with handheld firearms due to the differences in shooting position could not be con-
firmed. There was a lack of specificity in the available data to fully assess this hypothesis. Fourteen of the studies examined a wide variety of sports, leading to shooting sports being combined into one category instead of multiple. The only shooting sport that had its own category in each study, except for the 2014 Paralympic study, was the biathlon.7,16,22,26 Shooting event categories were only distinguished when listing specific injuries or if the study was seeking out the differences between the individual shooting events. Thus, it is unknown if one event had more injuries than the other, however trends were seen in terms of common types of injuries prevalent in each event. This is due to the different stances and demands placed on the body from the type of firearm being shot.14

SEX DIFFERENCES

Injury rates for Olympic-style shooting events differed between sexes. Women had more injuries in the summer Olympics, while men had more in the winter Olympics.5,7,22,23,25,26 The increase in injuries for women in the summer Olympics may have been due to the style of the shooting events as they emphasize holding positions without the strain of cross-country skiing. It is possible that women experience more strain from holding these unnatural positions than men due to the differences in anatomy, particularly in the pelvis. Women have a wider pelvis and men have a more narrow pelvis.52 Other differences include increased muscle mass, increased bone density, and decreased fat in men.53 The winter Olympics saw the opposite in injury rates as men had more than women.7,22,26,28 This may be due to the anatomical differences in pelvic structure between sexes. The pelvic structure of women may lead to more injuries from the static shooting positions in the summer Olympics than the dynamic sport of biathlon in the winter Olympics.

CLINICAL IMPLICATIONS

Back pain, particularly in the lumbar region, has been shown to occur in elite athletes across many sports including shooting events.34,35 Identifying early signs of back pain can be important to prevent acute injuries from becoming chronic. Elite female athletes in particular may be more susceptible to this type of injury, shown in both previous literature34 and the present study. It has been suggested that female anatomy, such as a wider pelvis and lower muscle mass, may predispose the development of back pain in elite sports like shooting events.32–34 This present study revealed that a higher number of females have injuries in the summer Olympic events. These events require more endurance to hold positions compared to the winter Olympics, so it may be necessary for these athletes to undergo a proper strength training program with a focus on trunk stabilizing muscles and proper form while participating in this sport.

The results of this systematic review demonstrate a need to expand injury surveillance to not just include acute injuries, but to also consider chronic musculoskeletal injuries. This can better inform medical staff on the needs of these unique athletes. These athletes in particular may benefit from a robust injury prevention program to prevent chronic musculoskeletal injuries. Each shooting event requires athletes to maintain unnatural or strenuous body positions, as depicted in Figures 1 and 2. They also place different physiological demands on the body that challenge the focus of the athlete’s accuracy during the shooting event.1–4,8 Summer shooting events require the athlete to hold specific shooting positions for long amounts of time.2,8 Depending on the specific event’s time limit, rifle and pistol athletes may stand for one to two hours without leaving the firing line.2 The winter biathlon puts cardiovascular and musculoskeletal demands on the body for cross-country skiing before requiring a controlled breathing for the shooting portions.4 All shooting events require the ability to control one’s heart rate for improved accuracy.1 The type of firearm and the weight of the firearm can force the shooter to shift their center of balance and place prolonged stress on the neck, arms, trunk stabilizers, low back, and lower extremities.2,8,14 These rigid positions place much of the body weight, as well as the firearm weight, asymmetrically on the lower back, neck, shoulders, hips, and knees. With athletes having to hold specific postures for long periods of time, it is also likely that there needs to be a focus on ensuring the postures are safe and correct to prevent injury from occurring, as repetitive mechanical strain and extreme body positions have been implicated to contribute to back pain occurring in athletic populations.34 It has been observed that elite athletes who experience back pain may have a lower intensity of pain when they spend more time on back-strengthening activities.55 These activities may be particularly beneficial to shooting sport athletes due to the back strain that can occur from the traditional shooting postures.

STRENGTHS AND LIMITATIONS

This systematic review was the first to examine the literature for injury incidence and prevalence for shooting events. It utilized a search strategy to thoroughly search for relevant studies. However, several limitations were encountered. Although the research strategy was robust, only five databases were searched, which may have impacted the number of studies identified. Two had to be excluded due to being in languages other than English, further limiting the number of extracted studies. A limitation of some of the included studies (n=6) is that pain was classified as an injury based on the location of the pain on the body, and the underlying condition likely remained undiagnosed.13–15,19–21 This could lead medical staff to treat the pain location, rather than the cause of the pain, and could lead to suboptimal outcomes for the athlete. While pain itself can cause major limitations for athletes, it is also important to recognize if an underlying condition is present. Injury surveillance programs for Olympic firearm events should take this into consideration with injury tracking.

CONCLUSION

Injury incidence and prevalence was low for athletes in shooting sports compared to other sports. Future research should seek to capture injury incidence and prevalence data that is more relevant to the shooting sports by including
chronic injury surveillance and seeking out injury rates for different shooting events. While the results of this systematic review indicate that there is a higher injury rate in winter Olympic events, likely due to increased physiological demands, the overall injury rates for each event may be low due to the lack of focus on chronic injuries. With the lack of data and the lack of differentiation between events, more data are needed to capture the effects that the type of firearm might have on prevalence of injuries. The sex differences in injury rates and the most common types of injuries should also be explored further. More research on injury surveillance may help with resource allocation and provide a better understanding of injury patterns for athletes that compete in shooting events.

CONFLICTS OF INTEREST

The authors report no potential conflicts of interest in the development of this article.

ACKNOWLEDGEMENTS

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REFERENCES


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APPENDIX

<table>
<thead>
<tr>
<th>Specific Search</th>
<th>Term Combination</th>
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<tr>
<td>Gun</td>
<td>Rifle or Firearms or Shotguns or Pistols or Shooting or Shooting Sports or Pistols or Skeet or Air Rifle or Air Pistol or Rapid Fire Pistol or Rapid Fire or Biathlon</td>
</tr>
<tr>
<td>Event/organization</td>
<td>Olympics or Olympic or NCAA or National Collegiate Athletic Association or Club or Collegiate or World Cup or Sport or Competition or Match or Summer or Winter or USA Shooting or NRA or National Rifle Association or CMP or Civilian Marksmanship Program or ASSA or American Smallbore Shooting Association or Championships or Nationals or PyeongChang 2018 or Rio 2016 or Sochi or Sochi 2014 or London or London 2012 or Vancouver or Vancouver 2010 or Beijing or Beijing 2008 or Turin or Turin 2006 or Athens or Athens 2004 or Salt Lake or Salt Lake 2002 or Sydney or Sydney 2000 or Nagano or Nagano 1998 or Atlanta or Atlanta 1996</td>
</tr>
<tr>
<td>Profession</td>
<td>Sports Medicine or Physical Therapy or Performance or Athletic Training or Physiotherapist or Injury Muscle Stretching or Muscle Stretching Musculoskeletal Manipulations or Musculoskeletal or Breathing Exercises or Manipulations or Orthopedic or Osteopathic or Spinal or Soft Tissue or Trauma or Incidence or Injury Surveillance or Athlete or Athletic Injuries or Epidemiology or Medical Records or Population Surveillance or Risk Factors or Prospective Studies or Comparative Study or Statistics or Numerical Data</td>
</tr>
<tr>
<td>&quot;not&quot; terms</td>
<td>War or Warfare or Suicide or Law or Police or Chemistry</td>
</tr>
</tbody>
</table>
The Functional Assessment of Balance in Concussion (FAB-C) Battery

Thaer Manaseer1, Jackie L. Whittaker2, Codi Isaac3, Kathryn J. Schneider4, Douglas P. Gross5

1 Department of Physical Therapy, Faculty of Rehabilitation Medicine, University of Alberta; Department of Sport Rehabilitation, Faculty of Physical Education and Sport Sciences, the Hashemite University; 2 Department of Physical Therapy, Faculty of Rehabilitation Medicine, University of Alberta; Department of Physical Therapy, Faculty of Medicine, University of British Columbia; Arthritis Research Canada, 3 Glen Sather Sports Medicine Clinic, University of Alberta, 4 Sport Injury Prevention Research Centre, Faculty of Kinesiology, Alberta Children’s Hospital Research Institute; Hotchkiss Brain Institute, Cumming School of Medicine, University of Calgary, 5 Department of Physical Therapy, University of Alberta

Keywords: postural control, return to sport, sports, brain concussion, athletes

Background

There is no clinical tool that assesses multiple components of postural control potentially impacted by sport-related concussion (SRC).

Objective

To develop and assess the feasibility and construct validity of the Functional Assessment of Balance in Concussion (FAB-C) battery.

Study Design

Cross-sectional study.

Methods

Tests for inclusion in the FAB-C battery were identified through a search of the literature. The feasibility and construct validity of the battery was assessed with a convenience sample of active individuals (15–24 years) with and without a SRC. Feasibility outcomes included battery completion (yes/no), number of adverse events, time to administer (minutes) and cost of the battery (Canadian Dollars). Construct validity was assessed by examining correlations between tests included in the battery, and describing differences [mean (standard deviation), median (range) or proportion] in outcomes between uninjured participants and participants with SRC.

Results

Seven tests were included in the FAB-C battery. All 40 uninjured participants [12 female; median age 17 years] completed the FAB-C assessment compared to 86% of seven participants with SRC [1 female; median age 17]. No participants demonstrated adverse effects. The median administration time of the battery was 49 minutes (range 44–60). The cost of the battery was low (~$100 Canadian Dollars). Limited correlations (r<0.7) between tests in the battery were observed. A greater percentage of uninjured participants (52% to 82%) passed individual tests in the battery compared to participants with SRC (17% to 66%).

Conclusion

Although promising, the FAB-C battery requires further evaluation before adoption for widespread clinical use.
The Functional Assessment of Balance in Concussion (FAB-C) Battery

Level of Evidence
Level 3b

INTRODUCTION

Adequate balance control is required for safe sport participation. Postural control is a complex task requiring continuous interaction and adaptation between sensory, motor and cognitive functions. The components of postural control have been conceptualized to include: (1) movement strategies, (2) control of dynamics, (3) sensory strategies, (4) cognitive contributions, (5) orientation in space, and (6) biomechanical elements. Postural impairments may result from deficits in one or more of these components.

Sport-related concussion (SRC) is a traumatic brain injury induced by a biomechanical force. Impaired postural control is a common sign of SRC, presenting in up to 80% of athletes who suffer a SRC. Accordingly, postural control assessment is critical for SRC diagnosis and return-to-sport (RTS) decisions. The most commonly used clinical (i.e., non-instrumented) postural control assessment tools for SRC, the Balance Error Scoring System (BESS) and modified Balance Error Scoring System (m-BESS) are relatively inexpensive and easy to administer. These tools are based on the premise that SRC postural control impairments are the result of sensory deficits alone, which have been shown to resolve within three to five days following injury. However, more sophisticated laboratory assessments of postural control have demonstrated that SRC postural control impairments are also associated with motor and cognitive deficits that may persist beyond five days. Given that typical standing balance tests are unable to challenge cognitive and motor resources, additional tests are required to evaluate the potential postural control consequences of SRC.

Given the inadequacies of common clinical tests and limited feasibility of using laboratory measures in clinical settings, it is plausible that an athlete may be cleared for RTS despite ongoing postural control impairments. This may increase their risk of future injury. In response to this problem, there is a need for comprehensive clinical methods to assess postural control following SRC. The primary objective of the current study was to describe the development of a comprehensive battery (the Functional Assessment of Balance in Concussion or FAB-C) that assesses the sensory, motor, and cognitive components of postural control that may be impacted by a SRC. Secondary objectives were to examine the feasibility of administration, and construct validity (i.e., correlations between individual tests included and the ability to identify differences in performance between uninjured active individuals and those who had recently RTS following SRC) of the battery.

METHODS

DEVELOPMENT OF THE FAB-C BATTERY

The development of the FAB-C battery was guided by a recently proposed model of postural control assessment following SRC. This model proposed that a comprehensive assessment of postural control following a SRC should include clinical tests that challenge sensory strategies, control of dynamics, movement strategies, and cognitive contributions components of postural control under single-task, dual-task, and sport-specific testing paradigms.

To identify tests that challenge these multiple components of postural control under various testing paradigms for possible inclusion in the FAB-C battery, the research team initially searched the literature to identify existing clinical tests with established clinometric properties. This list was reduced by comparing existing clinical tests’ purposes (i.e., the evaluated component of postural control) and clinimetric properties. Findings from the steps aforementioned were used to develop an unrefined version of the FAB-C battery, which was further examined for feasibility and preliminary construct validity.

TESTING THE FAB-C BATTERY

PARTICIPANTS

A convenience sample of active (Cincinnati Sports Activity Scale level one or two), youth (13–17 years old) and young adult (18-24 years old) athletes who either recently returned to sport (RTS) following SRC or without a concussion were recruited from private physiotherapy clinics, sport organizations, through advertisements, social media, or word of mouth between December 2017 to May 2019. Participants with SRC must have been diagnosed with SRC as per the 5th International Consensus on Concussion in Sport and returned to sport (i.e., unrestricted return to practice, game, or competition) within the 60 days prior to testing. Uninjured participants were individuals who had not been diagnosed with SRC within the prior year. Participants were excluded if they were not active in recreational or competitive sport; reported a history of lower extremity injury that caused absence from recreational/sport activities greater than one week within the last three months; had inner ear or sinus infection over the week prior to testing, uncorrectable (i.e., neither with vision glasses nor contacts) vision dysfunction at time of testing, history of cognitive deficits such as concentration abnormalities, history of attention deficit hyperactivity disorder; or were non-English speakers. Ethics approval (No: Pro00077091) was acquired from the University of Alberta Health Research Ethics Board, and informed consent and/or assent was obtained from all participants prior to testing as appropriate.

PROCEDURES

Data were collected at either a university lab or a private physiotherapy clinic. On the day of testing, participants completed study questionnaires that gathered demographic and medical history information. Participants were familiarized with the FAB-C testing protocol and performed a warm-up (i.e., 1 minute of sidestepping, one minute of jogging backward, and three minutes of jogging forward) prior to data collection. The lead investigator, who is a physical therapist with seven years of experience in SRC management, scored the participants’ performance as they
completed three trials of the FAB-C battery. Short rest breaks (i.e., one to two minutes) were provided between trials as needed. The lead investigator also recorded all feasibility outcomes of interest.

OUTCOMES

A questionnaire adapted from the Sports Concussion Assessment Tool–5th edition (SCAT5)\textsuperscript{16} was used to collect information on participants’ sex, age, primary sport and medical history (i.e., history of previous concussions, current medications, number of days since injury, number of days since RTS, the health care provider who made a diagnosis of SRC, and the health care provider who made a RTS decision). Feasibility outcomes included the number of participants who completed the entire assessment, potential for adverse events (i.e., falls, near-miss falls, injury, or increased symptoms), and burden (i.e., the cost of required equipment and time required to complete the assessment). FAB-C scores included the individual scores from the tests that made up the battery.

ANALYSIS

Descriptive statistics [mean (standard deviation), median (range) or proportion as appropriate] were used to summarize all FAB-C clinical test outcomes. To evaluate the feasibility of the FAB-C, the percentage of participants who completed the entire FAB-C battery, the percentage of participants who demonstrated adverse events during and/or after testing, average time (in minutes) required to administer the FAB-C battery, and cost (in Canadian Dollars) of equipment required were calculated. Data from participants who completed the entire testing battery were included in the analysis. To evaluate the construct validity of the FAB-C, a multitrait Spearman’s correlation coefficient matrix was used to examine correlation patterns between clinical tests included in the FAB-C battery to identify whether they assessed similar or unique components of postural control.\textsuperscript{17} The non-parametric Spearman’s correlation was used given the small sample size in this study. If the Spearman’s correlation between two clinical tests was 0.7 or higher, it was assumed that one of them could be replaced with another clinical test based on tests’ purposes and clinometric properties.\textsuperscript{18} An $\alpha$ level of 0.001 was chosen to judge significance to account for multiple comparisons. Differences in performance on the FAB-C battery between uninjured participants and participants who had recently RTS following SRC were calculated and reported using basic descriptive statistics [mean (standard deviation), median (range) or proportion as appropriate]. All analyses were performed using IBM SPSS 25 for Windows (Armonk, New York).

RESULTS

DEVELOPMENT OF THE FAB-C BATTERY

The literature search identified 15 clinical tests that were cited as appropriate in individuals SRC and were potential tests for inclusion in the FAB-C battery. Appendix 1 shows the tests with their purposes and established clinometric properties as well as the decisions used to include or omit each test in the FAB-C. This list was reduced to seven tests taking into consideration a tests’ purpose(s) and clinometric properties. These seven included the Balance Error Scoring System, Tandem Gait Test, and Clinical Reaction Time Tests in both single and dual-task (concurrent cognitive task) testing conditions. As no sport-specific testing paradigms were identified, the research team developed a Sport-Related Movement Control Test using the scale development framework of Johnson and Morgan (Figure 1).\textsuperscript{19} Finally, the research team incorporated a symptom checklist (The Post-Concussion Symptom Inventory)\textsuperscript{20} to ensure the FAB-C was comprehensive. A full description of these tests follows.

The Balance Error Scoring System. This test is commonly used to measure the sensory strategies component of postural control following SRC.\textsuperscript{4} The test involves the completion of three 20-second stance trials (i.e., double leg, single leg, tandem stance) on firm and foam surfaces. These are scored based on the number of errors committed (i.e., total score ranges from 0 – 60). For the dual-task condition, participants were asked to subtract by seven from a randomly assigned number while performing the test.\textsuperscript{21} The research team scored both the single- and dual-task Balance Error Scoring System by averaging the number of errors a participant commits from three testing trials to obtain the most reliable scores.\textsuperscript{22}

The Tandem Gait Test. The test is currently an accepted measure of the control of dynamics component of postural control following SRC,\textsuperscript{4} and involves walking in a forward direction as fast and accurately as possible down and back along a 38mm-wide three-meter line using an alternate foot heel-to-toe gait. During the test, the administrator records the time (in seconds) required for participants to complete the test, as well as the participants’ ability to complete the test (i.e., pass/fail). For the dual-task condition, participants were asked to spell-out a five-letter word backward while performing the test.\textsuperscript{21} To obtain the most reliable scores for both the single- and dual-task Tandem Gait Test, the research team scored the time assessment by averaging time across three testing trials, and the pass/fail assessment based on a participant’s performance in trial three.\textsuperscript{22}

The Clinical Reaction Time Test. The participants were asked to catch a numbered rod as quickly as possible. Drop distance is converted to speed. For the dual-task condition, participants were asked to verbally spell a five-letter word backward while waiting for the testing apparatus to fall.\textsuperscript{23} The research team scored both the single- and dual-task Clinical Reaction Time Test by averaging reaction time (in milliseconds) across three testing trials to obtain the most reliable scores.\textsuperscript{22}
<table>
<thead>
<tr>
<th>Required Test Development stage</th>
<th>Research Activities Performed</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Defining the construct</td>
<td>- Reviewed the scientific literature to identify underlying systems of postural control potentially affected following sport-related concussion.</td>
<td>- Potentially affected underlying systems involved: reaction time, control of dynamics, sensory integration, and cognitive contributions.</td>
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<td></td>
<td>- Literature review to create a list of available tests of postural control assessment following sport-related concussion.</td>
<td>- The interaction between these systems is task dependent.</td>
</tr>
<tr>
<td></td>
<td>- Interviewed a physical therapist with &gt;10 years of experience in sport-related concussion management to assess the comprehensiveness of the list.</td>
<td>- Available tests included the Balance Error Scoring System, Clinical Test of Sensory Interaction in Balance, Clinical Reaction Time, Dynamic Gait Index, Functional Gait Assessment, Romberg Test, Standing Balance Test, Stoop Test, Tandem Gait Test, and Walking While Talking Test.</td>
</tr>
<tr>
<td></td>
<td>- Reviewed the list with the investigative team to identify whether the included tests assessed postural control while performing specialized movements involved in sport.</td>
<td>- The therapist confirmed the comprehensiveness of the list.</td>
</tr>
<tr>
<td></td>
<td>A new test was developed through:</td>
<td>- None of the tests assessed postural control recovery status during specialized movements involved in sport.</td>
</tr>
<tr>
<td></td>
<td>- Literature review to identify specialized movements commonly involved in sport.</td>
<td>- A rapid whole-body movement with change of velocity and/or direction is commonly involved in sport.</td>
</tr>
<tr>
<td></td>
<td>- Building a consensus between the members of the investigative team to organize the identified movement into a preliminary testing protocol that challenged the potentially affected underlying systems of postural control following sport-related concussion.</td>
<td>- The preliminary sport-related movement control test that included one component was developed. This was named the Turn and Go component.</td>
</tr>
<tr>
<td>2. Generating item pool through literature review and discussion with experts</td>
<td>- Interviewed a neurologist, neuropsychologist, and two physical therapists with &gt;5 years of experience in SRC management to assess the comprehensiveness and relevance of the generated item pool.</td>
<td>- Content experts confirmed comprehensiveness and relevance of the generated item pool.</td>
</tr>
<tr>
<td></td>
<td>- Both examiners and participants confirmed the clarity of instruction.</td>
<td>- The neurologist suggested adding a patient-reported outcome measure to capture participants' symptoms after performing the test to make the test more comprehensive.</td>
</tr>
<tr>
<td></td>
<td>- The median testing time was 16.9 seconds (ranged from 13 to 22 seconds).</td>
<td>- No adverse effects were reported.</td>
</tr>
<tr>
<td></td>
<td>- No adverse effects were reported.</td>
<td>- Another test component was added (named the Lateral Shuffle component) to include more specialized movements involved in sport.</td>
</tr>
<tr>
<td></td>
<td>- The members of the investigative team agreed to score both tests' components based on time required to finish a component as well as a participant's ability to stay within the assigned paths (pass/fail).</td>
<td>- The members of the investigative team agreed to score both tests' components based on time required to finish a component as well as a participant's ability to stay within the assigned paths (pass/fail).</td>
</tr>
<tr>
<td>3. Item pool review by content experts</td>
<td>- Examined the relative and absolute reliability (intra and inter) of the sport-related movement control test’s components, based on the average of 3 testing trials. Tested a subset sample of 25 active participants with and without history of sport-related concussion (female = 39%, median age [range] = 17 [13-24], history of previous concussion = 39%).</td>
<td>- Estimated intraclass correlation coefficient, standard error of measurement, minimal detectable change, and Kappa statistic for the ‘Turn and Go’ and ‘Lateral Shuffle’ components ranged from 0.85 to 0.97, 0.3 to 0.7, 0.9 to 2.0, and 0.23 to 0.9, respectively.</td>
</tr>
<tr>
<td>4. Pilot testing</td>
<td>- Assessed feasibility (i.e., clarity of instructions, duration, and safety) of the Turn and Go component in a sample of five uninjured active participants (female = 40%, median age [range] = 14 [13-19], history of previous concussion = 0%).</td>
<td>- Estimated intraclass correlation coefficient, standard error of measurement, minimal detectable change, and Kappa statistic for the ‘Turn and Go’ and ‘Lateral Shuffle’ components ranged from 0.85 to 0.97, 0.3 to 0.7, 0.9 to 2.0, and 0.23 to 0.9, respectively.</td>
</tr>
</tbody>
</table>

Figure 1. The development of the Sport-Related Movement Control Test
Table 1: Participant Characteristics (n=47).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Uninjured (n=40)</th>
<th>Injured (n=7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (female), n (%)</td>
<td>12 (30%)</td>
<td>1 (14.2%)</td>
</tr>
<tr>
<td>Age (years), median (min-max)</td>
<td>17 (13–24)</td>
<td>17 (13-20)</td>
</tr>
<tr>
<td>History of previous concussion (yes), n (%)</td>
<td>13 (32.5%)</td>
<td>4 (57%)</td>
</tr>
<tr>
<td>Current medication (yes), n (%)</td>
<td>2 (5%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Days since injury to return-to-play, median (min-max)</td>
<td>NA</td>
<td>31 (9-40)</td>
</tr>
<tr>
<td>Days since return-to-play to testing, median (min-max)</td>
<td>NA</td>
<td>34 (9-46)</td>
</tr>
</tbody>
</table>

Note. None of the recruited participants reported sport-related concussion related symptoms at baseline.

**Sport-Related Movement Control Test.** The test includes both a 'Turn and Go' (i.e., a sport-related movement control measure which involves forward running with repeated turning in five different directions within a limited base-of-support), and 'Lateral Shuffle' (i.e., a sport-related movement control measure which involves side-shuffle and backward running in five different directions within a limited base-of-support) components (Figure 2). Both tests’ components are scored based on time (in seconds) required for participants to complete the components (i.e., running in five directions), as well as the participant’s ability to complete the components (i.e., pass/fail). The research team scored the time assessment by averaging time across three testing trials, and the pass/fail assessment based on a participant’s ability to pass all three testing trials to obtain reliable scores (Figure 2).

**The Post-Concussion Symptom Inventory.** The Post-Concussion Symptom Inventory Self-assessment (ages 13 – 18) was used to document participants’ symptoms before and after testing. This version of the Post-Concussion Symptom Inventory has been validated for use with individuals following SRC, with acceptable test-retest reliability (intraclass coefficients ICC = 0.65–0.89).20

**TESTING THE FAB-C BATTERY**

**PARTICIPANT CHARACTERISTICS**

**Uninjured (Table 1):** Of 59 individuals who expressed interest in study participation, seven did not meet the inclusion criteria (history of concussion within the year prior to testing), three declined to participate (time constraints), and nine did not respond to communications, leaving a sample of 40 participants. The majority (70%) of uninjured participants reported hockey, basketball, ringette, or soccer as their primary sport and two (5%) participants reported current use of antibiotics for ongoing dermatological conditions.

**Previous SRC with RTS in past 60 days (Table 1):** Of nine individuals who expressed interest in participating in the study, one did not meet the inclusion criteria (history of lower extremity injury that caused absence from recreational/sport activities greater than one week within the last three months), and one declined to participate (time constraints), leaving a sample of seven participants. The majority (85%) of recently concussed participants reported football and hockey as their primary sport. Four (57%) participants were initially diagnosed with SRC by a physician, and three (43%) by an athletic therapist. Three (42%) and four (58%) participants RTS based on clearance from a physician and a physical therapist, respectively. The most frequently reported criteria for making RTS decision included symptoms resolution (43%), individual ability to perform physical tasks while being symptom-free (28.5%), or both (28.5%).

**FEASIBILITY**

All (100%) uninjured participants completed the entire assessment on the FAB-C (see Table 2). No participants demonstrated adverse events during and/or after administering the FAB-C battery. The median total time needed to administer the FAB-C battery was 49 minutes (ranging from 44 to 60 minutes). The cost of equipment required to administer the FAB-C battery was ~$100 Canadian Dollars.
### Table 2. Summary Statistics for Participant Performance on the FAB-C battery (n=46).

<table>
<thead>
<tr>
<th>Task</th>
<th>Uninjured (n=40)</th>
<th>Injured (n=6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BESS-ST (number of errors)</td>
<td>16 (26)</td>
<td>15 (10)</td>
</tr>
<tr>
<td>TGTT-ST (seconds)</td>
<td>19 (14)</td>
<td>16 (8)</td>
</tr>
<tr>
<td>TGTE-ST (% passing)</td>
<td>67</td>
<td>50</td>
</tr>
<tr>
<td>CRT-ST (millisecond)</td>
<td>250 (80)</td>
<td>238 (73)</td>
</tr>
<tr>
<td>BESS-DT (number of errors)</td>
<td>14 (30)</td>
<td>13 (21)</td>
</tr>
<tr>
<td>TGTT-DT (seconds)</td>
<td>19 (23)</td>
<td>17 (10)</td>
</tr>
<tr>
<td>TGTE-DT (% passing)</td>
<td>82</td>
<td>66</td>
</tr>
<tr>
<td>CRT-DT (millisecond)</td>
<td>250 (110)</td>
<td>230 (60)</td>
</tr>
<tr>
<td>Turn and Go (seconds)</td>
<td>18 (8)</td>
<td>17 (5)</td>
</tr>
<tr>
<td>Turn and Go (% passing)</td>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>Lateral Shuffle (seconds)</td>
<td>17 (9)</td>
<td>17 (4)</td>
</tr>
<tr>
<td>Lateral Shuffle (% passing)</td>
<td>52</td>
<td>17</td>
</tr>
</tbody>
</table>

Note. None of the recruited participants reported sport-related concussion related symptoms after performing the FAB-C battery. Values are presented as median (range) unless otherwise noted. Data from one injured participant who did not complete the entire testing protocol was excluded from the analysis. BESS: Balance Error Scoring System, CRT: Clinical Reaction Time, DT: dual-task, FAB-C battery: the Functional Assessment of Balance in Concussion battery, Lateral Shuffle: a sport-related movement control measure that involves side-shuffling and backward running, ST: single-task, TGTT: Tandem Gait Test (time), TGTE: Tandem Gait Test (error), Turn and Go: a sport-related movement control measure that involves forward running and turning.

### CONSTRUCT VALIDITY

Correlations between clinical tests included in the FAB-C battery ranged from -0.33 to 0.84 (see Table 3). Non-significant correlations between the Balance Error Scoring System, Tandem Gait Test, Clinical Reaction Time Test, and Sport-Related Movement Control Test were observed. Despite the high correlation between the Turn and Go and Lateral Shuffle components of the sport-related movement control test ($r = 0.84$, $p < 0.001$), the research team decided to keep both in the FAB-C battery given that each component involves a different set of movements required for sports participation (i.e. forward running with repeated turning versus backward running and side shuffle). The research team, therefore, did not remove any clinical tests from the FAB-C battery. Appendix 2 presents the final FAB-C battery inclusive of scoring, examiner, and patient instructions.

All (100%) uninjured participants and six (86%) participants who had recently RTS following SRC completed the entire FAB-C testing. One (14%) recently concussed participant withdrew after data collection due to the reproduction of SRC symptoms including headache, dizziness, and reported sadness. The percentage of uninjured participants who passed the single-task Tandem Gait Test, dual-task Tandem Gait Test, Turn and Go test, and Lateral Shuffle Test were 67%, 82%, 60%, and 52%, respectively; compared to 50%, 66%, 0%, and 17% of participants who had recently RTS following SRC, respectively (Table 2).

### DISCUSSION

This paper introduces the FAB-C battery aimed at assessing different components of postural control relevant to SRC. The battery consists of seven performance-based clinical tests and a symptom checklist intended to be used in combination (and not in isolation) to determine a patient’s postural control assessment. The battery appears safe, feasible and inexpensive (i.e., its cost is comparable to the cost of the Balance Error Scoring System, which is commonly used for postural control assessment in SRC). However, the total time required to administer the battery is lengthy (44 – 60 minutes).

Although the FAB-C battery requires a considerable administration time, a comprehensive battery of tests that includes evaluation of various components of postural control that may be affected by SRC is needed and may help professionals to identify areas of ongoing dysfunction. In addition, specific components of postural control may benefit from targeted rehabilitation and may also identify additional areas that may increase the risk of subsequent musculoskeletal injuries and concussion. Moreover, the time required to administer the battery is comparable to that required to administer a comprehensive assessment of motor skills in individuals with SRC (e.g., Bruininks-Oseretsky Test of Motor Proficiency Second Edition) yet with a lower associated cost. To reduce the time of administration, future studies should examine the clinical utility of using total versus subdomain scoring of the FAB-C battery.
Table 3. Multitrait Spearman Correlation Matrix among Postural Control Tests in Healthy Control Participants (n=40).

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. BESS-ST</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>2. TGTT-ST</td>
<td>0.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3. TGTE-ST</td>
<td>0.42*</td>
<td>-0.19</td>
<td></td>
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<tr>
<td>4. RT-ST</td>
<td>-0.30</td>
<td>0.18</td>
<td>-0.14</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>5. BESS-DT</td>
<td>0.63**</td>
<td>0.10</td>
<td>0.41</td>
<td>-0.06</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>6. TGTT-DT</td>
<td>0.18</td>
<td>0.52**</td>
<td>-0.03</td>
<td>0.11</td>
<td>0.25</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. TGTE-DT</td>
<td>0.27</td>
<td>0.15</td>
<td>0.54**</td>
<td>-0.01</td>
<td>0.29</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. RT-DT</td>
<td>-0.10</td>
<td>0.18</td>
<td>-0.01</td>
<td>0.15</td>
<td>-0.12</td>
<td>0.01</td>
<td>0.14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Turn and Go (second)</td>
<td>0.26</td>
<td>0.14</td>
<td>0.21</td>
<td>-0.13</td>
<td>0.19</td>
<td>0.08</td>
<td>0.38*</td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Turn and Go (%pass)</td>
<td>0.19</td>
<td>0.07</td>
<td>0.18</td>
<td>0.13</td>
<td>0.29</td>
<td>0.07</td>
<td>0.00</td>
<td>-0.14</td>
<td>-0.23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Lateral Shuffle (second)</td>
<td>0.29</td>
<td>0.15</td>
<td>0.24</td>
<td>-0.11</td>
<td>0.20</td>
<td>0.21</td>
<td>0.36*</td>
<td>0.04</td>
<td>0.84**</td>
<td>-0.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Lateral Shuffle (%pass)</td>
<td>0.12</td>
<td>-0.12</td>
<td>0.19</td>
<td>-0.07</td>
<td>0.04</td>
<td>0.13</td>
<td>-0.01</td>
<td>0.34*</td>
<td>-0.33*</td>
<td>0.35*</td>
<td>-0.18</td>
<td></td>
</tr>
</tbody>
</table>

Note. Numbers in the top raw represent the same measures listed in the first column. Dashes along the diagonal represent perfect correlation (r = 1.0). *Correlations are significant at 0.05 level (2-tailed). ** Correlations are significant at 0.001 level (2-tailed). BESS: Balance Error Scoring System, CRT: Clinical Reaction Time, DT: dual-task, ST: single-task, Lateral Shuffle: a sport-related movement control measure that involves side-shuffling and backward running, TGTT: Tandem Gait Test (time), TGTE: Tandem Gait Test (error), Turn and Go: a sport-related movement control measure that involves forward running and turning.
Data analysis showed limited correlations between individual tests included in the FAB-C battery. This indicates that each test assesses a different component of postural control and the tests should not be used interchangeably or in isolation when examining a patient’s postural control. The analysis also showed that all uninjured participants were able to complete the entire FAB-C battery; and passed the single-task Tandem Gait, dual-task Tandem Gait, Turn and Go, and Lateral Shuffle tests whereas only a proportion of recently RTS participants (Table 2). This observation provides preliminary evidence of the construct validity of the FAB-C battery to identify postural control impairments in youth and young adults who had recently RTS following SRC. This observation also supports previous studies suggesting that some athletes with SRC may RTS with residual postural control deficits.12,24

Future studies examining the proposed FAB-C battery in samples of individuals diagnosed with SRC of varying age, sex, gender, and sporting history are required before widespread use in clinical and clinical research settings. At this point, there is a need for studies examining the effect of different sources of variance (e.g., age, sex, and history of SRC) within individual clinical tests included in the FAB-C battery. Findings from these studies inform subsequent studies evaluating the clinimetric properties (i.e., validity and reliability) of the FAB-C battery. If the FAB-C battery is valid, reliable, and can differentiate which components of postural control are affected by a concussion, it could be used to inform the design and evaluation of rehabilitation strategies (i.e., selection of exercises that target affected components). Future studies may also examine the clinical utility capturing the accuracy of cognitive responses included in the battery.

STRENGTHS AND LIMITATIONS

To the research team knowledge, the current study presents the first clinical assessment of postural control that aims at differentiating between various potentially affected components of postural control following SRC. This study, however, has limitations. Specifically, the research team recruited uninjured athletes who had not experienced a SRC over the year prior to testing, and analyzed data from only participants who completed the entire assessment, which introduced potential selection bias.25 The clinical tests used under the dual-task and sport-specific domains of the FAB-C battery have not been previously validated, which introduced potential measurement bias.25 Finally, the generalizability of the our findings from the current study is limited as the majority of the recruited sample involved uninjured athletes (85%), male athletes (63%), and athletes who played hockey, ringette, basketball, or soccer (60%).

CONCLUSION

The proposed FAB-C battery aims at differentiating between the potentially affected components of postural control following SRC. The results of this study indicate that the battery appears safe, feasible, inexpensive, and demonstrated preliminary construct validity to identify postural control impairments in youth and young adults who had recently RTS following SRC. Further studies evaluating the clinimetric properties and clinical utility of the FAB-C battery are required before adoption for widespread use in clinical settings.

COMPETING INTERESTS

The authors acknowledge that they have no conflicts of interest that are directly relevant to the contents of this research study.

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REFERENCES


Original Research

Direction-Specific Signatures of Sport Participation in Center of Pressure Profiles of Division I Athletes

Stephen M. Glass¹  Scott E. Ross²
¹ Physical Therapy, Radford University, ² Kinesiology, UNC Greensboro

Keywords: athletes, balance, training adaptations, sport-specificity

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Background
Descriptive and comparative studies of human postural control generally report effects for component or resultant dimensions of a measured signal, which may obscure potentially important information related to off-cardinal directionality. Recent work has demonstrated highly specific balance behavior that is often not easily reconciled with conventional theories of postural control.

Purpose
The purpose of this study was to quantify the effects of sport-specific training history on directional profiles of center of pressure (COP) displacement and velocity among collegiate athletes.

Study Design
Cross-Sectional Study.

Methods
One-hundred sixty-seven NCAA Division-I varsity athletes (80 female: 19.12±1.08 years, 169.79±7.03 cm, 65.69±10.45 kg; 87 male: 19.59±1.33 years, 181.25±9.06 cm, 76.40±12.73 kg) representing four sports (basketball, soccer, tennis, and cross county) participated in this study. Participants balanced barefoot with eyes closed on a force plate for 10-s. in double leg and single leg stance. Effects of sport on mean COP velocity and total displacement were assessed within eight non-overlapping directions (i.e. heading bins).

Results
Greater double leg COP displacement and velocity were observed within specific heading bins in cross country athletes when compared to soccer athletes. Greater double leg COP velocity was also observed in multiple heading bins in basketball athletes when compared to soccer athletes. Greater single leg (non-dominant limb) COP displacement was observed in the 135° heading bin in basketball athletes when compared to soccer athletes.

Conclusions
The observed effects are likely attributable to sport-specific sensorimotor adaptations, including lower extremity strength/power, proprioceptive acuity, and efficiency of integrating vestibular information. Other potential mechanism—namely the involvement of cutaneous feedback and/or muscle synergies—deserve consideration. Directional profiling of spontaneous COP motion may improve understanding of sport-related

Corresponding author:
Stephen M. Glass, PhD
RUC Department of Physical Therapy
101 Elm Avenue, Suite 830
Roanoke, VA 24013
smglass1@radford.edu
Phone: (540) 224-6674
Fax: (540) 224-6660
balance behavior, enhancing its application in therapeutic and performance monitoring contexts.

**Level of evidence**

3b

**INTRODUCTION**

Balance studies generally report statistical effects for magnitude and/or variability of measured outcomes such as center of pressure (COP) or center of mass (COM). Frequently, these effects are assessed using the component dimensions of the signal, roughly aligned with the antero-posterior (AP) and mediolateral (ML) anatomical planes. Another approach is to use the resultant signal, which may increase the likelihood of observing meaningful effects, but in doing so obscures potentially important information related to directionality.

Whether referring to component or resultant analyses, greater magnitude of motion is conventionally considered to reflect postural control deficits.\(^1\) In the context of sports medicine, it is common to observe increased postural sway following injury to the lower extremity or brain,\(^2\) which may affect various combinations of peripheral sensation, central integration, and motor effectors. While this perspective of sway is prevalent among both clinicians and scientists, recent work may suggest a more nuanced meaning of postural motion.\(^3\)–\(^6\) Considering the context-specific nature of recent findings—particularly those that seem to challenge the presumed meaning of COP/COM outcomes—it is possible that prevailing analytical approaches are not sufficiently specific for use in broad-ranging clinical applications.

Meaningful postural behavior may occur outside the cardinal anatomical planes.\(^7\) It is known from perturbation and sensory manipulation paradigms that localized stimulus can induce sway behaviors in specific directions (such as depicted in Figure 1). Such responses are likely mediated by a variety of sensory\(^8\),\(^9\) and motor\(^10\) components of postural control and could suggest the presence of similar directional tendencies in spontaneous (i.e. quiet, unperturbed standing) sway when an individual’s sensorimotor adaptations result in localized variation in the ability to create and/or control postural motion. If quantifiable, these tendencies may present an opportunity for creating more descriptive measures of balance behavior while also providing insight into observations that conflict with conventional understandings of postural control. Further, profiles of such directional tendencies may partially control for the dependence of balance measures on anthropometric factors as such profiles can be assessed not only on the basis of their magnitude, but also their shapes or patterns.

One factor that may contribute to directional specificity within postural sway behavior is training history. Sport specialization at the varsity collegiate level would hypothetically create reasonably homogeneous groups differentiated by the influence of training adaptations on balance behavior. The athletic adaptations that are generally most relevant to performance vary across the sports sampled in this study. Soccer prioritizes speed, power, and endurance, with long-duration sprints, numerous turns, jumps, and changes in speed and direction.\(^11\) Tennis involves repeated bouts of rapid acceleration and deceleration, frequent changes in direction, and high-intensity frontal and transverse motion of the upper body.\(^12\),\(^13\) Basketball, like tennis, is characterized by frequent changes in direction, starts and stops, and movement mode transitions including lateral shuffling, with a relatively greater emphasis on frequent high-power vertical jumps. Finally, relative to the comparison sports used in this study cross country prioritizes sustained forward running gait with associated sagittal plane foot mechanics and comparatively small adjustments in the mediolateral direction.

The purpose of this study was to quantify the effects of sport-specific training history on directional profiles of center of pressure displacement and velocity among collegiate athletes. Based on the attributes summarized in the preceding paragraph, the authors hypothesized that participation in basketball and tennis will be characterized by a greater degree of control in the medial and lateral headings when compared with soccer and cross country.

**METHODS**

This research was approved by The University of North Carolina at Greensboro Institutional Review Board. All participants provided written, informed consent prior to participating. Division I collegiate varsity athletes performed a series of balance tests as part of an annual, station-based preparticipation exam. The sample included 80 female (19.12±1.08 years, 169.79±7.03 cm, 65.69±10.43 kg) and 87 male (19.59±1.33 years, 181.25±9.06 cm, 76.40±12.73 kg) participants representing 4 varsity sports: basketball, soccer, tennis, and cross county. The present analysis is limited to those subjects who were cleared for sports participation at the time of data collection and had no history of lower extremity surgery or fracture. Data were averaged across years for any athletes with data from multiple years.

Subjects performed one trial each of double leg and single leg stance (each limb tested once). Subjects were familiarized with the task, but were not allowed to practice. The dominant limb was defined as the limb one would stand on when kicking a ball for maximum distance.\(^14\) All trials were completed with bare feet, eyes closed, and hands on hips. Athletes were instructed to remain as motionless as possible for the duration of each 10 second trial. Stance width in double leg stance was determined by height using short, medium, and tall guidelines commonly applied in dynamic posturography.\(^15\) For single leg trials, the long axis of the foot was aligned with the forward/backward axis of the force plate. Participants were instructed to touch down on the force plate if unable to complete a single leg trial.\(^16\) In order to prevent such touch downs from excessively influencing the data, single leg trials in which COP displacement exceeded conservative boundaries defined using criterion data from the authors’ prior work\(^17\) were discarded. Any discarded trial was discarded in its entirety. That is, all
analyzed trials were 10 seconds in duration.

Ground reaction forces were recorded at 100 Hz using an AMTI Accusway force plate (AMTI Inc., Watertown, MA) and used to create time histories of AP and ML COP coordinates, which were then low-pass filtered (2nd order Butterworth with a cutoff frequency of 15 Hz).18 Subsequently, a directional heading was calculated at each sample of the differenced COP time series using the atan2 function in base R (The R Foundation, Vienna, Austria). All heading time series samples were then discretized into one of eight equally-spaced, nonoverlapping bins with each accounting for a 45° (~0.79 radians) arc (Figure 1). For double leg trials and single leg trials on the right limb, 0° corresponded to the subject’s right. For single leg trials on the left, 0° was redefined as corresponding to the subject’s left and positive rotation was redefined as clockwise. Therefore, the anatomical meaning of the heading bins for single leg trials does not depend on whether the right or left leg was used (Figure 1).

Average COP velocity and total displacement were then calculated within each directional bin and used for further analysis. Two points of clarification should be noted: 1) Each data point’s heading is expressed relative to the previous data point rather than the coordinate system origin. Because of this, absolute positioning of the participant’s foot on the force plate does not affect results; only foot orientation is important. 2) Computations of within-heading COP velocity and displacement involve only those data points in which the COP was moving positively (i.e. forward) in the associated direction. Thus, for example, a datapoint adding to displacement within the 90° bin would not also subtract from displacement in the reciprocal 270° bin.

The effect of sport on the average COP velocity and total displacement vectors in each heading was examined using profile analysis.19 Profile analysis is akin to a multivariate version of repeated measures ANOVA in which vectors of the dependent measure are evaluated for null hypotheses related to parallelism, equality, and flatness in that order. In practical terms, a rejection of parallelism would indicate that distribution of COP displacement or velocity within different heading bins varies by sport. A rejection of equality would indicate that average COP displacement or velocity, but not their distribution within heading bins, differed by sport. Lastly, a rejection of flatness would indicate that COP velocity or displacement vary by heading, but that sport had no effect on average or within-heading magnitudes. While the present analyses were conducted in keeping with standards for profile analysis, it should be noted that, because the vectors are not expected to be flat in this case, neither rejections of flatness nor comparisons between heading bins collapsed across sport are of great interest to the present study.

The effect of sport at individual levels of COP heading was tested using one-way ANOVA models with sport as the grouping variable. These models should be considered exploratory where not predicated by significant findings for parallelism or equality. Pairwise comparisons were performed with the false discovery rate controlled using the Benjamini-Hochberg method.20 Finally, for purposes of comparing the results of the current study with more conventional methods of analysis, one-way ANOVA models for average total COP displacement and velocity are also presented.

RESULTS

From the greater station-based preparticipation exam, a total of 776 balance trials met the criteria for inclusion in analysis. Of these, 165 trials (~21%) were discarded on the basis of exceeding screening boundaries. Three additional trials were excluded due to coding errors.

Parallelism of the total displacement summary vectors (Figure 2) was rejected for double leg stance (Wilks Λ = 0.813, F(21.00, 445.63) = 1.590, p < 0.05) and single leg (dominant limb) stance (Wilks Λ = 0.752, F(21.00, 353.74) = 1.756, p = 0.02). Neither parallelism nor equality was rejected for single leg (non-dominant limb) stance (parallelism: Wilks Λ = 0.849, F(21.00, 339.38) = 0.946, p = 0.53; equality: F(3.00, 124.00) = 1.307, p = 0.22). Following these nonsignificant tests for parallelism and equality, flatness was rejected for single leg (non-dominant limb) stance displacement profiles (flatness: F(7.00, 118.00) = 18.799, p = 0.01).

Significant follow up contrasts for within-heading displacement (Table 1) in double leg stance were observed in the 135° (anterior/left) and 315° (anterior/right) headings, wherein displacement was greater in cross country than in soccer. The follow up contrast for average (i.e. all headings) displacement was also significant, with greater displacement in both basketball and cross country when compared with soccer. Significant follow up contrasts for within-heading displacement were also observed in single leg (non-dominant limb) stance. Here, displacement in the 135° (anterior) heading was significantly greater in basketball than in soccer. The follow-up contrast for the 270° (posterior) heading was significant at the omnibus level; however, no significant pairwise effects were observed.

Parallelism of mean velocity vectors (Figure 3) was rejected for double leg stance (Wilks Λ = 0.799, F(21.00, 445.63) = 1.724, p = 0.025). Neither parallelism nor equality of the vectors of mean velocities was rejected for single leg (dominant limb) stance (Wilks Λ = 0.845, F(21.00, 353.74) = 1.017, p = 0.44; equality: F(3.00, 129.00) = 0.588, p = 0.62). Similarly,
neither parallelism nor equality of the vectors mean velocities was rejected for single leg (non-dominant limb) stance (Wilks $\Lambda = 0.856, F_{(21,00, 339,38)} = 0.896, p = 0.60$; equality $F_{(3,00, 124,00)} = 1.457, p = 0.23$). Flatness of the mean velocity vectors was rejected for both single leg stance conditions (dominant limb: $F_{(7,00, 123,00)} = 34.950, p = 0.01$; non-dominant limb: $F_{(7,00, 118,00)} = 31.561, p = 0.01$) stance.

Follow up contrasts for within-heading velocity (Table 2) in double leg stance indicated significant effects for sport in the 0° (right), 90° (anterior), 135° (anterior/lef t), 225° (posterior/lef t), 270° (posterior), and 315° (posterior/right) headings, as well as the all-heading average. Pairwise contrasts indicated greater COP velocity in cross country compared with soccer in the 90° (anterior), 135° (anterior/le ft), 270° (posterior), and 315° (posterior/right) headings, as well as for the all-heading average COP velocity. Additionally, greater COP velocity was observed in basketball when compared with soccer for the 90° (anterior), 225° (posterior/lef t), and 315° (posterior/right) headings. The follow-up contrast for single leg (non-dominant limb) stance COP velocity in the 135° (anteromedial) heading was significant at the omnibus level; however, no significant pairwise effects were observed.

**DISCUSSION**

The purpose of this study was to quantify the effects of sport-specific training history on directional profiles of center of pressure displacement and velocity among collegiate athletes. The principle finding was that profiles of COP motion in specific headings vary by sport. Specific differences by sport were observed for double leg COP displacement in the 135° (anterior/lef t) and 315° (posterior/right) headings (cross country > soccer), non-dominant limb single leg COP displacement in the 135° (anteromedial) heading (basketball > soccer), double leg COP velocity in the 90° (anterior), 135° (anterior/lef t), 270° (posterior), and 315° (posterior/right) headings (cross country > soccer), and double leg COP velocity in the 90° (anterior), 225° (posterior/lef t), and 315° (posterior/right) headings (basketball > soccer). The hypothesis regarding relatively greater control of COP motion in the medial and lateral headings among basketball and tennis players was not supported. However, some observations may suggest that training adaptations in basketball may preferentially affect postural control in off-sagittal headings in ways that are less evident in other sports. Because this study featured NCAA Division I athletes, sport-specific adaptations likely play a role in the observed differences. This discussion first considers whether the present observations agree with previous findings. On this topic, comparison is mostly limited to the more conventional AP, ML, and resultant metrics. The authors then address adaptations that might contribute to the patterns observed, emphasizing that their observations may result from preferential adaptation of different postural regulatory mechanisms or directional specificity within these mechanisms.

Published findings concerning the effect of sport specialization on non-cardinal direction COP motion are lacking. Athletes generally control their posture better than non-athletes, and increasing levels of competitiveness appear to strengthen this effect.\(^1\)\(^{22–23}\) Balance test performance is also known to vary by sport, possibly reflecting sport-related adaptations.\(^21\)\(^{24}\) As is the case in the current study, previous work has found more confined postural motion in soccer than in basketball whether through clinical rating\(^24\) or laboratory instruments.\(^25\)\(^{26}\) There is some evidence for a similar effect in tennis and basketball in single leg stance, although the study in question also reports substantially lower COP path length for tennis in comparison with soccer, which contrasts with the current findings.\(^26\) Thus, these results are somewhat novel by virtue of the sports compared but appear to align with previous findings regarding postural control in soccer and basketball.\(^25\)\(^{26}\)

The relevant adaptations to specific training involve changes in muscular properties; vestibular or proprioceptive sensory function; or central processing at varying levels of involvement.\(^22\) Visual adaptations are intentionally not considered as the trials in this study were performed with eyes closed, which should exclude the ability to use visual information in direct support of maintaining balance from affecting the present results. Further, the adaptations contributing to balance control in the study participants—especially for basketball, soccer, and tennis—are likely non-visual in nature as visual attention must largely be allocated to game play.\(^27\) Even so, the authors acknowledge here the possibility that visual adaptations may affect balance behavior to the extent that different athletes may have vary-
ing levels of visual dependence.
Table 1. Follow up one-way and pairwise tests for COP Displacement stance outcomes.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>ANOVA</th>
<th>Mean (SD)</th>
<th>Pairwise Comparison Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>p</td>
<td>BKB</td>
</tr>
<tr>
<td>Double Leg Displacement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0°</td>
<td>1.821</td>
<td>0.14</td>
<td>0.72 (0.45)</td>
</tr>
<tr>
<td>045°</td>
<td>0.181</td>
<td>0.91</td>
<td>1.13 (0.49)</td>
</tr>
<tr>
<td>090°</td>
<td>1.602</td>
<td>0.19</td>
<td>3.91 (1.45)</td>
</tr>
<tr>
<td>135°</td>
<td>2.775</td>
<td>0.043*</td>
<td>1.17 (0.54)</td>
</tr>
<tr>
<td>180°</td>
<td>1.005</td>
<td>0.39</td>
<td>0.73 (0.44)</td>
</tr>
<tr>
<td>225°</td>
<td>2.070</td>
<td>0.11</td>
<td>3.00 (1.75)</td>
</tr>
<tr>
<td>270°</td>
<td>2.251</td>
<td>0.08</td>
<td>5.39 (1.33)</td>
</tr>
<tr>
<td>315°</td>
<td>3.890</td>
<td>0.01*</td>
<td>1.20 (0.66)</td>
</tr>
<tr>
<td>Avg.</td>
<td>3.674</td>
<td>0.014*</td>
<td>1.73 (0.40)</td>
</tr>
</tbody>
</table>

Single Leg Dominant Displacement

| 0°      | 1.431 | 0.24      | 11.34 (4.10) | 10.12 (3.40) | 11.86 (3.87) | 10.23 (4.39) | 0.40 | 0.80 | 0.50 | 0.40 | 0.90 | 0.40 |
| 045°    | 1.525 | 0.21      | 8.94 (2.59) | 10.94 (3.61) | 10.32 (4.41) | 10.89 (4.69) | 0.24 | 0.52 | 0.29 | 0.76 | 0.96 | 0.76 |
| 090°    | 1.319 | 0.27      | 9.19 (3.41) | 7.98 (3.61) | 8.34 (3.80) | 9.57 (4.40) | 0.59 | 0.72 | 0.74 | 0.74 | 0.48 | 0.59 |
| 135°    | 1.849 | 0.14      | 7.97 (2.91) | 6.75 (2.48) | 7.86 (2.36) | 6.77 (2.87) | 0.26 | 0.97 | 0.26 | 0.26 | 0.97 | 0.26 |
| 180°    | 0.564 | 0.64      | 11.55 (5.29) | 10.29 (3.68) | 11.10 (3.51) | 10.36 (5.11) | 0.87 | 0.89 | 0.87 | 0.87 | 0.94 | 0.87 |
| 225°    | 0.788 | 0.50      | 10.03 (2.91) | 11.44 (4.32) | 12.06 (6.68) | 10.89 (3.85) | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 |
| 270°    | 2.638 | 0.05      | 8.60 (4.68) | 6.61 (2.99) | 6.67 (2.76) | 8.21 (3.89) | 0.14 | 0.16 | 0.85 | 0.95 | 0.16 | 0.22 |
| 315°    | 0.924 | 0.43      | 8.43 (3.12) | 7.52 (3.21) | 8.32 (3.13) | 7.28 (3.93) | 0.53 | 0.77 | 0.53 | 0.53 | 0.77 | 0.53 |
### Direction-Specific Signatures of Sport Participation in Center of Pressure Profiles of Division I Athletes

<table>
<thead>
<tr>
<th>Outcome</th>
<th>ANOVA</th>
<th>Mean (SD)</th>
<th>Pairwise Comparison Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>p</td>
<td>BKB</td>
</tr>
<tr>
<td>Avg.</td>
<td>0.541</td>
<td>0.66</td>
<td>9.53 (2.42)</td>
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<tr>
<td><strong>Single Leg Non-Dominant Displacement</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0°</td>
<td>0.994</td>
<td>0.40</td>
<td>10.70 (4.06)</td>
</tr>
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<td>045°</td>
<td>0.264</td>
<td>0.85</td>
<td>9.94 (3.36)</td>
</tr>
<tr>
<td>090°</td>
<td>0.444</td>
<td>0.72</td>
<td>8.71 (4.06)</td>
</tr>
<tr>
<td>135°</td>
<td>4.409</td>
<td>0.006*</td>
<td>8.62 (4.13)</td>
</tr>
<tr>
<td>180°</td>
<td>0.928</td>
<td>0.43</td>
<td>10.72 (4.45)</td>
</tr>
<tr>
<td>225°</td>
<td>0.117</td>
<td>0.95</td>
<td>10.62 (4.59)</td>
</tr>
<tr>
<td>270°</td>
<td>2.745</td>
<td>0.046*</td>
<td>7.65 (4.00)</td>
</tr>
<tr>
<td>315°</td>
<td>0.820</td>
<td>0.48</td>
<td>9.07 (4.43)</td>
</tr>
<tr>
<td>Avg.</td>
<td>1.507</td>
<td>0.22</td>
<td>9.51 (2.92)</td>
</tr>
</tbody>
</table>

One-way ANOVA models analyzing the effect of sport within each heading. The false discovery rate for pairwise comparisons was controlled using the Benjamini-Hochberg method. BKB = basketball, SOC = soccer, TEN = tennis, XC = cross country.
Table 2. Follow up one-way and pairwise tests for COP Velocity outcomes.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>ANOVA</th>
<th>Mean (SD)</th>
<th>Pairwise Comparison Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>BKB</td>
</tr>
<tr>
<td>Double Leg Velocity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0°</td>
<td>3.213</td>
<td>0.25*</td>
<td>0.98 (0.42)</td>
</tr>
<tr>
<td>045°</td>
<td>1.505</td>
<td>0.21</td>
<td>1.07 (0.30)</td>
</tr>
<tr>
<td>090°</td>
<td>3.328</td>
<td>0.021*</td>
<td>1.65 (0.46)</td>
</tr>
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<td></td>
<td></td>
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<td>1.13 (0.35)</td>
</tr>
<tr>
<td>135°</td>
<td>4.812</td>
<td>0.003*</td>
<td>0.94 (0.38)</td>
</tr>
<tr>
<td>180°</td>
<td>1.414</td>
<td>0.24</td>
<td>1.21 (0.35)</td>
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<tr>
<td>225°</td>
<td>2.866</td>
<td>0.038*</td>
<td>1.69 (0.50)</td>
</tr>
<tr>
<td>270°</td>
<td>3.648</td>
<td>0.014*</td>
<td>1.18 (0.42)</td>
</tr>
<tr>
<td>315°</td>
<td>4.996</td>
<td>0.002*</td>
<td>1.23 (0.31)</td>
</tr>
<tr>
<td>Avg.</td>
<td>4.151</td>
<td>0.007*</td>
<td>8.78 (2.66)</td>
</tr>
</tbody>
</table>

Single Leg Dominant Velocity

|          |       |           | BKB | SOC | TEN | XC | BKB | SOC | TEN | XC | BKB | SOC | TEN | SOC v BKB | TEN v BKB | XC v BKB | TEN v SOC | XC v SOC | XC v TEN |
|----------|-------|-----------|     |     |     |    |     |     |     |    |     |     |     |      |      |      |      |      |      |
| 0°       | 0.906 | 0.44      | 8.78 (2.66) | 7.83 (2.26) | 8.43 (2.57) | 8.12 (2.79) | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 |      |      |      |      |      |      |
| 045°     | 0.051 | 0.98      | 7.34 (1.75) | 7.36 (2.11) | 7.24 (2.30) | 7.49 (2.06) | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 |      |      |      |      |      |      |
| 090°     | 0.253 | 0.86      | 6.72 (1.81) | 6.40 (1.88) | 6.41 (2.00) | 6.71 (2.06) | 0.93 | 0.93 | 0.99 | 0.99 | 0.93 | 0.93 |      |      |      |      |      |      |
| 135°     | 0.965 | 0.41      | 6.77 (1.80) | 6.13 (1.65) | 6.61 (1.46) | 6.40 (1.96) | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 |      |      |      |      |      |      |
| 180°     | 0.547 | 0.65      | 8.52 (2.68) | 7.80 (2.34) | 8.32 (2.15) | 8.06 (2.89) | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 |      |      |      |      |      |      |
| 225°     | 0.458 | 0.71      | 8.13 (2.23) | 8.04 (2.43) | 8.81 (3.23) | 8.24 (2.52) | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 |      |      |      |      |      |      |
### Table 1: ANOVA and Pairwise Comparison Significance

<table>
<thead>
<tr>
<th>Outcome</th>
<th>ANOVA</th>
<th>Mean (SD)</th>
<th>Pairwise Comparison Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>p</td>
<td>BKB</td>
</tr>
<tr>
<td>270°</td>
<td>1.381</td>
<td>0.25</td>
<td>6.63</td>
</tr>
<tr>
<td>315°</td>
<td>0.899</td>
<td>0.44</td>
<td>7.59</td>
</tr>
<tr>
<td>Avg.</td>
<td>0.588</td>
<td>0.62</td>
<td>7.56</td>
</tr>
</tbody>
</table>

**Single Leg Non-Dominant Velocity**

<table>
<thead>
<tr>
<th>Direction</th>
<th>ANOVA</th>
<th>Mean (SD)</th>
<th>Pairwise Comparison Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>1.218</td>
<td>0.31</td>
<td>8.31</td>
</tr>
<tr>
<td>045°</td>
<td>1.293</td>
<td>0.28</td>
<td>7.46</td>
</tr>
<tr>
<td>090°</td>
<td>0.804</td>
<td>0.49</td>
<td>6.76</td>
</tr>
<tr>
<td>135°</td>
<td>3.095</td>
<td>0.029*</td>
<td>7.15</td>
</tr>
<tr>
<td>180°</td>
<td>1.656</td>
<td>0.18</td>
<td>8.19</td>
</tr>
<tr>
<td>225°</td>
<td>0.307</td>
<td>0.82</td>
<td>8.01</td>
</tr>
<tr>
<td>270°</td>
<td>1.700</td>
<td>0.17</td>
<td>6.51</td>
</tr>
<tr>
<td>315°</td>
<td>0.700</td>
<td>0.55</td>
<td>7.77</td>
</tr>
<tr>
<td>Avg.</td>
<td>1.457</td>
<td>0.23</td>
<td>7.52</td>
</tr>
</tbody>
</table>

One-way ANOVA models analyzing the effect of sport within each heading. The false discovery rate for pairwise comparisons was controlled using the Benjamini-Hochberg method. BKB = basketball, SOC = soccer, TEN = tennis, XC = cross country.

---

International Journal of Sports Physical Therapy
Greater strength and power of the lower extremity has been shown to correlate with better balance control. This could manifest as decreased COP motion in higher-strength/higher-power sports (e.g., basketball, soccer, tennis), with directional tendencies perhaps indicating sport-specific movement characteristics. The best case for such an argument in this dataset would likely be double leg stance, in which COP displacement and velocity tended to be highest for cross country athletes. Notably, both velocity and displacement in dominant-limb single leg stance appear to tell a contrasting story for cross country. Off-sagittal control of COP in cross country athletes was often good in comparison with other sports (differences non-significant) where it was expected that they would tend to perform comparatively poorly.

With one exception, follow-up models for COP displacement in single leg dominant-limb stance were nonsignificant at the pairwise level. Certain effects likely contributed more than others to the rejection of parallelism in this case. A relatively greater degree of COP motion for basketball in the 270° (posterior) heading, which appears confined to dominant limb displacement, may relate to well-developed plantarflexors and their influence on COP motion in these athletes. COP displacement in basketball is also higher than all other groups in 135° (anteromedial) and the opposing 315° (posterolateral) headings. Interestingly, this pattern is reversed in the perpendicular axis defined by headings 45° (anterolateral) and 225° (posteromedial).

It is not immediately clear why this unique drop in single leg (dominant limb) COP displacement along an anterolateral-to-posteromedial axis would be observed in basketball athletes and not others. The most obvious distinction of basketball performance is the greater involvement of vertical jumping relative to the other sports included in this study. While the dominant limb is defined as the stance limb used when kicking a ball for maximum distance, it is feasible that this definition would correspond with the preferred push-off limb used for unilateral jumping. Therefore, although non-significant, the observed trend may relate to unilateral vertical jump adaptations. It is worth noting that limb dominance does appear to be factor both for COP displacement and velocity. For example, the relative deficits in COP displacement control for basketball in the 90° (anterior) and 270° (posterolateral) headings and the relative advantages in the in 45° (anterolateral) and 225° (posteromedial) headings are far less pronounced for the non-dominant limb.

The potential mechanisms contributing to the present observations include directional strength and power adaptations at the muscular level, along with their corticospinal neural adaptations. In the study sample, subcortical and spinal reflexive loops may be most influential considering the simplicity of the task (i.e., quiet, unperturbed stance). While neural plasticity at these levels has been demonstrated in response to training generally, direct comparisons between sports are again scarce. In the case of differences between soccer and basketball, the observations coincided with a relative increase in high-frequency components of COP motion for soccer, which the authors contend could indicate greater use of somatosensory postural regulation mechanisms. As the competition level increases for multidirectional athletes, there are also tendencies for increased proprioceptive acuity and more efficient use of vestibular information. This might be expected both as a consequence of their training stimulus and from visual resources being allocated elsewhere during play.

Two additional potential mechanisms bear consideration, although based on what is currently known it would be premature to draw strong conclusions regarding their involvement. The first is cutaneous feedback, through which potnet directional effects have been demonstrated. These effects may have analogs which operate at the level of spontaneous COP motion where training or injury affect the intrinsic properties of involved structures. It is not clear whether such training adaptations exist, particularly in relation to shod activities. The second potential mechanism is the muscle synergy, a synchronous muscle activation pattern which theoretically serves to reduce the complexity of motor tasks. Muscle synergies have been temporally linked to specific compound COP motions in voluntary leaning tasks and in reaction to perturbations. This would appear to be a likely contributor to the extent that reactionary postural control behavior overlaps with chronic training-induced, static, unperturbed balance. Current evidence to support a training effect in postural muscle synergies is speculative.

Several limitations should be noted in this study. First, a single, 10-second trial may not be sufficient to create an

Figure 3. Mean COP velocity by sport and directional heading for double leg stance (top panel), single leg stance dominant limb stance (middle panel), and single leg non-dominant limb stance (bottom panel). The horizontal position of each point (and its error bar) is offset slightly for easier visual comparison. Headings may be interpreted as follows. For Double Leg stance, 90° = anterior, 45° = anterior/right, 0° = right, 315° = posterior/right, 270° = posterior, 225° = posterior/left, 180° = left, 135° = anterior/left). For Single Leg stance on either limb, 90° = anterior, 45° = anterolateral, 0° = lateral, 315° = posterolateral, 270° = posterior, 225° = posteromedial, 180° = medial, 135° = anteromedial). BKB = basketball, SOC = soccer, TEN = tennis, XC = cross country.
accurate representation of spontaneous directional COP behavior. Decisions regarding number of trials, trial duration, and forgoing practice were intended to optimize throughput during high-volume testing sessions. Scheduling constraints also precluded controlling for periodization cycles or any variation in training status associated with proximity to competition season. Lastly, it was determined that enrollment was not sufficient to allow for exclusion based on injury history beyond the criteria specified in the methods section.

In summary, directionally-specific spontaneous COP motion appears to be associated with sport type in varsity collegiate athletes. Specialization and training status within this population may suggest that sport-specific adaptations are partially responsible for the observed patterns. These adaptations likely reflect the sensorimotor demands of a given sport, including lower extremity strength and power, proprioceptive acuity, and efficiency of integrating vestibular information.

CONCLUSIONS

The results of the current study indicate that profiles of COP motion in specific headings vary with sport-specialization at the collegiate varsity level. Analysis of directional tendencies in postural control tasks could enhance the scientific and clinical utility of balance assessment in athlete populations. Potential future applications include increasing the specificity of reference norms used where baseline data are unavailable, as well as evaluating training effects that may have direction-specific influences on sway behavior. Additionally, while this manuscript focuses on training adaptations specific to athletes of collegiate sports, comparable COP/COM signatures associated with injury may exist. If injuries have directionally-specific balance effects (or causes), similar analyses could be used to provide information relevant to prevention or treatment in individual clinical cases.

CONFLICT OF INTEREST STATEMENT

The authors have nothing to disclose.

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REFERENCES


International Journal of Sports Physical Therapy
Background
Risk factors for different sports injuries vary between sexes. Deficits in postural stability have been associated with several lower extremity injuries. The purpose of this study was to examine the differences in static postural stability between male and female intercollegiate athletes with and without visual information.

Hypothesis
There will be no difference in visual reliance between sexes during static postural stability.

Study Design
Cross-sectional Study

Methods
Static postural stability was assessed during a single session for football, soccer, basketball, and volleyball intercollegiate athletes (males, n=135, females, n=51) under eyes open (EO) and eyes closed (EC) conditions via performance of single limb stance on a force plate. Ground reaction force component data in all directions were quantified as a unitless composite score (COMP) where lower values indicated better postural stability. The absolute change and percentage change between EO and EC conditions were calculated for each sex. Two-sample Kolmogorov-Smirnov tests were used to compare differences between sexes.

Results
Males had greater EO COMP (males=7.77±3.40; females=6.48±4.61; p=0.038; Cohen’s d=0.343) and EC COMP (males=19.43±8.91; females 14.66±6.65; p=0.001; Cohen’s d=0.571) than females. A significant difference in absolute change from EO to EC was observed between sexes (males=−11.65±7.05; females=−8.18±5.61; p=0.01, Cohen’s d=−0.520) indicating that males had a greater change between conditions for the worse. There was no significant difference in percent change from EO to EC between sexes (males=159.2±90.7; females=156.7±109.2; p=0.39; Cohen’s d=0.026).

Conclusions
The observed differences between males and females in EO COMP, EC COMP, and absolute difference in COMP indicate that there is some factor that causes a difference in static postural stability between sexes. No difference in percent change between groups.
indicates that the difference in static postural stability between sexes may not be due to visual reliance. Female athletes may inherently have better postural stability than males, but both sexes were able to compensate for the loss of visual input.

**Level of Evidence**

3

**INTRODUCTION**

Musculoskeletal injuries are highly prevalent within collegiate athletics and demonstrate both short-term and long-term consequences. Recent data highlight that over one million injuries have occurred in student-athletes over a five-year period across 25 NCAA sports. Injury rates and risk for injury vary based on the sport being played, whether an athlete is at a practice or competition, and the sex of the athlete. In fact, sex differences in injury rates are very common. For example, the anterior cruciate ligament injury rate for intercollegiate female athletes is 2.5 times higher than intercollegiate male athletes for sex-comparable sports, as well as concussion rates being higher in female athletes for sex-comparable sports. Furthermore, research has demonstrated that females have a higher rate of stress fracture than males, and males are at greater risk of an acromioclavicular joint sprain than females. Given the prevalence of sports injuries and the differences between sexes in injury rates, there appears to be a need to develop sex-specific injury prevention programs (IPP). To do so, sex-specific differences in risk factors for injuries must be identified.

Deficits in postural stability have been identified in several studies as a risk factor for lower extremity injuries such as anterior cruciate ligament and ankle injuries. The results of these studies support the need to address postural stability as part of IPP. Previous authors have shown that males demonstrate significantly worse postural stability as compared to females; however, the evidence has not yet identified a clear reason(s) for this difference. Postural stability is a complex process that incorporates input from the visual, somatosensory, and vestibular systems and may also be affected by articular, ligamentous, and muscular structural differences. One potential reason for sex differences in postural stability may be differences in reliance on visual input. If this is true, the differences between males and females could contribute to differences in postural stability and thereby contribute to sex-specific differences in injury rates. The purpose of this study was to examine the differences in static postural stability between male and female intercollegiate athletes with and without visual information. It was hypothesized that there would be no between-sex differences in postural stability between varied conditions of visual input. The outcomes of this study could play a role in the creation of IPP for musculoskeletal injuries, specifically addressing whether postural stability training with altered visual input should be incorporated in sex-specific IPP.

**METHODS**

**PARTICIPANTS**

In this cross-sectional study, all participants were Division I NCAA football, soccer, basketball, and volleyball student-athletes (135 males and 51 females) between the ages of 18 and 25, currently rostered and participating as a varsity level intercollegiate athlete and cleared by medical personnel (certified athletic trainer or team physician) to participate in the study. Subjects were excluded if they were not cleared by medical personnel to participate in full activity, if they had sustained a previous lower extremity surgery, or if they had sustained a lower extremity injury within the prior six months. All participants read and signed an informed consent form approved by the university where the data was collected.

**SINGLE LEG POSTURAL STABILITY ASSESSMENT**

**PROCEDURES**

Participants were tested in their respective athletic training rooms during a single session and were barefoot during testing. Controlled testing conditions included placing the force plate on a hard and level surface, eliminating noise during testing, removing distractions such as any movement of people in the area, and performing identical protocol regardless of physical space. Static postural stability was assessed (1200 Hz) while standing on a single force plate (Kistler 9286A, Kistler Corporation, Amherst, NY, USA) in two conditions: (1) eyes open (EO) and (2) eyes closed (EC). Testing for static postural stability began with participants assuming a single-leg stance on their dominant leg (self-reported preferred kicking foot), hands placed on hips; and with the non-stance leg flexed at the knee and hip in order to bring the foot to the height of the stance leg ankle, this same position was used during both EO and EC tests. For the EO condition, participants focused on a marker located approximately 6.10 m (20 feet) directly in front of the force plate on the wall at the height of the subject. For the EC condition, participants began identical to the EO condition and were directed to close their eyes once they were ready for data collection to begin. The protocol and data processing procedures employed for static postural stability allowed for touchdowns of the non-stance leg on the force plate, but participants were instructed to immediately return their non-stance leg back to the starting position if a touchdown occurred. A trial was discarded if the non-stance leg touched the stance leg or touched down on the ground off the force plate. The mean of three 10-second trials were collected for data analysis following the practice trials which consisted of a minimum of three repetitions but no more than five repetitions. The protocol used in the current study was based on a protocol previously described by

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Table 1. Descriptive data (Mean±SD) for all subjects, male subjects, and female subjects and independent t-test (p-values) between males and females.

<table>
<thead>
<tr>
<th>Variable</th>
<th>All</th>
<th>Males</th>
<th>Females</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>19.5 ± 1.3</td>
<td>19.6 ± 1.3</td>
<td>19.3 ± 1.2</td>
<td>0.103</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>181.6 ± 10.0</td>
<td>184.9 ± 8.4</td>
<td>172.9 ± 8.7</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>79.3 ± 14.6</td>
<td>83.7 ± 13.6</td>
<td>67.6 ± 10.1</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

Goldie et al. with demonstrated reliability and validity.14–16

INSTRUMENTATION

Force plate data were passed through an amplifier and an analog to digital board (DT3010, [Digital Translation, Marlboro, MA, USA]) to a personal computer for additional signal and data processing.

DATA PROCESSING

A MATLAB (v7.0.4; Natick, MA, USA) script file was written to process the data. All force plate data were initially filtered with a dual pass 4th order low pass Butterworth filter with the cutoff frequency set at 20 Hz. The standard deviation of each of the ground reaction force components (anterior-posterior, medial-lateral, and vertical) was calculated during the ten-second trial to derive the variables for statistical analysis which included the standard deviation of the anterior-posterior, medial-lateral, and vertical ground reaction forces.15 Lower values for all variables indicate better scores. For example, if an individual remained absolutely still, all of these variables would be zero. The more movement, the higher the scores. A unitless composite score (COMP) for EO and EC conditions was calculated by summing the standard deviation scores in each direction. The absolute change (EO-EC COMP, mean and standard deviation) was calculated as the difference between EO and EC conditions for each sex. The percent change ((EC-EO)/EO * 100, mean and standard deviation) for each sex was also calculated between EO and EC conditions.

STATISTICAL ANALYSIS

Statistical analysis was completed using STATA (v14.2, College Station, TX, USA). The means and standard deviations of COMP scores were calculated for both males and females under EO and EC conditions. Two-sample Kolmogorov-Smirnov tests of the equality of distributions were performed for each of the postural stability variables since a Shapiro-Wilk test for normality demonstrated that each of the variables were not normally distributed. The level of statistical significance was set at p < 0.05 a priori. Effect sizes (Cohen’s d) and 95% confidence intervals were also calculated.

RESULTS

A demographic breakdown of participants is presented in Table 1, which includes 135 males and 51 female participants. A significant difference was found for both height and weight between sexes. The means and standard deviations of the eyes open composite score (EO COMP), eyes closed composite score (EC COMP), absolute change, and percent change for both males and females are presented in Table 2. The two-sample Kolmogorov-Smirnov tests comparing male and female athletes and effect sizes are also reported in Table 2 for each variable. Male athletes had significantly worse static postural stability COMP scores than female athletes under both EO and EC conditions. The absolute change between EO and EC conditions was significantly different between groups with male athletes demonstrating a significantly greater change in scores (-11.65±7.05) than female athletes (-8.18±5.61; p=0.01, Cohen’s d=−0.520). The percent change from the EO to EC conditions between groups was not significantly different (p=0.39).

DISCUSSION

Females demonstrated significantly better overall single limb postural stability than males for both EO and EC conditions. There was no significant difference between sexes in percent change (from EO to EC conditions), which indicates that the observed difference in postural stability between males and females may not be due to a difference in the use of visual input. The hypothesis that there would be no meaningful between-sex difference in static postural stability in response to changes in visual input was supported. These data indicate that there may be a factor other than the use of visual input that contributes to the difference in static postural stability between males and females such as differences in anthropometric variables (e.g., height, weight), joint laxity, and other unknown factors. The observed differences between males and females may indicate that IPP should be adjusted according to sex to account for these postural stability differences, but it may not be necessary to have sex-specific adjustments in availability of visual cues. It is important to note that postural stability is important for injury prevention in both sexes.5,6 While females have a greater risk for LE injury, some males do remain at risk for lower extremity injury. Given the demonstrated differences between males and females, the results of the current study suggest that individuals designing comprehensive IPP for male athletes may want to consider additional focus/time on postural stability training.17

In order to further investigate differences in postural stability between sexes, the complex nature of postural sta-
Table 2. Eyes open composite, eyes closed composite, absolute change, and percent change scores based on sex.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Males (n = 135)</th>
<th>Females (n = 51)</th>
<th>p-value</th>
<th>Effect size (Cohen’s d)</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Range</td>
<td>Mean ± SD</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>Eyes Open Composite</td>
<td>7.77 ± 3.40</td>
<td>3.28 to 26.20</td>
<td>6.48 ± 4.61</td>
<td>2.96 to 27.77</td>
<td>0.038</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.343</td>
<td></td>
<td>0.018 to 0.666</td>
</tr>
<tr>
<td>Eyes Closed Composite</td>
<td>19.43 ± 8.91</td>
<td>6.49 to 75.52</td>
<td>14.66 ± 6.65</td>
<td>4.72 to 33.53</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.571</td>
<td></td>
<td>0.242 to 0.897</td>
</tr>
<tr>
<td>Absolute Change (EO-EC)</td>
<td>-11.65 ± 7.05</td>
<td>-52.75 to -1.80</td>
<td>-8.18 ± 5.61</td>
<td>-28.98 to 2.21</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.520</td>
<td></td>
<td>-0.846 to -0.193</td>
</tr>
<tr>
<td>Percent Change of EO to EC</td>
<td>159.2 ± 90.7</td>
<td>27.5 to 639.7</td>
<td>156.7 ± 109.2</td>
<td>3.9 to 636.7</td>
<td>0.875</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.026</td>
<td></td>
<td>-0.296 to 0.348</td>
</tr>
</tbody>
</table>

SD: Standard deviation
EO: Eyes open
EC: Eyes closed

The current study has some limitations. First, without testing conditions involving the presence and absence of visual, somatosensory, and vestibular input, the conclusion cannot be drawn that any observed differences were due to only visual cues. Another limitation of this study is that there were unequal groups with males having 135 participants and females having 51 participants. Anthropometric differences between groups were also not taken into consideration and could play a role in postural stability differences as discussed above. Lastly, the study consisted only of intercollegiate athletes with an average age of 19.5 years who played football, soccer, basketball, or volleyball. Therefore, the results of this study cannot be generalized to other age groups, sports, or competition levels.

CONCLUSION

The observed differences between males and females in EO COMP, EC COMP, and absolute difference in COMP indicate that there is some factor that causes a difference in static postural stability between males and females. Postural stability is important for injury prevention in both sexes. The results of the current study suggest that individuals designing comprehensive IPP for males may want to consider additional focus/time on postural stability training as compared to those for females. No observed difference in percent change between groups indicates that the difference in static postural stability between males and females is likely not due to availability of visual information alone. Further research should be performed to determine if it is necessary for sex-specific IPP to address visual input during postural stability exercises. The differences observed between sexes in this study are likely due to some other inherent differences between the two groups included in this study or other factors not tested in the current study.

CONFLICTS OF INTEREST

We have no conflicts of interest to disclose.

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REFERENCES


Original Research

Kinetic Asymmetry During a Repetitive Tuck Jump Task in Athletes with a History of Anterior Cruciate Ligament Reconstruction

Adam W. VanZile, Matthew J. Snyder, Emily A. Watkins, Jithmie Jayawickrema, Tricia L. Widenhoefer, Thomas G. Almonroeder

Optimum Performance Therapy, Department of Sports Medicine, Fort Wayne Orthopedics, Department of Exercise Science, Trine University, Parkview TherapyONE, Physical Therapy Program, Trine University, Department of Health Professions, University of Wisconsin–La Crosse (WI)

Keywords: sports medicine, rehabilitation, plyometrics, force, biomechanics

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Background
Athletes who have undergone anterior cruciate ligament reconstruction typically exhibit relatively high/rapid loading of their uninvolved limb during bilateral landing and jumping (vs. their limb that underwent reconstruction), which may place their uninvolved limb at risk for injury. However, previous studies have only examined forces and loading rates for tasks involving an isolated land-and-jump.

Purpose
The purpose of this study was to examine bilateral landing and jumping kinetics during performance of a repetitive tuck jump task in athletes who had undergone anterior cruciate ligament reconstruction and completed rehabilitation.

Study Design
Cross-sectional study

Methods
Nine athletes (four males, five females) participated in this study. All participants had undergone successful unilateral anterior cruciate ligament reconstruction, had completed post-operative rehabilitation, and were in the process of completing return-to-sport testing. Athletes performed a repetitive tuck jump task for 10 seconds, while ground reaction forces were recorded for their uninvolved and involved limbs via separate force platforms. Two-way analysis of variance, for within-subjects factors of limb and cycle, was performed for the impact forces, loading rates, and propulsive forces from the first five land-and-jump cycles completed.

Results
There was not a limb-by-cycle interaction effect or main effect of cycle for the impact forces, loading rates, or propulsive forces; however, there was a main effect of limb for the impact forces (F(1, 8) = 14.64; p=0.005), loading rates (F(1, 8) = 5.60; p=0.046), and propulsive forces (F(1, 8) = 10.38; p=0.012). Impact forces, loading rates, and propulsive forces were higher for the uninvolved limb, compared to the involved limb, over the five land-and-jump cycles analyzed.

Corresponding author:
Thomas G. Almonroeder, DPT, PhD
Assistant Professor
Department of Health Professions
University of Wisconsin - La Crosse
1300 Badger Street, 54601, La Crosse, WI, USA
E-mail: talmonroeder@uwlaux.edu
Phone: 608-785-8475
Fax: 608-785-8460
Kinetic Asymmetry During a Repetitive Tuck Jump Task in Athletes with a History of Anterior Cruciate Ligament Reconstruction

INTRODUCTION

Anterior cruciate ligament (ACL) tears are common among young athletes who compete in sports that involved frequent landing and jumping, such as basketball. Surgical reconstruction of the ACL is commonly recommended for athletes who plan to resume sports participation. Unfortunately, athletes who have undergone ACL reconstruction are at relatively high risk for sustaining another ACL injury after returning to sport (compared to athletes without a history of ACL injury). In most cases the second ACL injury occurs during the first year following return to sport and involves the athlete’s previously uninjured limb (i.e. contralateral to the limb that underwent ACL reconstruction). It appears there is an urgent need to identify factors that contribute to secondary risk of ACL injury (uninvolved limb) in athletes who return to sport following ACL reconstruction.

Athletes often exhibit inter-limb asymmetries in limb loading during bilateral landing and jumping, even after they have completed rehabilitation and returned to sport. Typically, athletes apply higher and more rapid loads to their uninjured limb during landing and jumping, compared to their ACL-reconstructed limb. For example, Paterno et al. examined vertical ground reaction forces during performance of a drop vertical jump task in a group of 14 athletes who had undergone ACL reconstruction, completed rehabilitation, and been cleared to return to sport by their physician and physical therapist, and found that the athletes in their study demonstrated higher peak vertical ground reaction forces for their uninjured limbs (vs. their involved limbs) during the initial landing phase of the drop vertical jump (impact forces) and immediately prior to takeoff (propulsive forces). In addition, they also demonstrated higher loading rates for their uninjured limbs during landing. These inter-limb kinetic asymmetries may help to explain why ACL injuries are common for the uninjured limb in athletes who have undergone ACL reconstruction, as relatively high/rapid impact forces contribute to a movement pattern that strains the ACL and may increase ACL injury risk.

While previous authors have found that athletes who have undergone ACL reconstruction tend to exhibit higher and more rapid loading of their uninjured limb during bilateral landing and jumping, these studies have only included tasks that involve a single land-and-jump. As a result, it is unclear whether inter-limb asymmetry in limb loading changes as athletes complete multiple land-and-hop cycles. This is important to examine since athletes must often perform a series of landing-and-jumping cycles in short succession during competition. For instance, a basketball player pursuing a rebound may need to land and quickly jump, repeatedly. Athletes also often complete multiple land-and-jump cycles during plyometric training (e.g. repeated tuck jumps). In addition, previous studies have not examined symmetry in foot initial contact timing during performance of a repetitive tuck jump task. Examining foot initial contact timing could provide additional insight, since the limbs are loaded very rapidly during landing, and therefore, even subtle asymmetries in initial contact timing could contribute to an overreliance on one limb for support.

The purpose of this study was to examine bilateral landing and jumping kinetics during performance of a repetitive tuck jump task in athletes who had undergone ACL reconstruction and completed rehabilitation. It was hypothesized that athletes would demonstrate higher impact forces, loading rates, and propulsive forces for their uninjured limb, compared to their involved limb, for each land-and-jump cycle analyzed. No a priori hypotheses were proposed regarding how the degree of inter-limb asymmetry would change as athletes completed successive land-and-jump cycles, since previous studies have not examined changes in limb loading across multiple jump-landings. A secondary purpose of this study was to examine foot initial contact timing during performance of the repetitive tuck jump task, as this could provide additional insight into why athletes who have undergone ACL reconstruction tend to exhibit greater loading of their uninjured limb during landing.

METHODS

Nine athletes (four males, five females) participated in this cross-sectional study. All data were collected during the athlete’s return to sport testing session, which took place at the Academy of Sports and Health Centre (Fort Wayne, IN, USA). Athletes were eligible to participate if they were between 14-25 years of age, had undergone successful unilateral primary ACL reconstruction within the previous 18 months, intended to return to a sport that involved landing/jumping, had completed conventional post-operative rehabilitation, and had been cleared by their physician and physical therapist to resume landing and jumping activities. Athletes who were 14-25 years of age were selected for this study because this appears to be the age range where most ACL injuries occur and the risk of a second ACL injury appears to be particularly high in athletes 25 years of age or younger. Athletes were excluded from participating if they had a history of surgery or significant injury involving their uninjured limb. All athletes had isolated ACL injuries, with no other concomitant injuries. The mean ± standard deviation age, mass, and height of the athletes were 16.9 ± 1.8 years, 70.3 ± 12.4 kg, and 1.8 ± 0.1 m. The median (range) number of days since their ACL reconstruction surgery was 175 days (152-223 days). Six athletes had received bone-patellar tendon-bone autografts and three had received hamstrings tendon autografts. Five athletes reported that they had injured their dominant limb, while
four athletes reported that they had injured their non-dominant limb. For the purpose of this study, the dominant limb was defined as the leg the athletes reported that they would have used to kick a ball for maximal distance prior to their injury. This study protocol was approved by the Institutional Review Board at Lutheran Hospital (Fort Wayne, IN, USA). All athletes provided informed consent/assent prior to enrollment and informed consent was obtained from a parent or guardian for athletes who were younger than 18 years of age.

Athletes completed the Sport and Recreation subscale of the Knee Injury and Osteoarthritis Outcome Score (KOOS) questionnaire prior to testing. The Sport and Recreation subscale of the KOOS asks individuals to rate their perceived level of difficulty with squatting, running, jumping, twisting/pivoting, and kneeling on a Likert scale (none, mild, moderate, severe, extreme) and values are transformed into a percentage where 0% represents extreme difficulty and 100% represents no deficits in knee-related function. The Sport and Recreation subscale of the KOOS has been shown to demonstrate good test-retest reliability in individuals with a history of ACL injury (intraclass correlation coefficient = 0.81) and is responsive to changes in knee-related function following ACL reconstruction. This self-reported measure was recorded in order to describe the athletes’ perceived level of knee-related function.

Next, athletes completed a standardized warm-up that included various landing and jumping tasks. They then completed the repetitive tuck jump task described by Myer et al.16 Athletes started in a standing position with their feet on separate, adjacent force platforms (AccuPower, Advanced Mechanical Technology, Inc., Watertown, MA, USA) (Figure 1). They initiated the tuck jump task by performing a rapid countermovement, jumped vertically bringing their knees upward until their thighs were parallel to the ground (tuck jump), and then landed on both limbs. Upon landing, they immediately performed the next tuck jump as quickly as possible. The athletes continued to perform tuck jumps for 10 seconds. The force platforms simultaneously recorded three-dimensional ground reaction forces at a sampling rate of 600 Hz throughout performance of the repetitive tuck jump task. Athletes were encouraged to focus on jumping vertically during the task so that their feet continued to contact the same force platforms. An investigator monitored the locations of the athletes’ feet during the landings and noted when an athlete’s foot did not appear to land completely within the respective force platform. Each athlete was given a demonstration and performed a limited practice trial prior to testing.

Ground reaction force data were filtered using a 4th order, zero lag, low-pass Butterworth filter with a cutoff frequency of 50 Hz and normalized to body weight (BW). The peak vertical ground reaction forces (impact forces) and loading rates during the initial 25% of stance and the peak vertical ground reaction forces during last 25% of stance (propulsive forces) were identified from the time series associated with each force platform during the first five land-and-jump cycles of the repetitive tuck jump task (Figure 1). All athletes successfully landed with their feet on separate force platforms for the first five land-and-jump cycles. Additional land-and-jump cycles beyond the first five were not examined since many athletes failed to continue to land with their feet on separate force platforms. The stance phase was defined as the total time when the vertical ground reaction force exceeded a threshold of 10 N (i.e. initial contact to takeoff). Loading rates were calculated by dividing the impact forces by the time from initial contact until the impact force (BW/s). Inter-limb symmetry indices were also calculated for the impact forces, loading rates, and propulsive forces for each land-and-jump cycle by dividing the values for the involved limb by those of the uninvolved limb, and multiplying by 100. As a result, inter-limb symmetry index values less than 100% reflect lower or less rapid loading of the involved limb.

In order to examine initial contact timing during the landings, the first frame where the vertical ground reaction force exceeded 10 N (initial contact) and remained greater than 10 N for at least 50 frames was identified. The difference between the initial contact frames for each limb (uninvolved, involved) was then converted to milliseconds (ms) based on the sampling rate of the force platforms. Calculations were performed so that positive values represented earlier initial contact for the uninvolved limb, negative values represented earlier initial contact for the involved limb, and zero values represented simultaneous initial contact. Unfiltered ground reaction force data were used for examining the initial contact timing, since filtering can result in inaccurate temporal events, especially when there is a rapid change in signal amplitude. All data processing was completed using custom MATLAB scripts (MathWorks Inc., Natick, MA, USA).

**STATISTICAL ANALYSIS**

Two-way analysis of variance for within-subjects factors of ‘limb’ (uninvolved, involved) and ‘cycle’ (1st, 2nd, 3rd, 4th, 5th land-and-jump cycle) were performed for the impact forces, loading rates, and propulsive forces. Main effects of limb and cycle were examined when there was not a significant limb-by-cycle interaction effect. A repeated measures analysis of variance, for a within-subjects factor of cycle, was conducted to examine initial contact timing differences among the landings. An alpha of .05 was used for all statistical tests. SPSS software was used for statistical analysis (Version 27; IBM Corp., Armonk, NY, USA). 95% confidence intervals (95% CI) were calculated for the initial contact timing intervals (95% CI) were calculated for the initial contact timing differences.
Table 1. Impact forces, loading rates, and propulsive forces for the uninvolved limb (Uninv) and ACL-reconstructed (involved) limb (ACLR) for the first five land-and-jump cycles of the repetitive tuck jump task.

<table>
<thead>
<tr>
<th></th>
<th>1st Cycle</th>
<th>2nd Cycle</th>
<th>3rd Cycle</th>
<th>4th Cycle</th>
<th>5th Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Uninv</td>
<td>ACLR</td>
<td>Uninv</td>
<td>ACLR</td>
<td>Uninv</td>
</tr>
<tr>
<td>Impact Forces</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(BW)</td>
<td>1.98 ±0.41</td>
<td>1.55 ±0.25</td>
<td>2.17 ±0.63</td>
<td>1.53 ±0.34</td>
<td>2.07 ±0.50</td>
</tr>
<tr>
<td>(BW/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Propulsive Forces</td>
<td>2.01 ±0.72</td>
<td>1.63 ±0.58</td>
<td>2.05 ±0.85</td>
<td>1.63 ±0.62</td>
<td>1.88 ±0.75</td>
</tr>
<tr>
<td>(BW)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean ± standard deviation impact forces, loading rates, and propulsive forces for each landing. Uninv = uninvolved limb; ACLR = ACL-reconstructed (involved) limb; BW = bodyweight; BW/s = bodyweight/second.

Table 2. Impact force, loading rate, and propulsive force inter-limb symmetry indices for the first five land-and-jump cycles of the repetitive tuck jump task.

<table>
<thead>
<tr>
<th></th>
<th>1st Cycle</th>
<th>2nd Cycle</th>
<th>3rd Cycle</th>
<th>4th Cycle</th>
<th>5th Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact Force Inter-Limb Symmetry Index (%)</td>
<td>80.10 ±14.56</td>
<td>76.52 ±28.28</td>
<td>83.60 ±15.89</td>
<td>80.91 ±19.76</td>
<td>86.81 ±11.81</td>
</tr>
<tr>
<td>Loading Rate Inter-Limb Symmetry Index (%)</td>
<td>79.00 ±14.25</td>
<td>79.41 ±36.01</td>
<td>88.96 ±20.70</td>
<td>96.00 ±38.11</td>
<td>93.32 ±25.72</td>
</tr>
<tr>
<td>Propulsive Forces Inter-Limb Symmetry Index (%)</td>
<td>81.60 ±9.40</td>
<td>83.83 ±20.25</td>
<td>94.04 ±24.67</td>
<td>83.91 ±13.77</td>
<td>88.03 ±12.08</td>
</tr>
</tbody>
</table>

Mean ± standard deviation impact force, loading rate, and propulsive force inter-limb symmetry indices for each land-and-jump cycle analyzed. Symmetry index values less than 100% reflect higher or more rapid loading of the uninvolved limb, compared to the involved limb.

Table 3. Initial contact timing differences for the first five landings of the repetitive tuck jump task.

<table>
<thead>
<tr>
<th></th>
<th>1st Cycle</th>
<th>2nd Cycle</th>
<th>3rd Cycle</th>
<th>4th Cycle</th>
<th>5th Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (ms)</td>
<td>4.4 ± 7.5 (-1.4, 10.2)</td>
<td>5.0 ± 12.1 (-4.3, 14.3)</td>
<td>6.5 ± 14.2 (-4.4, 17.4)</td>
<td>6.1 ± 16.0 (-6.2, 18.4)</td>
<td>5.6 ± 14.7 (-5.7, 16.9)</td>
</tr>
</tbody>
</table>

Mean ± standard deviation and 95% confidence interval (lower bound, upper bound) for the initial contact timing differences for each landing analyzed. Positive values indicate that the uninvolved limb made contact prior to the involved limb. ms = milliseconds.

RESULTS

The mean (range) score on the Sport and Recreation subscale of the KOOS questionnaire was 90.0% (80-100%).

For the impact forces, there was not a limb-by-cycle interaction effect (F(4, 32) = 1.14; p=0.355) or main effect of cycle (F(4, 32) = 0.45; p=0.770); however, there was a main effect of limb (F(1, 8) = 14.64; p=0.005). Impact forces were higher for the uninvolved limb across all five landings analyzed (Tables 1 & 2).

For the loading rates, there was not a limb-by-cycle interaction effect (F(4, 32) = 1.02; p=0.412) or main effect of cycle (F(4, 32) = 0.35; p=0.839); however, there was a main effect of limb (F(1, 8) = 10.38; p=0.012). Loading rates were higher for the uninvolved limb across all five land-and-jump cycles analyzed (Tables 1 & 2).

The repeated measures analysis of variance indicated that there was no difference in initial contact timing among the five landings (F(4, 32) = 0.062; p=0.993) (Table 3).
DISCUSSION

The primary purpose of this study was to examine bilateral landing and jumping kinetics during performance of a repetitive tuck jump task in athletes who had undergone ACL reconstruction and completed rehabilitation. As hypothesized, athletes demonstrated higher impact forces, loading rates, and propulsive forces for their uninjured limb, compared to their involved limb, for each land-and-jump cycle analyzed (main effects of limb). The degree of inter-limb kinetic asymmetry did not change significantly across the five land-and-jump cycles (no limb-by-cycle interaction effects). As a result, it appears that the athletes maintained a fairly consistent level of inter-limb kinetic asymmetry when performing the repetitive tuck jump task. The results of this study build on those of earlier studies5-11 that have identified persistent inter-limb kinetic asymmetry during performance of tasks involving a single land-and-jump in athletes who have undergone ACL reconstruction and may help to explain why ACL injuries are common for the uninjured limb in athletes who return to sport following ACL reconstruction.

The athletes in this study exhibited inter-limb impact force differences ranging from 14.6-34.7% for the five successive land-and-jump cycles analyzed. In each instance, impact forces were greater for the uninjured limb. This finding that athletes tend to offload their involved limb is consistent with previous studies that have examined isolated, double-leg landings in athletes post-ACL reconstruction.5-11 Inter-limb symmetry in loading rates and propulsive forces have been less frequently examined in athletes who have undergone ACL reconstruction. However, Paterno et al.7 reported that loading rates during the landing phase of a drop vertical jump were 45.4% higher for the uninjured limb, compared to the involved limb, in a group of athletes who had undergone ACL reconstruction and been cleared to return to sport. In addition, they also reported that propulsive forces were 16.7% higher for the uninjured limb. In general, there appears to be agreement among studies that the uninjured limb tends to experience higher and more rapid loading following ACL reconstruction, during both single (previous studies)5-11 and multiple jump land-and-jump cycles (the current study). This shift in loading toward the uninjured limb likely places greater demands on the uninjured knee, as asymmetries in ground reaction forces appear to correlate with asymmetries in knee loading.22,23 In addition, previous studies have also found that athletes who have undergone ACL reconstruction demonstrate greater knee loading (e.g. increased knee extension moments) for their uninjured limb during bilateral landing and jumping.5,10,11 These persistent kinetic asymmetries may increase risk of a secondary ACL injury and/or contribute to knee degenerative changes.11,25,26 As a result, there appears to be a need to explore novel rehabilitation approaches that could potentially more effectively target these persistent kinetic asymmetries. For instance, providing visual feedback related to side-to-side differences in limb loading during movement performance may be particularly effective for promoting inter-limb kinetic symmetry and minimizing maladaptive changes in an athlete’s movement pattern following ACL reconstruction. It is also important to continue to examine factors that contribute to inter-limb kinetic asymmetry following ACL reconstruction (e.g. fear of re-injury, strength deficits, motor pattern adaptations)10,28,29.

Although not the primary purpose of this study, it is interesting that athletes tended to make earlier initial contact with their uninjured limb during landing (based on the sign of the average initial contact timing differences). While it should be noted that the 95% CIs all included zero, on average, initial contact occurred 4.4-6.5 ms earlier for the uninjured limb across the five landings analyzed. Ford et al.19 examined initial contact limb preference during the initial landing phase of a drop vertical jump in 101 athletes who had undergone ACL reconstruction and found that 71.3% made initial contact first with their uninjured limb. It appears that athletes who have undergone ACL reconstruction have a tendency to make initial contact with their uninjured limb, prior to their involved limb, upon landing. Perhaps this reflects a movement strategy to reduce loading of the involved limb during bilateral landings.

The repetitive tuck jump task is a common plyometric training exercise for athletes.15 The results of this study indicate that athletes who have undergone ACL reconstruction may consistently offload their involved limb when performing repeated tuck jumps. Physical therapists, athletic trainers, and strength and conditioning coaches should consider this when prescribing the repetitive tuck jump task for athletes with a history of ACL reconstruction, as consistently offloading the involved limb and placing greater loads on the uninjured limb may contribute to the development, or further development, of inter-limb neuromuscular asymmetries.

Although the findings from this study make a valuable contribution to an important body of literature, the study limitations need to be acknowledged. First, only the initial five land-and-jump cycles of the repetitive tuck jump task were examined; inter-limb symmetry could change as athletes complete additional cycles. In addition, the tuck jump task may not reflect the type of repetitive landing and jumping routinely performed in sports such as basketball. In-shoe kinetic sensors30 and inertial measurement units31 offer opportunities to examine inter-limb kinetic symmetry during landing and jumping under more game-like conditions. This study also did not include a comparison group of uninjured athletes. However, previous studies have already determined that athletes who have undergone ACL reconstruction demonstrate greater inter-limb kinetic asymmetry compared to athletes without a history of ACL reconstruction.

CONCLUSION

During performance of a repetitive tuck jump task, athletes who had undergone ACL reconstruction applied higher and more rapid loads to their uninjured limb, compared to their involved limb. They also exhibited a tendency to make initial foot contact first with their uninjured limb during landing. These inter-limb asymmetries may help to explain why athletes often sustain ACL injuries involving their previously uninjured limb upon returning to sport following ACL reconstruction.
CONFLICTS OF INTEREST
The authors have no conflicts of interest to disclose.

DISCLOSURE
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REFERENCES


Original Research

The Landing Error Scoring System (LESS) and Lower Limb Power Profiles in Elite Rugby Union Players

Stephen Rowell, MSc 1, Nicola Relph, PhD 2

1 Institute of Health, University of Cumbria, 2 Health, Social Care & Medicine, Edge Hill University

Keywords: landing, performance, rugby, movement system

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Background
The Landing Error Scoring System (LESS) is a clinical test that assesses landing biomechanics during a drop-jump task. Performance measures such as jump height, power, contact time and reactive strength index are used commonly in athletic populations. Comparing results from the LESS against these performance measures has not been reported in elite rugby union.

Purpose
To report i.) normative LESS scores for elite rugby union players ii.) correlations between LESS scores and performance measures and iii.) differences in performance measures between LESS scoring groups. A secondary purpose was to report the intra- and inter-rater reliability of the LESS test when used in elite rugby union players.

Study Design
Cross-sectional design.

Methods
Thirty-six male, elite rugby union players participated. Each participant completed three trials of the LESS and performance measures were recorded concurrently using the Optojump™. LESS trials were scored independently by the authors. Statistical analyses were used to confirm reliability, data normality, and between group differences (p<0.05).

Results
The LESS test is a reliable testing tool in elite rugby union players (excellent intra- (ICC=0.96) and inter-rater (ICC=0.94) reliability). One player demonstrated an excellent LESS score, six players had good scores, eight players moderate scores and the majority of the group, 21 players, scored poorly. LESS scores were correlated to contact time (r = -0.461, p = 0.005) only. Participants with moderate to poor LESS scores (a score ≤5) produced greater power (p=0.056, η² = 0.139), contact time (p=0.002, η² = 0.268) and reactive strength index (p=0.016, η² = 0.180). There were no differences in jump height (p=0.842) between players scoring excellent to good and moderate to poor.

Conclusion
The results of the current study demonstrate excellent intra- and inter-rater reliability for the LESS, supporting its use as a clinical assessment tool in elite rugby union players. The majority of players presented with moderate to poor LESS scores, indicating an area of concern in this population. Participants scoring moderate to poor in the LESS recorded significantly higher power and reactive strength index, increased contact time but not...
Jump height. This suggests participants with high-risk landing biomechanics may also produce higher performance measures, but these do not necessarily result in an improved jump height.

INTRODUCTION

Injury surveillance data demonstrates that elite rugby union has a high lower-limb injury occurrence, with an incidence rate of 41.1 injuries per 1000 player-hours in match situations. Furthermore, data from the 2015 Rugby World Cup indicates that at the international level, knee ligament injuries are responsible for causing the greatest time loss at almost 30% of the total days lost due to injury. Domestically, injury surveillance of the English Premiership indicates that knee injuries also accounted for the highest number of days lost. While the total number of knee injuries sustained reported by English Premiership teams has not changed significantly over recent years, there has been an increase in the incidence of severe knee injury. Furthermore, the knee joint has been classified as an area at high risk of injury across all playing positions in professional rugby union.

Damage to the anterior cruciate ligament (ACL) is a severe knee injury which is relatively common in athletic populations. Professional rugby players may be at risk of 1.26 ACL injuries for every 1000 players-hours of match play and absence caused from this injury is on average 261 days. The most common non-contact mechanisms of this injury in professional rugby union are side-stepping, landing, stopping, passing, and running. ACL injuries frequently require surgical reconstruction, a lengthy period of rehabilitation, and have potential long-term consequences for the individual. Post ACL reconstruction, individuals are more likely to demonstrate high risk landing mechanics associated with elevated future ACL injury risk compared to a normal population. In elite sport, these injuries can negatively impact upon a team’s success, highlighting the need for appropriate strategies to reduce injury risk in this population. Despite ACL injuries being serious and relatively common in rugby, there is a lack of research in the area specific to elite rugby union.

It is important to understand injury mechanisms and also identify risk factors to inform prevention strategies. A recent systematic evaluation of tools which assess risk factors for ACL injury in a clinical setting emphasised that while laboratory-based measures are accurate, they often are not practically applicable. Measures relating to neuromuscular control have been identified as modifiable risk factors for ACL injury and interventions related to neuromuscular training have proven to reduce ACL injury risk. While successful, results of these interventions are affected by poor compliance in athletic populations. It has also been suggested that identification of individuals at high-risk of injury may be important in improving the adherence to risk reduction programs.

The Landing Error Scoring System (LESS) is a clinical test that assesses landing biomechanics during a jump-landing task in order to assess the risk of ACL injury. The LESS requires minimal and inexpensive equipment in comparison to laboratory-based biomechanical measures; while offering good inter- and intra-rater reliability and concurrent validity against laboratory based three-dimensional analysis. However, there is a lack of population specific data available for elite rugby union players, and hence further research has been advised.

Measures of performance in jumping tasks can also be used as markers of athletic ability in sporting populations. Information on power (P) and jump height (JH) are outcome measures which are regularly used in practice. More recently, reactive strength index (RSI), calculated as JH divided by contact time with the ground (CT), has been measured in evaluation of athletes. These measures provide information on the capacity of an athlete’s stretch-shortening cycle and are related to athletic performance and monitoring of neuromuscular fatigue. A shorter contact time improves power output in this test. Measurement of these parameters is now more accessible in practical settings with systems such as the Optojump™, a relatively inexpensive, portable system that offers data of comparable quality to laboratory-based measurements. However, as with the LESS test, published data on these measures are lacking in elite rugby union populations.

An ACL injury to a professional rugby player can be career threatening and unfortunately is relatively common in the game. Therefore, it is imperative that risk factors are identified in this population and linked to performance measures for targeted prevention programs. The purpose of this study was to report i) normative LESS scores for elite rugby union players; ii) correlations between LESS scores and performance measures and iii) differences in performance measures between LESS scoring groups. A secondary purpose was to report the intra- and inter-rater reliability of the LESS test when used in elite rugby union players.

MATERIALS AND METHOD

PARTICIPANTS

Thirty-six elite rugby union players participated in the study (age 24.9±4.63 years; height 184.6±7.54 cm, mass 105.9±14.84 kg). All participants were members of a squad playing in the Premier division of rugby union in England. The Club’s medical team approved the participation of all players, who were all uninjured. Informed consent was obtained from each participant, and they were advised of their right to withdraw from the study at any time.

PROCEDURES

All procedures were approved by the University of Cumbria Ethics Review Board (Reference: 15/55). Height in centimetres (cm), weight in kilograms (kg), date of birth, playing position and lower limb dominance was recorded for each participant. A standardized warm up protocol was used for each participant which consisted of a self-paced five-minute jog, 10 body weight squats, 10 body weight lunges and 10 body weight push-ups. Each participant then performed the LESS.
LESS PROCEDURE

Testing procedure for the LESS was taken from previous work.22 Participants started the LESS standing on top of a 30 cm high box and were asked to jump forwards a distance equal to half of their height (indicated by a line on the floor), immediately upon landing they were required to perform a maximal vertical jump (Figure 1). Participants were provided with a verbal explanation and visual demonstration prior to testing; they were also permitted practice trials until comfortable with the procedure. Each participant completed three trials of the LESS and the average taken for analysis.

Each LESS trial was recorded from frontal and sagittal planes with video cameras (HX-WA30, Panasonic Corporation, Osaka, Japan) located 156 inches from the landing area, with the lens of each camera set at a height of 48 inches (Figure 2). Simultaneously, measurements of P (Watts/kg), JH (cm), CT (seconds) and RSI (m/s) were recorded using the OptojumpTM optical measurement system (Microgate, Bolzano, Italy). Each LESS trial was analyzed using the scoring criteria22 which can be seen in Appendix 1. On the basis of their LESS score, participants were individually divided into the following groups: excellent (LESS score, <4), good (LESS score, 4-5), moderate (LESS score, 5-6) and poor (LESS score, >6) jump landing mechanics.22

STATISTICAL ANALYSIS

All statistical analyses were completed in SPSS (Version 22, IBM Corporation, New York, USA). Intra- and inter-rater reliability of the LESS scoring procedure was confirmed using intra-class correlation coefficients (ICC 2, 1), 95% Confidence Intervals and Cronbach’s α.29,30 A randomly selected data set of 32 LESS trials was analysed by two independent researchers; the ICC value between the researchers was 0.94 and 95% confidence intervals ranged from 0.89-0.97. The Cronbach’s α value was 0.97. One researcher repeated the analysis of the randomly selected data set of 32 trials; the ICC value within the researcher was 0.96 and 95% confidence intervals ranged from 0.92-0.98. The Cronbach’s α value was 0.98. ICC results greater than 0.75 are excellent, between 0.40-0.75 are modest and less than 0.40 are poor.31 Therefore, it can be confirmed that the intra-rater and inter-rater reliability of the LESS analysis technique was at an acceptable level in this study and can be used reliably in elite rugby union players.29,31

The Kolmogorov-Smirnov test was used to confirm normality of the data. Significant correlations between LESS scores and lower limb performance data were tested using a Spearman’s rho analysis with significance levels set at p < 0.05. Differences between excellent – good LESS scores (≤ 5) and moderate – poor LESS scores (> 5) for all testing data were analysed using a multi-variate ANOVA with significance set at p <0.05. Effect sizes were reported as partial eta-squared (η²) and were interpreted using Cohen’s (1992) classifications as follows; 0 – 0.1 is a small effect, 0.1-0.5 is a small to medium effect, 0.5-0.7 is a medium to large effect and 0.5 and above is a large effect.

RESULTS

Table 1 presents individual results for each player. The overall mean LESS score for all players was 7.039 (± 2.378), a poor LESS score.22 Figure 3 provides a breakdown of the LESS scores in the four LESS score groups.22 Table 2 details lower limb performance data in the two LESS groups; excellent – good and moderate – poor LESS scores. LESS score significantly correlated to only one of the
lower limb performance tests conducted in this study; this was contact time of the LESS test \( (r = -0.461, p = 0.005) \). However, when the participants were divided into excellent to good LESS scores \((\leq 5) \) \( (n = 7) \) and moderate to poor LESS scores \((> 5) \) \( (n = 29) \), to allow for lower samples sizes in the excellent scoring group, there were significant differences in performance. Participants with LESS scores \( > 5 \) produced significantly greater power \((\text{mean difference} = 8.45\text{W/kg}, p = 0.036, \eta^2 = 0.139)\), lower contact time \((\text{mean difference} = 0.1\text{s}, p = 0.002, \eta^2 = 0.268)\) and greater reactive strength index \((\text{mean difference} = 0.46\text{m/s}, p = 0.016, \eta^2 = 0.180)\) compared to the participants with LESS scores \( \leq 5 \) during the LESS testing procedure. No significant differences were found between participants with excellent to good and moderate to poor LESS scores in the performance parameter of JH \( (p = 0.842) \). There was also no significant correlation between body mass and LESS score \( (p = 0.932) \).

**DISCUSSION**

The purpose of this study was to report i.) normative LESS scores for elite rugby union players ii.) correlations between
LESS scores and performance measures and iii.) differences in performance measures between LESS scoring groups. A secondary purpose was to report the intra- and inter-rater reliability of the LESS test when used in elite rugby union players.

Results from the current study are in agreement with previous work in reporting excellent intra and inter-rater reliability for the LESS scoring procedure. In light of this, the current results support the use of the LESS for assessment of landing mechanics in elite level rugby union players. There is evidence that the LESS is able to identify individuals at risk of sustaining ACL injury in elite-youth soccer players. While the current results were not used to attempt to identify individuals at risk, the proportion of elite rugby union players presenting with scores ranked as moderate-poor (81%), suggests further investigation is warranted in this population.

Interestingly, results demonstrated that participants recording moderate-poor LESS scores recorded significantly higher P, and RSI but longer CT and lower JH when compared to those scoring excellent-good in the LESS test. Participants are advised to jump as high as possible when performing the LESS. It is not known if higher risk mechanisms which were displayed by these participants (such as increased power) occur during an attempt to improve performance measures or due to an inability to perform what are considered more optimal landing biomechanics when performing a maximal drop jump. Furthermore, it is not known where the higher performance measures are derived from in the moderate-poor LESS group; whether they are being created through the active neuromuscular system or through the loading of passive structures through the observed biomechanics. It is important to note that low effect sizes reported indicate that the magnitude and hence meaningfulness of these findings may be limited. These results suggest that future research should consider concurrent measurement of these performance markers alongside the LESS to develop a greater understanding of this relationship.

There was no significant relationship between body mass and LESS scores. This is an unexpected finding as it is perhaps logical to assume that heavier players would use differing biomechanics than lighter players. However, this finding may be due to the limited sample size and should be considered by researchers in the future.

Neuromuscular training is known to improve neuromuscular control and reduce ACL injury risk, although practical application has proven problematic. Whether improvements in neuromuscular control would affect performance measures, such as those measured in the current study, is not known. The lack of significant difference in JH in participants with moderate-low LESS scores compared with significant differences in P, CT and RSI may suggest that high risk landing biomechanics can translate to potential performance decrements; an area which has not yet been investigated with this clinical tool.

Recently it has been suggested that the goal of predicting injury risk through the use of a specific test is unlikely to be sufficiently successful, however, may offer an insight into factors related to the injury process. In elite rugby union players the mechanism of injury for the ACL has been reported to occur more commonly during episodes of contact, in contrast to non-contact sports where non-contact mechanisms (such as jumping/landing) are more regularly observed. While this may be the case, the present study highlights the need for further investigation into the relationship between landing biomechanics and performance measures. This may be more clinically feasible in an elite rugby union setting, where player management is multi-disciplinary in nature.

While not measured in this study, distinct biomechanical differences have been identified when comparing single- and double-leg landings and suggest that clinical assessments such as the LESS should reflect this when assessing lower limb landing biomechanics. Injury data supports this view and highlights that most commonly the mechanism of ACL injuries occurs in a single-leg position. Further development and investigation of the LESS to incorporate a single-leg landing assessment may be beneficial in improving the quality of results obtained for this clinical test.

CONCLUSION

The results of the current research indicate that a large percentage of elite rugby union players recorded poor results for the LESS. Participants recording moderate-poor LESS produced significantly greater measures of P, CT and RSI during their drop-jump performance, while JH was not significantly different compared to those scoring good-excellent in the LESS. Reliability of the LESS as a clinical tool is further supported. The authors suggest that further inves-

### Table 2. Lower limb performance test data (means ± SD displayed).

<table>
<thead>
<tr>
<th>Lower Limb Test</th>
<th>Excellent to Good LESS Score Group</th>
<th>Moderate to Poor LESS Score Group</th>
<th>p value</th>
<th>$n^2$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jump Height (cm)</td>
<td>45.0 ± 6.12</td>
<td>45.8 ± 8.52</td>
<td>0.842</td>
<td>0.001</td>
</tr>
<tr>
<td>Power (W/kg)</td>
<td>37.0 ± 5.43</td>
<td>45.4 ± 8.98</td>
<td>0.036*</td>
<td>0.139</td>
</tr>
<tr>
<td>Contact Time (s)</td>
<td>0.40 ± 0.069</td>
<td>0.30 ± 0.068</td>
<td>0.002†</td>
<td>0.268</td>
</tr>
<tr>
<td>Reactive Strength Index (m/s)</td>
<td>1.14 ± 0.246</td>
<td>1.60 ± 0.418</td>
<td>0.016*</td>
<td>0.180</td>
</tr>
</tbody>
</table>

*Significant difference between the two LESS groups at p < 0.05 level.
†Significant difference between the two LESS groups at p < 0.01 level.
tigation of the utility of the LESS in an elite rugby environment is warranted given results from the current research, scarcity of other data, and significance of knee injury in the sport.
REFERENCES


International Journal of Sports Physical Therapy
SUPPLEMENTARY MATERIALS

Appendix 1

Original Research

Utilizing Hip Abduction Strength to Body-Weight Ratios in Return to Sport Decision-Making After ACL Reconstruction

Steven Higbie, PT, DPT, SCS, CSCS, Jacquelyn Kleihege, PT, SCS, Brian Duncan, PT, DPT, SCS, OCS, FAAOMPT, Walter R. Lowe, MD, Brian Y. Cho, PT, SCS, OCS, FAAOMPT

Sports Medicine and Rehabilitation, Memorial Hermann Ironman Sports Medicine Institute, Orthopaedic Surgery, McGovern Medical School at UT Health

Keywords: strength ratio, return to sport, hip abduction strength, acl injury

Background

Despite the association between hip abduction weakness and non-contact anterior cruciate ligament (ACL) injury, hip abduction strength is rarely considered in return to sport decision-making following ACL reconstruction (ACLR).

Hypothesis/Purpose

The purpose of this study was to compare self-reported function, objective functional test performance, and re-injury rates in patients with high (≥33%) versus low (<33%) isometric hip abduction strength to body weight (BW) ratios when returning to activity following ACLR.

Study Design

Cohort study

Methods

Data were gathered from a single-surgeon database and included baseline demographics. Clinical outcomes were assessed at the time of release to activity and included self-reported outcomes and a functional testing battery. Isometric hip abduction strength was obtained using a handheld dynamometer. Groups were dichotomized into those with low vs high strength to BW ratios. Two-year follow-up was performed using the single assessment numeric evaluation (SANE). Data were analyzed using univariate general linear models with an alpha level of .05.

Results

Of the 528 enrolled patients, 364 (68.9%) demonstrated a low strength to BW ratio. Baseline comparisons revealed more females and higher BMI (P <.05) in the <33% group. At release to activity, the <33% BW group demonstrated lower International Knee Documentation Committee survey scores (88.2 ± 13.6 vs 93.5 ± 10.3, P<.01), ACL-Return to Sport After Injury (76.2 ± 15.4 vs 88.5 ± 16.9, P<.01) scores, and isokinetic hamstring peak torque (P=.04). At 2-years, the <33% group reported lower SANE scores (83.3 ± 21.1 vs 92.83 ± 11.4, P=.05) with no significant differences in re-injuries.

Conclusion

Patients with low hip abduction strength to BW ratios demonstrated lower subjective function, psychological readiness, and isokinetic hamstring peak torque when completing functional testing following ACLR. Subjective deficits remained at 2-years.

Level of Evidence

Level 3

Corresponding author: Steven Higbie, PT, DPT, SCS, Memorial Hermann Ironman Sports Medicine Institute, Department of Sports Medicine & Rehabilitation, Houston, TX, 77030, USA. Steven.higbie@memorialhermann.org
Utilizing Hip Abduction Strength to Body-Weight Ratios in Return to Sport Decision-Making After ACL Reconstruction

Key Terms
ACL injury, hip abduction strength, return to sport, strength ratio

Clinical Relevance
Assessing isometric hip abduction strength to body weight ratio may be beneficial in determining readiness to return to sport following ACL reconstruction.

What is Known About the Subject
Three prospective studies have provided conflicting evidence regarding the relationship between hip abduction strength and ACL injury. A clinical cut-point of hip abduction strength:BW ratio >55.4% has been suggested to identify athletes at risk of sustaining a non-contact ACL injury. To our knowledge no studies have examined isometric hip abduction strength:BW ratios in athletes attempting to return to sport following ACLR.

What This Study Adds to Existing Knowledge
This study examines the potential for hip abduction strength:BW ratio to be included as an additional metric in return to sport testing batteries.

INTRODUCTION
Non-contact injury mechanisms are responsible for approximately 70% of anterior cruciate ligament (ACL) ruptures. Several biomechanical and neuromuscular factors have been identified as risk factors for non-contact injuries, with prevention strategies often targeted at reducing dynamic knee valgus. Hip abductor strength may assist in controlling dynamic knee valgus by reducing hip adduction and internal rotation associated with dynamic knee valgus. Strengthening programs targeting the hip abductors are frequently included following ACL reconstruction (ACLR) to assist in normalizing lower-extremity strength and facilitating normal trunk, hip, and knee mechanics when returning to sport. However, despite the supporting evidence, few studies have included hip abduction strength as a functional criterion when determining readiness for return to sport.

Perhaps the omission of hip abduction strength from return-to-sport decision-making may be due to the inconsistencies found within the current literature and heterogeneity in testing procedures. Specifically, three prospective studies have provided conflicting evidence regarding the role of hip abduction strength in identifying athletes at risk for non-contact ACL injury. An investigation of 867 elite Norwegian female athletes demonstrated no association between hip abduction strength and ACL injury. In contrast, an additional study suggested increased hip abduction strength was an independent risk factor for non-contact ACL injury in female Japanese high school basketball athletes. The authors suggested that athletes with greater hip abduction strength may be predisposed to move into hip adduction in an attempt to counterbalance, highlighting the lack of consistent findings with regard to this clinical measure. Khayambashi et al. identified hip abduction weakness as an independent predictor of non-contact ACL injuries. In a study of 501 athletes, hip abduction weakness was significantly associated with ACL injury and explained 10.2% of the variation in injury status. A clinical threshold of hip abduction strength < 35.4% of body weight (BW) was reported to identify athletes at risk for future non-contact injury. The authors suggested using this hip abduction strength to BW ratio (sensitivity 0.87, specificity 0.65) to assist in screening for ACL injury risk.

Despite the potential link between hip abduction strength and ACL injury, little evidence exists regarding the inclusion of hip abduction strength in return to sport assessments. A recent systematic review of 209 studies identified only 86 studies utilizing strength measures as return to sport criteria, with minimal reporting of hip abduction strength. Several case-control and cross-sectional studies have compared hip abduction strength between healthy controls and ACLR patients who had already returned to sport, though none utilized hip abduction strength as a return to sport decision-making tool. To our knowledge, no studies have assessed the relationship between isometric hip abduction strength on a combined subjective and objective functional testing battery at time to return to sport. Further, no studies have examined if meeting a suggested hip abduction strength to body weight (BW) ratio is associated with improved outcomes following ACLR. Therefore, the purpose of this study was to compare self-reported function, objective functional test performance, and re-injury rates in patients with high (>33%) versus low (<33%) isometric hip abduction strength to BW ratios when returning to activity following ACLR. The authors hypothesized that individuals demonstrating hip abduction strength >33% BW would perform better on self-reported outcomes, demonstrate superior objective functional testing performance, and demonstrate a lower re-injury rate when compared to those who exhibited lower strength ratios.

METHODS
A retrospective comparison study was conducted in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines using a single surgeon (WRL) database of 829 patients who underwent ACLR from 2017-2019. All participants provided verbal and written consent. This study was approved by the University of Texas Health Sciences Center Institutional Review Board (HSC-MH-14-0734) and registered with Clinicaltrials.gov (NCT05704376). The study inclusion criteria were patients who underwent ACLR, completed hip abduc-
tion strength testing and functional testing at time of release to activity, and completed follow-up surveys at two years post-surgery. Patients were excluded if they had orthopaedic conditions or medical complications preventing them from performing standard post-operative rehabilitation (fracture or deep vein thrombosis) or if they did not intend to return to sports participation. A total of 829 patients were reviewed in the database with 528 patients meeting inclusion criteria.

HIP STRENGTH-TO-BODYWEIGHT RATIOS

Bilateral isometric hip abduction strength testing was performed with the patient in supine and the hip in ten degrees of abduction (Figure 1). The testing leg was secured to the table with a belt placed proximal to the lateral femoral condyle. A HOGGAN microfet-2 handheld dynamometer (Hoggan Scientific, 3653 W. 1987 S., Salt Lake City, UT, USA) was secured between the belt and the testing leg. The patient was instructed to perform a maximum hip abduction contraction into the fixed resistance of the belt and examiner (make test) for 5 seconds. Standard verbal cueing instructions were used to minimize compensatory strategies. Three trials were completed and then averaged with the force being recorded in pounds. All testers completed reliability training and demonstrated excellent reliability with intraclass correlation coefficients ranging from 0.921-0.927 (P < .01). Patients were dichotomized into two groups for analysis: those demonstrating <33% hip abduction strength to BW ratio (low strength) and those >33% (high strength). The cut-off of >33% BW was used instead of the previously referenced 35.4% as it seemed more practical for clinical use. Specifically, >33% BW may provide a notable threshold to aid in guiding clinical decision and counseling patient readiness to return to sport with the sports medicine team.

DATA COLLECTION

Baseline patient demographic characteristics were obtained for age, gender, height, weight, body mass index (BMI), and preinjury activity level via the Marx activity score. Subjective function at time of activity to be assessed was compared using an independent Student t-test. An a priori alpha of .05 was considered to be statistically significant for between groups’ comparisons. All statistical analyses were performed using IBM SPSS Statistics (version 24, Armonk NY, USA) statistical software.

STATISTICAL ANALYSIS

Baseline patient demographic and surgical (graft type, use of platelet-rich-plasma (PRP) or bone marrow aspiration (BMA), and type of rehabilitation protocol (accelerated or delayed). All patients followed a standardized accelerated or delayed rehabilitation protocol based on physician judgement at time of surgery. Patients in the delayed protocol group had protected weight-bearing and knee flexion ROM for the first four weeks following surgery. Two-year follow-up data was collected via electronic survey and included the Single Assessment Numeric Evaluation (SANE), current level of sport participation, and re-injury status.

RESULTS

Of the 528 patients enrolled in the study, 364 (68.9%) had a ratio of <33% hip abduction strength to BW, and 164...
Table 1. Patient Demographics

<table>
<thead>
<tr>
<th></th>
<th>Low Strength (n=364)</th>
<th>High Strength (n=164)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>25.59 ± 12.36</td>
<td>22.84 ± 9.99</td>
<td>.031*</td>
</tr>
<tr>
<td>Gender (% male)</td>
<td>189 (51.9%)</td>
<td>103 (62.8%)</td>
<td>.036*</td>
</tr>
<tr>
<td>Height (inches)</td>
<td>68.03 ± 4.61</td>
<td>68.55 ± 4.10</td>
<td>.289</td>
</tr>
<tr>
<td>Weight (pounds)</td>
<td>172.61 ± 45.12</td>
<td>157.35 ± 30.91</td>
<td>.001*</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>26.03 ± 5.12</td>
<td>23.47 ± 3.45</td>
<td>.000*</td>
</tr>
<tr>
<td>MARX Score (0-16)</td>
<td>9.10 ± 5.48</td>
<td>10.39 ± 5.35</td>
<td>.347</td>
</tr>
</tbody>
</table>

Values reported as mean ± std dev. *Statistical Significance at ≤ .05; Low Strength= patients demonstrating hip abduction strength: body weight (BW) ratio < 33%; High Strength= patients demonstrating hip abduction strength ratio ≥ 33%.

Table 2. Subjective Scores and Functional Test Performance at Time of Release to Activity

<table>
<thead>
<tr>
<th></th>
<th>Low Strength (n=364)</th>
<th>High Strength (n=164)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IKDC (0-100)</td>
<td>88.15 ± 13.59</td>
<td>93.52 ± 10.27</td>
<td>.000*</td>
</tr>
<tr>
<td>ACL-RSI (0-100)</td>
<td>76.19 ± 15.39</td>
<td>88.52 ± 16.90</td>
<td>.000*</td>
</tr>
<tr>
<td>Extension ROM Deficit (deg.)</td>
<td>2.22 ± 1.75</td>
<td>2.38 ± 1.98</td>
<td>.432</td>
</tr>
<tr>
<td>Flexion ROM Deficit (deg.)</td>
<td>3.73 ± 4.41</td>
<td>3.86 ± 4.78</td>
<td>.782</td>
</tr>
<tr>
<td>Single Leg Balance Deficit (cm)</td>
<td>2.12 ± 4.13</td>
<td>2.19 ± 4.90</td>
<td>.892</td>
</tr>
<tr>
<td>Quadriceps LSI at 60 °/sec (%)</td>
<td>89.25 ± 20.24</td>
<td>86.55 ± 19.48</td>
<td>.149</td>
</tr>
<tr>
<td>Quadriceps LSI at 180 °/sec (%)</td>
<td>87.35 ± 17.60</td>
<td>87.88 ± 18.23</td>
<td>.511</td>
</tr>
<tr>
<td>Quadriceps LSI at 300 °/sec (%)</td>
<td>89.73 ± 15.94</td>
<td>89.77 ± 14.15</td>
<td>.723</td>
</tr>
<tr>
<td>Hamstring LSI at 60 °/sec (%)</td>
<td>94.38 ± 9.14</td>
<td>93.55 ± 6.27</td>
<td>.833</td>
</tr>
<tr>
<td>Hamstring LSI at 180 °/sec (%)</td>
<td>93.95 ± 7.03</td>
<td>96.23 ± 5.42</td>
<td>.035*</td>
</tr>
<tr>
<td>Hamstring LSI at 300 °/sec (%)</td>
<td>93.45 ± 7.37</td>
<td>99.93 ± 8.82</td>
<td>.041*</td>
</tr>
<tr>
<td>Single Leg Hop (LSI)</td>
<td>93.90 ± 6.86</td>
<td>94.04 ± 5.09</td>
<td>.248</td>
</tr>
<tr>
<td>Triple Hop (LSI)</td>
<td>92.37 ± 7.10</td>
<td>92.26 ± 7.37</td>
<td>.983</td>
</tr>
<tr>
<td>Cross-Over Hop (LSI)</td>
<td>91.29 ± 6.27</td>
<td>91.49 ± 6.95</td>
<td>.172</td>
</tr>
<tr>
<td>6m Timed Hop (LSI)</td>
<td>99.14 ± 1.14</td>
<td>99.13 ± 1.15</td>
<td>.681</td>
</tr>
</tbody>
</table>

Values reported as mean ± std dev. *Statistical Significance at ≤ .05; Low Strength= patients demonstrating hip abduction strength: body weight (BW) ratio < 33%; High Strength= patients demonstrating hip abduction strength ratio ≥ 33%; IKDC= International Knee Documentation Committee Questionnaire; ACL-RSI= Anterior Cruciate Ligament Return to Sport After Injury Scale; ROM= Range of Motion; LSI= Limb Symmetry Index (involved limb/uninvolved limb).

(31.0%) exhibited a ratio ≥33%. Table 1 outlines the baseline demographic characteristics of each cohort. Differences existed between the groups with the <33% BW group having a significantly lower percentage of males (51.9% vs 62.8%), older age (25.59 ± 12.36 vs 22.84 ± 9.99 years), higher weight (172.61 ± 45.12 vs 157.35 ± 30.91), and a higher BMI (26.03 ± 5.12 vs 23.47 ± 3.45). No significant differences existed for height or the Marx score (P > .05).

Subjective scores and functional test results at time to release to activity are shown in Table 2. The <33% BW group reported lower IKDC (88.15 ± 13.59 vs 93.52 ± 10.3) and ACL-RSI (76.19 ± 15.39 vs 88.52 ± 16.90) scores. No significant differences were present between groups on ROM, Y-balance anterior reach testing, the single-leg hop tests, and three-speed quadriceps isokinetic testing (P > .05). Patients in the <33% BW group demonstrated significantly lower isokinetic hamstring peak torque LSI at 180°/sec (93.45 ± 7.03 vs 96.25 ± 5.42, P = .055) and 300°/sec (93.45 ± 7.37 vs 99.93 ± 8.82, P = .041). There were no significant differences in graft type, procedure type, surgical use of PRP or BMA, or rehabilitation protocol between groups. At two-year follow-up the <33% BW group reported significantly lower SANE scores (83.32 ± 21.06 vs 92.82 ± 11.36). No significant differences were observed for current level of sports participation (P = .071) and graft re-injury rate (4% vs 4%, P = .986) at two-years.

DISCUSSION

Hip abduction weakness is associated with altered jumping and landing mechanics and impaired running biomechanics. While these activities play a role in sports participation and returning to high-level activities, hip abduction...
strength is rarely considered as a metric when considering an athlete’s readiness to return to sport. Little evidence exists examining hip abduction strength following ACLR and its potential impact on subjective function and other objective measures of strength or stability. The current study is the first to our knowledge to demonstrate that athletes with low hip abduction strength to BW ratios report significantly lower subjective function and psychological readiness at time of release to activity and significantly lower subjective function at two-year follow-up.

A large percentage of patients in our study (68.9%) failed to demonstrate hip abduction strength >33% BW. Significant demographic differences existed between groups with those demonstrating <33% BW being more female, older, heavier, and having a higher BMI. This aligns with previous work demonstrating a reduction in hip abductor isometric peak torque with aging\(^{27}\) and gender differences.\(^{28}\) Patients with higher BMI’s may have struggled to achieve the cutoff strength ratio as they needed to reach larger raw strength values. Previous work has demonstrated that obese individuals demonstrate lower quadriceps peak torque:BW ratios when compared to leaner counterparts,\(^ {29}\) though little evidence has examined the impact of BMI on absolute and relative hip strength. Adjusting the 33% BW ratio based on gender or age may result in better identifying athletes with functional deficits at time of RTS.

In alignment with our hypothesis, those with low strength:BW ratios reported significantly lower psychological readiness and self-reported function at time of release to activity. Subjective deficits remained at two-year follow-up with the <33% BW group reporting significantly lower function via the SANE score. Lower psychological readiness when returning to sport has been linked with second ACL injury\(^ {30}\) and failing to return to previous activity level.\(^ {31}\) However, this study found no significant differences between re-injury rate and level of sport participation at two-year follow-up. Caution should be used when interpreting these results as the between group differences, though statistically significant, did not exceed the minimal important difference for the IKDC-2000 or SANE score.\(^ {32}\) Further, the ACL-RSI scores, though significantly lower in the <33% BW group, were above suggested cutoffs and previously reported average scores.\(^ {33,34}\)

No significant between group differences were present for knee ROM, YBT performance, quadriceps isokinetic peak torque, and single leg hop testing in this study. This aligns with previous work concluding hip abduction strength was not predictive of single-leg hop performance following ACLR\(^ {15,18}\) but differs from Clagg et al.\(^ {35}\) who found hip abduction strength was positively correlated with YBT reach distance. The subjective deficits observed in the <33% BW group may potentially be explained by hip abduction strength, as no significant differences existed between quad strength or functional performance. Patients in the <33% BW group had a significantly lower isokinetic hamstring peak torque LSI at 180 and 300 °/sec. Hip abduction weakness may occur alongside posterior chain weakness and assist in explaining these deficits. Although significantly different, both groups demonstrated hamstring LSI values greater than the 90% value typically used for RTS clearance. Despite the <33% BW group reporting lower subjective function at two-year follow-up, no significant difference existed with re-injuries. This may be explained by both groups demonstrating >85% LSI for quad strength and >90% LSI for all hop testing.\(^ {36,37}\)

Limitations of this study include the retrospective design and the lack of controlling for potential concomitant procedures (multi-ligament procedure, cartilage procedure, etc.) amongst the groups. The authors opted to use a cutoff score of 33% BW instead of the previously recommended 35.4% BW as it seemed more practical for clinical practice. The use of a different BW ratio may serve as a more optimal cutoff to identify athletes who may perform more poorly at time of release to activity or two-year follow-up. Few previous studies exist for comparison with a wide heterogeneity in the methods used for hip abduction strength testing. The authors recommend future studies adopt a standardized, reliable methodology for assessing hip abduction strength. Future prospective studies would assist in determining the effect of hip abduction strengthening on outcomes following ACLR. Hip extensor strength,\(^ {15}\) external rotation strength,\(^ {15,18}\) and hip ROM\(^ {38}\) have been linked to ACL injury and should also be investigated in those returning to sport following ACLR.

**CONCLUSIONS**

Hip abduction strength to body weight ratio may provide helpful insight for clinical decision-making when determining when to release patients back to sport after ACL reconstruction. Patients failing to demonstrate hip abduction strength >33% BW demonstrated lower psychological readiness, subjective function, and isokinetic hamstring peak torque at time of release to activity. Self-reported knee function remained significantly lower at two-year follow-up. Clinicians should consider the potential utility of hip abduction strength to body weight ratio when assessing readiness for return to sport following ACLR.

**DISCLOSURES**

Dr. Walter Lowe is a medical consultant of Don Joy Inc. and Arthrex Inc.

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REFERENCES


Effects of Sex and Age on Quadriceps and Hamstring Strength and Flexibility in High School Basketball Athletes

Takashi Nagai1, Nathaniel Bates1, April McPherson1, Rena Hale2, Timothy Hewett4, Nathan D. Schilaty2

1 United States Army Research Institute of Environmental Medicine; Mayo Clinic, 2 Mayo Clinic, 3 United States Olympic & Paralympic Committee, 4 Rocky Mountain Consortium for Sports Research

Keywords: age, hamstring, high school basketball athletes, risk factors, sex

Background
Eccentric hamstring strength and hamstring/quadriceps strength ratios have been identified as modifiable risk factors of hamstring strains. Additionally, those strength and flexibility characteristics are commonly used as clinical tests to monitor progress of athletes with acute or chronic hamstring strains. Although hamstring strains are common among basketball athletes, normative values of knee strength and flexibility characteristics are scarce. Normative values for these athletes would be important in prevention and management of hamstring strains.

Purpose
To establish quadriceps and hamstring isokinetic strength and flexibility values among high school basketball athletes and examine the effects of sex and age.

Study Design
Cross-sectional research

Methods
Isokinetic knee muscular strength (concentric quadriceps [QuadC], concentric hamstring [HamC], eccentric hamstring [HamE], and strength ratios ([HamC/QuadC and HamE/Quad]), flexibility of hip flexors and quadriceps during a Modified Thomas test, and flexibility of hip extensors and hamstring during passive straight leg raise (SLR) and passive knee extension (PKE) tests were measured. Effects of sex and age were analyzed using t-tests and analysis of variance, respectively with Bonferroni corrected post hoc tests ($p \leq 0.01$).

Results
A total of 172 high school basketball athletes (64 males/108 females; mean age (range): 15.7 (14-18) years old) participated in the study. Male athletes were significantly stronger than female athletes (QuadC: $p<0.001$; HamC: $p<0.001$) while no differences were observed in strength ratio (HamC/QuadC: $p=0.759-0.816$; HamE/QuadC: $p=0.022-0.061$). Among male athletes, a significant effect of age on quadriceps and hamstring strength was observed: older male athletes were stronger than younger male athletes. Contrarily, there were no effects of age on strength among female athletes. There were significant sex differences in quadriceps flexibility, SLR, and PKE (female athletes were more flexible; $p=0.001-0.005$) while no sex differences were found in hip flexor flexibility ($p=0.105-0.164$). There were no effects of age for any flexibility variables within male and female athletes ($p=0.151-0.984$).
Conclusion
The current results provide normative values for hamstring strength and flexibility in high school basketball athletes. These normative values may further assist sports medicine specialists to develop screening tests, interventions, and return-to-sport criteria in this population.

Level of Evidence
3B

INTRODUCTION
Hamstring strains are significant and frequent musculoskeletal injuries as they typically result in persistent symptoms and lengthy recovery periods, which limit an athlete’s ability to participate.1–4 Hamstring strains also exhibit high rates of re-injury.5,6 Professional and college basketball athletes are inherently at risk for hamstring strains as ballistic movements that include jumping and sprinting are common causes of hamstring strains.7–9 Based on the National Collegiate Athletic Association Injury Surveillance data, rate of hamstring strains in basketball was the sixth highest (after field hockey, soccer, outdoor track, lacrosse, and indoor track) among 13 women’s sports while rate of hamstring strains in men’s basketball was the third lowest among 12 men’s sports.7 Additionally, rate of hamstring strains in female basketball athletes was twice as high as their male counterparts.7 Among high school basketball athletes, percentages of hip/thigh/upper leg injury rates (including hamstring strains, but, not specified) out of all basketball injuries were similar between sexes (girls: 8.7%; boys: 8.2% of all injuries).10 Interestingly, these hip/thigh/upper leg injuries occur more frequently during practices in girls and during games in boys.10 More epidemiological studies are needed to confirm sex differences in hamstring strains.

In an effort to reduce hamstring strains, there have been several prospective risk factors identified. Recent meta-analyses reveal that older age, higher body mass, higher body mass index, and a prior history of injury are prospective risk factors for lower extremity musculoskeletal injuries including hamstring strains.11,12 Among modifiable neuromuscular characteristics, lower quadriceps, hamstring, and hamstring-to-quadriceps strength ratios have been identified to increase prospective injury risk of hamstring strains in Australian football and soccer athletes.13–16 A lack of flexibility of the hip flexors discerned using the Modified Thomas test and of the hamstring using the straight-leg raise (SLR) test was identified prospectively to increase injury risk of hamstring strains among older (>25 years old) Australian football athletes17 and among male professional soccer athletes,18 respectively. Contrarily, several studies did not find these neuromuscular characteristics such as weaker eccentric hamstring strength19,20 and poor hamstring flexibility21 as prospective risk factors of hamstring strains. A systematic review has reported that concentric and eccentric hamstring muscular strength was not a strong prospective risk factor.22 Similarly, poor hamstring flexibility, using active knee extension (AKE), was not a prospective risk factor among Gaelic football athletes.21

From a rehabilitation perspective, hamstring eccentric strength (HamE) and the ratio of HamE divided by quadriceps concentric strength (QuadC) was significantly reduced in the injured limb compared to the contralateral uninjured limb in male athletes with hamstring strains.23 The authors utilized this particular ratio (HamE/QuadC) to screen athletes for risk of hamstring strains, to track rehabilitation progress, and to determine safe return-to-sport after hamstring strains.23,24 A systematic review also supports the contention that hamstring strength and flexibility testing could provide a valuable tool to monitor progress and safe return-to-sport after hamstring strains.25 This review also included average recovery time of hamstring strength (within 20 days) and flexibility (within 50 days) after hamstring strains.25 Although there are mixed findings on clinical importance of baseline isokinetic hamstring strength and flexibility testing, it appears beneficial in sports medicine / physical therapy clinics where each subject/patient has dedicated time and repeat testing to monitor progress objectively.

Although there is a high prevalence of hamstring strains in basketball (the second highest injury rates after indoor track and field among all indoor sports) and high clinical relevance for hamstring strength and flexibility testing, few studies have provided normative values for isokinetic hamstring strength and common clinical flexibility tests for each sex and age among high school basketball athletes. Generally, older male athletes exhibit stronger muscular strength,26 while female athletes are more flexible and exhibit better stretch pain tolerance.27 Understanding the effects of sex and age on these strength and flexibility characteristics is clinical relevant and important. Sports medicine specialists could quantitatively monitor athlete’s progress and make a better decision on return-to-sport during rehabilitation. Therefore, the purpose of this study was to examine effects of age and sex on hamstring and quadriceps strength and flexibility in high school basketball athletes. The hypothesis was that male athletes and older athletes would exhibit significantly greater strength than female athletes and younger athletes, respectively. Contrarily, it was hypothesized that female athletes and younger athletes would exhibit significantly greater hamstring and hip flexors flexibility than male athletes and older athletes.

METHODS
The study was reviewed and approved by the Mayo Clinic Institutional Review Board (17-003905). This investigation was part of a large prospective study to examine the risk factors of hamstring strains. The current dataset was collected at the beginning of the high school basketball season in the first year of the project. Basketball athletes were...
Effects of Sex and Age on Quadriceps and Hamstring Strength and Flexibility in High School Basketball Athletes

recruited from local high schools and tested at the start of their basketball season. Informed consents and assents were obtained from each player and his/her parent (for 14-17 years old athletes). Inclusion criteria were ages 14-18 years old with no previous knee injuries or surgeries in the past year. Strength and flexibility testing each took approximately 15 minutes.

After height and weight were measured with a standard stadiometer and scale (Seca North America, East Hanover, MD), knee extension (quadriceps concentric muscular strength) and knee flexion strength (hamstring concentric muscular strength) at 240°/sec and eccentric knee flexion strength (hamstring eccentric muscular strength) at 30°/sec were assessed using the HumacNorm dynamometer (CSMi, Stoughton, MA). These speeds for concentric and eccentric muscular strength testing were chosen based on the previous studies, examining risk factors of hamstring strains. Subjects were seated on the dynamometer chair with straps secured around shoulder, waist, and thigh to isolate movement to the targeted lower extremity during testing. The testing leg was securely attached to the dynamometer around the distal shank 3 cm proximal to the lateral malleolus with the axis of the dynamometer aligned with the knee axis of rotation. Then, limb weight was measured and accounted for each subject. After familiarization trials, subjects were asked to extend and flex their knee as hard as possible (and verbally encouraged) for a full-range of motion for 10 repetitions. Subjects then performed the hamstring eccentric strength test. Eccentric trials started with the knee at full flexion. Subjects were then asked to resist the dynamometer arm by flexing their knee as hard as possible while the dynamometer arm articulated their shank towards full extension. Peak knee flexion torque was recorded during three trials. This methodology has previously reported good reliability.

The current authors have also established good test-retest reliability of 20 participants using the same testing protocols and found intraclass correlation coefficient ranges from 0.706 to 0.937. For statistical analyses, the average of 10 and three trials were used for concentric and eccentric strength, respectively. The average peak torque (Nm) normalized to body mass (kg) was used for analyses (%BM). The concentric hamstring over concentric quadriceps strength ratio (HamC/QuadC) was calculated by the peak hamstring concentric strength divided by the peak quadriceps concentric strength multiplied by 100 in order to express a percentage. A ratio of the peak hamstring eccentric strength over the peak quadriceps concentric strength (HamE/QuadC) was also used for statistical analyses.

A Modified Thomas test was used to assess flexibility of the ilioptosas and quadriceps muscles. Subjects laid in a supine position with the ischial tuberosities on the edge of the treatment table. A clinician elevated both subject’s legs simultaneously into hip flexion until a neutral pelvis position was established. From this position, the clinician held the contralateral leg stable and slowly lowered the testing leg. The assistant placed a digital inclinometer (Johnson Level & Tool, Mequon, WI) on top of the midpoint of the thigh and shin to measure the ilioptosas and quadriceps flexibility, respectively. The inclinometer was initially calibrated to 0 degrees on the horizon, and higher values represent greater iliopsoas and quadriceps flexibility.

Flexibility of the posterior hip (gluteal and hamstring muscles) and posterior knee (hamstring muscles) was assessed using passive SLR and passive knee extension (PKE), respectively. For the passive SLR, subjects laid supine while a clinician flexed their hip and kept their leg straight. Each subject’s pelvis was stabilized with a belt. An inclinometer was placed on the top of the shin midpoint. Flexibility was measured from the horizontal position (higher values represented greater flexibility). PKE was performed in a supine position with the testing leg positioned at 90 degrees hip and knee flexion. The examiner stabilized the testing leg’s thigh vertically and passively moved the lower leg to the point of muscle tautness. An inclinometer was placed on the top of the shin midpoint to measure flexibility (higher values represented greater flexibility). This procedure was repeated a few times until the examiner found a consistent end point of muscle tautness, and the last value was taken for statistical analysis.

Descriptive statistics (means and standard deviations) were calculated in each sex and age group. Each dependent variable was screened for normality using Shapiro-Wilk tests. Given the wide range of ages, sex differences were examine using independent t-tests or Mann-Whitney tests for each age group. Effects of age within male and female athletes were examined using one-way between-subjects analysis of variance (ANOVA) or Kruskal Wallis tests with five age-levels (14, 15, 16, 17, and 18 years old). In addition to normality, homogeneity of variance assumption was screened using Levene’s tests. If ANOVA/Kruskal Wallis tests were significant, post-hoc analyses were used to compare between each age group. In order to reduce Type I Error due to multiple comparisons, significance was adjusted with Bonferroni and set at p<0.01 a priori.

RESULTS

A total of 64 males (14 years old: n=8; 15 years old: n=17; 16 years old: n=19; 17 years old: n=15; 18 years old: n=7) and 108 females (14 years old: n=27; 15 years old: n=33; 16 years old: n=15; 17 years old: n=23; 18 years old: n=10) participated in the study. Demographics for male and female athletes as well as their age stratification are in Table 1.

For strength and strength ratio variables, descriptive statistics are shown in Table 2a-c and 3a-b, respectively. Overall, there were significant sex differences in quadriceps concentric and hamstring concentric strength (p<0.001). Specifically, sex differences in quadriceps and hamstring concentric strength were observed among the older ages: 16 years old (p<0.005), 17 years old (p=0.003) and 18 years old (p=0.001). Hamstring eccentric strength (p=0.024) and strength ratios (p=0.022-0.816) were not statistically different between sexes.

There were significant effects of age on all strength variables within male athletes (p=0.001-0.031). Specifically, quadriceps and hamstring strength values were lower in 14 and 15 years old male athletes than 16 and 18 years old male athletes. Contrarily, female athletes did not show any effects of age on strength variables (p=0.048-0.856).

Flexibility variables are shown in Table 4a-b and 5a-b. Iliopsoas (hip flexors) and quadriceps flexibility (Modified International Journal of Sports Physical Therapy
Table 1. Subject Demographics

<table>
<thead>
<tr>
<th>Age</th>
<th>Males</th>
<th>Females</th>
<th>Sex Diff</th>
<th>Males</th>
<th>Females</th>
<th>Sex Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>172.9 ± 6.3</td>
<td>168.4 ± 9.7</td>
<td>0.237</td>
<td>69.6 ± 9.1</td>
<td>63.2 ± 14.8</td>
<td>0.258</td>
</tr>
<tr>
<td>15</td>
<td>178.2 ± 7.5</td>
<td>169.9 ± 8.4</td>
<td>0.001*</td>
<td>66.7 ± 12.4</td>
<td>66.6 ± 14.7</td>
<td>0.814</td>
</tr>
<tr>
<td>16</td>
<td>182.6 ± 9.7</td>
<td>168.5 ± 3.9</td>
<td>&lt;0.001*</td>
<td>73.8 ± 10.6</td>
<td>67.6 ± 8.4</td>
<td>0.137</td>
</tr>
<tr>
<td>17</td>
<td>184.4 ± 8.5</td>
<td>173.5 ± 8.2</td>
<td>0.001*</td>
<td>78.9 ± 12.4</td>
<td>69.0 ± 16.1</td>
<td>0.031</td>
</tr>
<tr>
<td>18</td>
<td>184.0 ± 2.7</td>
<td>170.9 ± 10.0</td>
<td>0.002*</td>
<td>80.9 ± 8.2</td>
<td>66.9 ± 7.9</td>
<td>0.003*</td>
</tr>
<tr>
<td>All</td>
<td>180.7 ± 8.6</td>
<td>170.2 ± 8.5</td>
<td>&lt;0.001*</td>
<td>73.2 ± 11.9</td>
<td>66.4 ± 13.8</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

* represents significant differences between sexes (p≤0.01).

Table 2a. Effects of sex and age on quadriceps concentric strength (QuadC)

<table>
<thead>
<tr>
<th>Age</th>
<th>Males</th>
<th>Females</th>
<th>Sex Diff</th>
<th>Males</th>
<th>Females</th>
<th>Sex Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>125.5 ± 30.4</td>
<td>112.1 ± 19.6</td>
<td>0.167</td>
<td>125.5 ± 34.8</td>
<td>114.1 ± 23.2</td>
<td>0.314</td>
</tr>
<tr>
<td>15</td>
<td>141.1 ± 33.0</td>
<td>121.9 ± 16.6</td>
<td>0.071</td>
<td>139.8 ± 25.9</td>
<td>122.4 ± 21.1</td>
<td>0.032</td>
</tr>
<tr>
<td>16</td>
<td>162.7 ± 22.9</td>
<td>110.1 ± 22.3</td>
<td>&lt;0.001*</td>
<td>161.6 ± 28.2</td>
<td>114.3 ± 19.3</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>17</td>
<td>141.5 ± 11.3</td>
<td>125.0 ± 21.6</td>
<td>0.003*</td>
<td>151.5 ± 30.4</td>
<td>123.3 ± 21.7</td>
<td>0.003*</td>
</tr>
<tr>
<td>18</td>
<td>162.0 ± 30.6</td>
<td>128.5 ± 26.6</td>
<td>0.034</td>
<td>161.3 ± 23.5</td>
<td>120.4 ± 41.2</td>
<td>0.034</td>
</tr>
<tr>
<td>All</td>
<td>147.8 ± 28.4</td>
<td>118.8 ± 21.1</td>
<td>&lt;0.001*</td>
<td>149.2 ± 30.1</td>
<td>119.1 ± 23.8</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

* represents significant differences between sexes (p≤0.01). # represents significant differences among ages (p≤0.01).

Table 2b. Effects of sex and age on hamstring concentric strength (HamC)

<table>
<thead>
<tr>
<th>Age</th>
<th>Males</th>
<th>Females</th>
<th>Sex Diff</th>
<th>Males</th>
<th>Females</th>
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</tr>
</thead>
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<tr>
<td>14</td>
<td>61.9 ± 13.8</td>
<td>55.2 ± 12.0</td>
<td>0.281</td>
<td>56.7 ± 20.4</td>
<td>53.9 ± 14.0</td>
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<tr>
<td>15</td>
<td>62.3 ± 15.3</td>
<td>56.9 ± 17.4</td>
<td>0.302</td>
<td>65.9 ± 15.9</td>
<td>55.4 ± 17.4</td>
<td>0.053</td>
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<tr>
<td>16</td>
<td>77.8 ± 15.8</td>
<td>53.6 ± 12.8</td>
<td>&lt;0.001*</td>
<td>75.1 ± 17.8</td>
<td>59.3 ± 13.4</td>
<td>0.009*</td>
</tr>
<tr>
<td>17</td>
<td>68.7 ± 15.1</td>
<td>59.0 ± 12.4</td>
<td>0.048</td>
<td>64.4 ± 12.0</td>
<td>60.5 ± 16.1</td>
<td>0.465</td>
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<tr>
<td>18</td>
<td>90.3 ± 15.8</td>
<td>63.0 ± 13.4</td>
<td>0.002*</td>
<td>91.3 ± 16.2</td>
<td>58.9 ± 12.1</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>All</td>
<td>71.2 ± 17.5</td>
<td>57.0 ± 13.9</td>
<td>&lt;0.001*</td>
<td>70.0 ± 18.5</td>
<td>57.1 ± 15.2</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

* represents significant differences between sexes (p≤0.01). # represents significant differences among ages (p≤0.01).

Thomas test) were not significantly different between sexes (p=0.015-0.164) except the quadriceps flexibility of the left limb (males: 81.1 degrees, females: 84.0 degrees, p=0.005). For SLR and PKE tests, female athletes exhibited significantly greater hamstring flexibility (p=0.001). Among all flexibility variables, there were no significant effects of age (p=0.151-0.984).

DISCUSSION

The current study examined sex and age differences in hamstring and quadriceps muscular strength and flexibility. For strength variables, the hypothesis was partially supported as sex differences in both hamstring and quadriceps
### Table 2c. Effects of sex and age on hamstring eccentric strength (HamE)

<table>
<thead>
<tr>
<th>Age</th>
<th>Left Leg (%BW)</th>
<th>Sex Diff</th>
<th>Right Leg (%BW)</th>
<th>Sex Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males</td>
<td>Females</td>
<td>p-value</td>
<td>Males</td>
</tr>
<tr>
<td>14</td>
<td>145.7 ± 39.0</td>
<td>162.7 ± 47.1</td>
<td>0.390</td>
<td>162.6 ± 44.9</td>
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<tr>
<td>15</td>
<td>166.8 ± 42.1</td>
<td>178.4 ± 45.7</td>
<td>0.409</td>
<td>156.4 ± 36.4</td>
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<tr>
<td>16</td>
<td>219.3 ± 65.1</td>
<td>156.4 ± 48.8</td>
<td>0.005*</td>
<td>214.3 ± 50.8</td>
</tr>
<tr>
<td>17</td>
<td>204.4 ± 61.1</td>
<td>175.2 ± 50.9</td>
<td>0.138</td>
<td>204.1 ± 77.7</td>
</tr>
<tr>
<td>18</td>
<td>229.1 ± 56.0</td>
<td>171.9 ± 41.0</td>
<td>0.033</td>
<td>218.5 ± 41.4</td>
</tr>
<tr>
<td>All</td>
<td>194.2 ± 60.4</td>
<td>169.5 ± 47.1</td>
<td>0.024</td>
<td>190.5 ± 57.7</td>
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</tbody>
</table>

**Age Diff**

<table>
<thead>
<tr>
<th>p-value</th>
<th>0.005#; 14&lt;16</th>
<th>0.579</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.006#; 15&lt;16,18</td>
<td>0.856</td>
</tr>
</tbody>
</table>

* represents significant differences between sexes (p ≤ 0.01). # represents significant differences among ages (p ≤ 0.01).

### Table 3a. Effects of sex and age on concentric hamstring / quadriceps strength ratios (HamC/QuadC)

<table>
<thead>
<tr>
<th>Age</th>
<th>Left Leg (%)</th>
<th>Sex Diff</th>
<th>Right Leg (%)</th>
<th>Sex Diff</th>
</tr>
</thead>
<tbody>
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<td>Females</td>
<td>p-value</td>
<td>Males</td>
</tr>
<tr>
<td>14</td>
<td>51.4 ± 14.0</td>
<td>50.0 ± 10.2</td>
<td>0.762</td>
<td>48.8 ± 20.3</td>
</tr>
<tr>
<td>15</td>
<td>44.8 ± 10.4</td>
<td>47.4 ± 15.3</td>
<td>0.540</td>
<td>47.3 ± 9.0</td>
</tr>
<tr>
<td>16</td>
<td>48.3 ± 9.6</td>
<td>51.1 ± 17.8</td>
<td>0.573</td>
<td>47.7 ± 13.9</td>
</tr>
<tr>
<td>17</td>
<td>48.6 ± 9.9</td>
<td>48.2 ± 12.0</td>
<td>0.933</td>
<td>43.4 ± 8.1</td>
</tr>
<tr>
<td>18</td>
<td>56.3 ± 8.2</td>
<td>50.5 ± 12.7</td>
<td>0.311</td>
<td>57.5 ± 13.0</td>
</tr>
<tr>
<td>All</td>
<td>48.7 ± 10.6</td>
<td>49.1 ± 13.4</td>
<td>0.816</td>
<td>47.9 ± 12.6</td>
</tr>
</tbody>
</table>

**Age Diff**

| p-value | 0.148 | 0.874 | 0.213 | 0.572 |

### Table 3b. Effects of sex and age on eccentric hamstring / concentric quadriceps strength ratios (HamE/QuadC)

<table>
<thead>
<tr>
<th>Age</th>
<th>Left Leg (%)</th>
<th>Sex Diff</th>
<th>Right Leg (%)</th>
<th>Sex Diff</th>
</tr>
</thead>
<tbody>
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<td>Males</td>
<td>Females</td>
<td>p-value</td>
<td>Males</td>
</tr>
<tr>
<td>14</td>
<td>118.2 ± 27.1</td>
<td>145.7 ± 35.5</td>
<td>0.069</td>
<td>136.1 ± 40.3</td>
</tr>
<tr>
<td>15</td>
<td>119.7 ± 25.3</td>
<td>148.0 ± 41.0</td>
<td>0.009*</td>
<td>144.3 ± 31.1</td>
</tr>
<tr>
<td>16</td>
<td>134.6 ± 34.3</td>
<td>147.2 ± 52.8</td>
<td>0.425</td>
<td>134.7 ± 32.2</td>
</tr>
<tr>
<td>17</td>
<td>143.7 ± 37.6</td>
<td>141.7 ± 38.6</td>
<td>0.878</td>
<td>132.7 ± 30.8</td>
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<tr>
<td>18</td>
<td>141.6 ± 23.3</td>
<td>141.7 ± 57.5</td>
<td>0.998</td>
<td>135.4 ± 17.0</td>
</tr>
<tr>
<td>All</td>
<td>131.3 ± 31.6</td>
<td>145.2 ± 42.1</td>
<td>0.061</td>
<td>128.8 ± 31.6</td>
</tr>
</tbody>
</table>

**Age Diff**

| p-value | 0.169 | 0.881 | 0.290 | 0.880 |

* represents significant differences between sexes (p ≤ 0.01).

Strength were observed except for eccentric strength. All isokinetic strength values in the current study were similar in magnitude to the previous studies in high school athletes.26,31,32 It is interesting to note that sex differences become more apparent in later ages as male athletes become stronger while female athletes exhibit similar strength levels across ages in high school. The current findings align with the previous study that identifies stronger quadriceps and hamstring strength in males and an absence of strength changes in female athletes in middle/high school.26

The current results provide normative values for hamstring strength and flexibility in high school basketball athletes. Since there are few normative values available in the literature, these results are clinically important for physical therapists, athletic trainers, or other clinicians who regularly utilize an isokinetic dynamometer. When combined
with the previous findings (recovery time of hamstring strength within 20 days & flexibility within 50 days after hamstring strains)\(^{25}\), clinicians can utilize isokinetic hamstring strength and flexibility tests to objectively monitor rehabilitation progress and to determine the timing of return-to-sport.

When strength ratios were examined, no significant sex differences were observed, which is contrary to previous literature.\(^{33}\) Therefore, the hypothesis that males would have higher strength ratios than females was rejected. A concept of hamstring eccentric strength over quadriceps concentric strength ratio was developed two decades ago\(^ {34}\) and has been utilized to screen athletes.\(^ {23,24}\) Compared to the reported ratio (50%-60%), the current HamC/QuadC values...
were similar (43%-56%); however, the HamE/QuadC ratio in the current study (114%-148%) was higher than the previous study (75%-90%).25 Likely, differences in demographics such as age (25 years old vs. 14-18 years old in the current study) and testing procedures and methodologies potentially contribute to the current results.

Higher HamE/QuadC ratio was observed in female athletes. There are two potential reasons. First, female athletes exhibited a larger sex difference in quadriceps strength (females being 20-26% weaker) than a sex difference in the hamstring eccentric strength (females being 10-13% weaker), which naturally inflated the strength ratio. Second, most athletes exhibited greater variability during eccentric strength testing than during concentric strength testing. The overall coefficient of variation (a measurement of relative variability defined as the ratio of the standard deviation divided by the mean25) during hamstring eccentric strength testing was 30-31% and 27-28% in males and females, respectively. As a comparison, the coefficient of variation during quadriceps and hamstring concentric strength were 20% and 25-26% in male athletes and 18-20% and 24-27% in female athletes, respectively. Most likely, this protocol was the first time that these athletes had engaged in eccentric strength testing. Although test-retest reliability was good to excellent, high coefficient of variation suggests that peak torque values can fluctuate among three trials. Additional familiarization and practice trials during eccentric hamstring muscular strength testing might have produced more consistent values.

Muscular strength weakness and lower hamstring/quadriceps strength ratio have been identified as prospective risk factors in Australian-rule football and soccer athletes.24,26 Although the current subjects were younger than the subjects in those studies,24,26 lower strength ratio may play an important role in screening of individuals for a prospective risk factor of hamstring strains. In fact, a preliminary analysis of three female athletes who later suffered hamstring strains (within a few months after the baseline testing) demonstrated that they exhibited weaker hamstring eccentric strength (mean for injured athletes: 137.2%BM vs. mean for non-injured athletes: 170.2%BM) and lower HamE/QuadC ratio (mean for injured athletes: 112.3% vs. mean for non-injured 145.5%) when compared to the baseline values of female athletes who did not go on to injury. More injured subjects would be needed to run statistical analyses to explore this preliminary observation.

The current study was not aimed to establish the association between baseline strength and prospective hamstring strains. Instead, it aimed to establish normative values for hamstring strength and flexibility characteristics among high school basketball athletes. Regardless of athletes’ background and competition levels, hamstring exercises could reduce hamstring strains by 50% on average.37–39 Sports medicine specialists and coaches should incorporate hamstring exercises gradually for high school basketball athletes for their athletic performance development as well as hamstring strain injury prevention purposes with proper progressions.40 Eccentric exercises have been commonly used during rehabilitation of tendinopathies, muscle strains, and anterior cruciate ligament post-operation.41 Future studies can focus on eccentric exercise dose-response relationship and establish return-to-sport criteria for athletes with acute or chronic hamstring strains.

For flexibility variables, female athletes exhibited greater flexibility in both SLR and PKE tests. However, there were no effect of sex and age on hip flexors and quadriceps flexibility during the Modified Thomas test. From a clinical perspective, the SLR is used to target/stretch the proximal hamstring and hip extensors while PKE is used to target/stretch the extensibility of the distal hamstring with less constraint of the more proximal hip extensors.29 Based on the current findings, both flexibility tests for hamstring were sensitive enough to detect sex differences in high school basketball athletes. The current findings agree with previous studies.27,29

The current data also indicated that there were no significant effects of age on flexibility. That is also in accordance with a previous study.42 Interestingly, hamstring flexibility does not seem to change much throughout the lifespan from 20-29 years old group to 70-79 years old group.42 For younger populations, sex differences in general tissue laxity, commonly assessed with the Brighton Joint Mobility Test,43 may occur at the onset of puberty (ages: 11-12 years on both sexes).45 Therefore, the youngest group (14 years old) in the current study had likely entered the pubertal stage of their maturation. Nonetheless, the current findings

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<table>
<thead>
<tr>
<th>Age</th>
<th>Left Leg (degrees)</th>
<th>Right Leg (degrees)</th>
<th>p-value</th>
<th>Males</th>
<th>Females</th>
<th>Males</th>
<th>Females</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>52.1 ± 10.4</td>
<td>58.7 ± 10.1</td>
<td>0.116</td>
<td>53.4 ± 10.2</td>
<td>62.3 ± 9.1</td>
<td>0.023</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>50.0 ± 9.1</td>
<td>57.1 ± 10.7</td>
<td>0.023</td>
<td>53.0 ± 8.1</td>
<td>61.6 ± 8.8</td>
<td>0.001*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>52.2 ± 9.3</td>
<td>57.5 ± 7.5</td>
<td>0.051</td>
<td>53.7 ± 7.5</td>
<td>61.7 ± 6.9</td>
<td>0.003*</td>
<td></td>
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</tr>
<tr>
<td>17</td>
<td>49.7 ± 10.8</td>
<td>60.0 ± 9.2</td>
<td>0.005*</td>
<td>51.3 ± 8.1</td>
<td>63.0 ± 9.3</td>
<td>0.001*</td>
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<td></td>
</tr>
<tr>
<td>18</td>
<td>48.9 ± 8.0</td>
<td>58.3 ± 9.7</td>
<td>&lt;0.001*</td>
<td>51.3 ± 4.5</td>
<td>62.1 ± 10.6</td>
<td>0.013</td>
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</tr>
<tr>
<td>All</td>
<td>50.7 ± 9.4</td>
<td>58.3 ± 9.6</td>
<td>0.080</td>
<td>52.7 ± 7.7</td>
<td>62.1 ± 8.8</td>
<td>&lt;0.001*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* represents significant differences between sexes (p≤0.01).
with high school basketball athletes with ages 14–18 years adds to the existing literature and confirms that there are no age-related changes in hamstring flexibility among high school basketball athletes.

Decreased hamstring flexibility has identified as a risk factor for hamstring strains among male Australian-rule footballers and male professional soccer athletes.\textsuperscript{17,18,44} Since stretching exercises are already a part of most warm-up and cool-down exercises, few clinical studies have been conducted to actually evaluate the effects of stretching on hamstring strains.\textsuperscript{45} Based on the current findings and available literature, male athletes may benefit from a stretching program to a larger extent than female athletes who already have greater flexibility.

The authors recognize limitations in this study. First, as a limitation of the research design (cross-sectional study and age-/sex-group comparisons), the current results cannot be interpreted as an absence of strength changes. In a longitudinal study over three years (from 11 years to 14 years old), knee extension strength increased in girls.\textsuperscript{46} Therefore, the current findings should be interpreted cautiously and used to reflect sex- and age-group differences in their strength and flexibility. Second, because the current study used age as one of the inclusion criteria, the stages of biological maturation were not evaluated. Stratification by maturation scales such as Pubertal Maturation Observational Scale (PMOS)\textsuperscript{47,48} or Tanner Stage\textsuperscript{49} might be helpful with the youth population. Therefore, the current results only represent the age effect in high school basketball athletes. The authors are aware that the current research design is a cross-sectional study; therefore, the association between strength/flexibility and injury risk of hamstring strains cannot be established.

CONCLUSIONS

The results of this study indicate that male high school basketball athletes were stronger and less flexible than female athletes while younger male athletes were weaker than older males. The same trend was not found in female athletes. Future studies should explore if any of these differences might be associated with athletes with hamstring strains. The current results expand the available evidence on hamstring strength and flexibility characteristics in high school basketball athletes. These normative values may further assist sports medicine specialists to develop screening tests, interventions, and return-to-sport criteria in this population.

CONFLICTS OF INTEREST

No authors have any conflict of interests to disclose.

ACKNOWLEDGEMENTS

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DISCLAIMER

The views expressed in this manuscript are those of the authors and do not reflect the official policy of the Department of Army, Department of Defense, or the U.S. Government.

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REFERENCES


Original Research

Fractures and Chronic Recurrence are Commonly Associated with Ankle Sprains: a 5-year Population-level Cohort of Patients Seen in the U.S. Military Health System

Daniel I Rhon1, Tina A Greenlee2, Chad E Cook1, Richard B Westrick1, Jon A Umlauf2, John J Fraser3

1 Military Performance Division, United States Army Research Institute of Environmental Medicine; Department of Rehabilitation Medicine, Brooke Army Medical Center, 2 Rehabilitation Medicine, Brooke Army Medical Center, 3 Department of Orthopaedic Surgery, Duke University School of Medicine, 4 Military Performance Division, US Army Research Institute of Environmental Medicine, 5 Directorate for Operational Readiness & Health, Naval Health Research Center

Keywords: epidemiology, tactical athlete, injury severity, ankle sprain, ankle fracture, military medicine

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Background
Whereas ankle-foot injuries are ubiquitous and affect ~16% of military service-members, granularity of information pertaining to ankle sprain subgroups and associated variables is lacking. The purpose of this study was to characterize and contextualize the burden of ankle sprain injuries in the U.S. Military Health System.

Methods
This was a retrospective cohort study of beneficiaries seeking care for ankle sprains, utilizing data from the Military Health System Data Repository from 2009 to 2013. Diagnosis and procedural codes were used to identify and categorize ankle sprains as isolated lateral, isolated medial, concomitant medial/lateral, unspecified, or concomitant ankle sprain with a malleolar or fibular fracture. Patient characteristics, frequency of recurrence, operative cases, and injury-related healthcare costs were analyzed.

Results
Of 30,910 patients included, 68.4% were diagnosed with unspecified ankle sprains, 22.8% with concomitant fractures, (6.9%) with isolated lateral sprains, (1.7%) with isolated medial sprains and 0.3% with combined medial/lateral sprains. Pertaining to recurrence, 44.2% had at least one recurrence. Sprains with fractures were ~2-4 times more likely to have surgery within one year following injury (36.2% with fractures; 9.7% with unspecified sprains) and had the highest ankle-related downstream costs.

Conclusion
Fractures were a common comorbidity of ankle sprain (one in five injuries), and operative care occurred in 16.4% of cases. Recurrence in this cohort approximates the 40% previously reported in individuals with first-time ankle sprain who progress to chronic ankle instability. Future epidemiological studies should consider reporting on subcategories of ankle sprain injuries to provide a more granular assessment of the distribution of severity.
Level of evidence

3b

BACKGROUND

Ankle-foot injuries are ubiquitous and one of the most common injuries, particularly in individuals who engage in physical activity and sport. The largest single contributor to all reported injuries in collegiate athletes was ankle sprains (14.8%), occurring at a consistent rate of 0.83 per 1000 athlete exposures between 1988 and 2004. In military service members, who experience considerable physical demands and are required to function in diverse environments, ankle-foot injuries can substantially curtail the ability to complete duty requirements and operational objectives. Ankle-foot injuries were the third leading factor of lost work time of the US Armed Forces in 2002, and by 2017-2018 they were ranked first for all U.S. Army soldiers. Among ankle-foot injuries, lateral ankle sprains (LAS) are among the most common.

The rate of ankle sprains in military personnel (~35 per 1000 person-years) is nearly five times greater than that reported in the civilian population. While several epidemiological studies have assessed the incidence of ankle sprains in military populations, none have provided treatment fidelity and contextualized morbidity (e.g. persistence of symptoms, recurrence, type and severity of injury). This is especially problematic since injury pathomechanics and the resulting ankle-foot neuromusculoskeletal impairments following ankle sprain are highly variable. Outcomes such as health care utilization, cost, and length of disability are likely mediated by injury severity and concomitant conditions. For example, presence of a comorbid fracture may complicate management of the injury and lead to a protracted recovery.

Recurrence of ankle sprains is also common in military members with repeat injuries occurring anywhere from two weeks to eight years or more following the index sprain. There is inconsistency in the reported rates of ankle injury recurrence, a consequence that is likely attributed to methodological heterogeneity and relatively short follow-up periods employed by most studies. In the first study to prospectively assess long term outcomes following a first-time lateral ankle sprain evaluated in a civilian emergency department, 40% of these individuals progressed to develop chronic ankle instability (CAI) a complex and heterogeneous neuromusculoskeletal condition characterized by episodic or perceived instability of the ankle that results in activity limitation and participation restriction at least 12 months following injury. While the prevalence of CAI in the military is currently unknown, it is highly plausible that the burden is similar to that found among the general populous. Epidemiological studies are currently underway to substantiate this supposition.

In the 2021 revision of the ankle instability clinical practice guideline put forth by the American Academy of Orthopaedic Physical Therapy, the authors emphasized the importance of evaluating and contextualizing granular examination findings following LAS to aid in prognostication and when developing individualized care plans. In the same context and applied at a more macro level, greater granularity for contextualizing burden is needed to properly plan medical staffing and resource requirements to mitigate the impact of ankle sprains and optimize recovery following injury. Therefore, the purpose of this study was to characterize and contextualize the burden of ankle sprain injuries in the U.S. Military Health System. A secondary aim was to assess disparities in healthcare utilization and costs stratified by ankle injury type.

METHODS

This was a retrospective cohort study of all beneficiaries of the U.S. Military Health System that assessed ankle injury burden, stratified by injury type, in a five-year epoch. Ethics approval was provided by the Institutional Review Board at Brooke Army Medical Center (Research Evidence Level 3b). The REpporting of studies Conducted using Observational Routinely collected health Data (RECORD) statement from the STROBE checklist was used to guide reporting.

DATA SOURCE

Data were sourced from the US Military Health System Data Repository (MDR) using billed diagnosis (International Classification of Diseases, 9th edition [ICD-9-CM]) and procedure (Current Procedural Terminology® [CPT]) codes. The MDR contains validated data derived from medical encounters provided within the Department of Defense’s (DoD) worldwide network of more than 260 health care facilities and from the TRICARE Purchased Care program. It is a closed, single-payer government health system of all active and retired military members, their families, and other affiliated beneficiaries. More information about the MDR can be accessed at health.mil.

COHORT SELECTION

Individuals diagnosed with an ankle sprain with and without concomitant fracture between 01 January 2009 and 31 December 2012 were included in this study, regardless of whether they were active-duty, retired service members or dependents. Anyone under the age of 18 or over the age of 50 was also excluded, to best capture the age range of most military service members. Rank and military service is based on the sponsor status (individual on active duty). Table 1 details the diagnosis codes used to identify the respective cases. To ensure included injuries were an initial diagnosis or episode, individuals diagnosed with an ankle-foot injury or surgery in the 12 months prior were excluded from analysis. Individuals that were not diagnosed with an ankle sprain or had an isolated fibular fracture, a fracture of the tibia or fibula superior to the malleoli or sustained an injury less than 12 months before the end of the study epoch were excluded from analysis. Figure 1 details the case selection in the identified cohort.
Table 1. Diagnosis Codes Used for Cohort Selection

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>845.00</td>
<td>Sprain of ankle, unspecified site</td>
</tr>
<tr>
<td>845.01</td>
<td>Sprain of deltoid (ligament), ankle</td>
</tr>
<tr>
<td>845.02</td>
<td>Sprain of calcaneofibular (ligament) of ankle</td>
</tr>
<tr>
<td>845.03</td>
<td>Sprain of tibiofibular (ligament), distal of ankle</td>
</tr>
<tr>
<td>845.09</td>
<td>Other sprains and strains of ankle</td>
</tr>
<tr>
<td>824.0</td>
<td>Fracture of medial malleolus, closed</td>
</tr>
<tr>
<td>824.1</td>
<td>Fracture of medial malleolus, open</td>
</tr>
<tr>
<td>824.2</td>
<td>Fracture of lateral malleolus, closed</td>
</tr>
<tr>
<td>824.3</td>
<td>Fracture of lateral malleolus, open</td>
</tr>
<tr>
<td>824.4</td>
<td>Bimalleolar fracture, closed</td>
</tr>
<tr>
<td>824.5</td>
<td>Bimalleolar fracture, open</td>
</tr>
<tr>
<td>824.6</td>
<td>Trimalleolar fracture, closed</td>
</tr>
<tr>
<td>824.7</td>
<td>Trimalleolar fracture, open</td>
</tr>
<tr>
<td>824.8</td>
<td>Unspecified fracture of ankle, closed</td>
</tr>
<tr>
<td>824.9</td>
<td>Unspecified fracture of ankle, open</td>
</tr>
</tbody>
</table>

Values represent codes from the International Classification of Diseases and Related Health Problems (ICD), 9th Edition

OUTCOME VARIABLES

A 60-day period without any foot or ankle related care, followed by an encounter for an ankle-related injury, was considered a new injury episode. These criteria have been previously employed to define discrete episodes of care, and can be considered a proxy for symptom recurrence or re-injury. Total costs for all encounters with an ankle-foot related diagnosis or procedure in the follow-up period were calculated and cases that required surgery or sought urgent care during the same timeframe were identified. Each distinct case was classified in only one category (i.e., an individual with a concomitant fracture was only counted once in that injury category). The actual cost of claims incurred by the DHA for care obtained in civilian network clinics and DHA-assigned costs for all encounters and procedures for care in military treatment facilities were utilized to determine costs of ankle-related care; both of which are provided in the MDR.

DATA INTEGRITY

Because the MHS is a single payer closed health system, the MDR is a robust data repository with few missing data. The MDR receives continuous data inputs in “RAW” form which are continuously validated for a minimum of 90 days through cross-referencing of other data sources, before the variable converts from “RAW” to “FINAL”. Absence of healthcare utilization data in the MDR implies either that servicemembers did not experience these injuries or could have sustained an injury but self-managed (non-care seeking behaviors) following injury. While less than 3% of beneficiaries were found to have supplemental health insurance listed in the MDR, the widespread presence of billed encounters for ankle sprain indicates they are likely relying on their primary coverage for the care of this condition.

RESULTS

Active-duty service members are much less likely to have other health insurance as all their medical needs are prioritized in the MHS, at zero cost to them.
After isolating the cohort to only ankle sprain related injuries and applying exclusion criteria (Figure 1), there were 30,910 unique individuals remaining in the final cohort (mean age: 31.7±8.9, male sex: 60.8%, active-duty service component: 63.2%). The mean time a case was available for follow-up in this dynamic cohort was 729±147 days, with a median of 730 days. The follow-up times did not substantially differ between the injury subgroups. Almost one quarter of all cases (22.8%, n=7049) were diagnosed with a fracture. The generic diagnosis "unspecified ankle sprain" was employed for most individuals (68.4%; n=21,135). A small proportion of the cohort had the specific diagnoses of isolated lateral sprain (6.9%; n=2128) or isolated medial sprain (1.7%; n=515), and less than one percent (0.3%; n=85) were diagnosed with a combined medial and lateral sprain (Figure 2). Service members who served in the Army, were junior enlisted, and on active duty accounted for the largest proportion of cases with ankle injuries (Table 2).

About half of all cases (55.9%) had only a single episode of medical care (any kind, to include rehabilitation), 41.4% had two to four distinct care episodes, and 2.8% had five or more distant episodes following the index injury (Table 2). This means that 44.1% of the entire cohort had at least one recurrence. Cases that had a sprain with concomitant fracture had the highest mean costs (USD $4161±656), with cases that had both medial and lateral complex injury had the highest one-year median costs ($1924). Sprains that were unspecified had the lowest median one-year cost (USD $780). Compared to the other injuries, cases that experienced a sprain with fractures were up to four times more likely to have surgery during the surveillance period (36.2%) compared to the other categories. The group with the fewest surgeries was the unspecified sprain group (9.7%). Patients with a concomitant fracture were also the most likely compared to any other group to have had an urgent care visit associated with their injury (4.5%). Approximately 41.9% of individuals received physical rehabilitation interventions to manage their ankle injury (i.e., exercise, therapeutic modalities, manual therapy), with the mean days to the first rehabilitation intervention being 72.6 (Table 2).

DISCUSSION

The primary finding of this study was that recurrence of ankle sprain post injury approximated the 40% previously reported in individuals with first-time ankle sprain who progress to chronic ankle instability.14 Fractures were a common comorbidity (one in five injuries), and operative care occurred in 16.4% of cases. Regardless of ankle injury diagnosis and complexity, more than half of individuals did not receive rehabilitation care following injury. Of the individuals who received care by a rehabilitation specialist, there was a substantially protracted delay from the time of injury to the first visit (mean of 72.6 days). This is the first study to have assessed and qualified population-level burden of ankle injuries at this level, with concomitant morbidity in the military. This is also innovative since this is also one of the first to report healthcare cost and utilization of rehabilitation services of ankle injuries within the US Military Health System. The mean healthcare cost for the treatment of ankle injuries was similar to the care of service members with low back pain, the leading sources of burden and cost in the Military Health System.19,20

Several previous studies have reported the burden of ankle sprain injuries in the military. One report found that 425,581 service members sustained an ankle sprain at a rate of 34.9 per 1000 person-years from 1998 to 2006.4 Between 2000 and 2006, 16% of all US Army soldiers sought care for an ankle sprain.21 In a more recent epidemiological study assessing lateral ankle sprain risk in the military, 360,256 service members incurred this injury from 2006 to 2015 at a rate of 28.8 per 1000 person-years in enlisted members and 13.2 per 1000 person-years in military officers.5 It is therefore no surprise to see the number of service members with these injuries and the substantial burden these injuries placed on the military health system. Considering there are a large subset of service members who do not seek care for ankle sprains, the true burden is likely even larger.22 Females in this study comprised 37.7% of the cohort, and approximately one third (29.3%) of the females were on active duty (11.1% of the total cohort; 21.2% of those on active duty), a proportion slightly higher than that of the population at risk (in 2019, female service members comprised 16.9% of the force).23 There are a few reasons this is likely. Female sex has been found to be a non-modifiable intrinsic risk factor for lateral ankle sprains, especially in the athletic population.24 This finding was similarly observed in service members across most military occupations, with female service members found to be 1.09 to 1.68 more likely to be diagnosed with an ankle sprain. This was also observed in another study where female service members were 21% more likely to sustain an ankle sprain than their male counterparts.4 These findings are likely attributed, in part, to footwear choices, hormonal influences, and differences in joint phenotypes observed in females.5 This may also be attributed to greater care seeking in females,5 a factor that is quite plausibly mediated by cultural influences in the military.22

The mean age of this study cohort (31.7±8.9 years) and specifically for those on active duty (30.4±7.4 years), generally reflected that of the military population as a whole (mean age in 2019 = 28.2).23 While the cohort includes de-
<table>
<thead>
<tr>
<th>Variable</th>
<th>Total Ankle Injuries N=30,910</th>
<th>Initial Ankle Injury Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Isolated Lateral Sprain n=2128 (6.9%)</td>
<td>Isolated Medial Sprain n=513 (1.7%)</td>
</tr>
<tr>
<td>Male Sex, n (p)</td>
<td>18,626 (60.8)</td>
<td>1364 (64.7)</td>
</tr>
<tr>
<td>Mean Age (SD)</td>
<td>31.7 (8.9)</td>
<td>31.8 (8.5)</td>
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<tr>
<td>Age Groups, n (p)</td>
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<td>18-30</td>
<td>15,343 (49.6)</td>
<td>1060 (49.8)</td>
</tr>
<tr>
<td>31-40</td>
<td>9327 (30.2)</td>
<td>662 (31.1)</td>
</tr>
<tr>
<td>41+</td>
<td>6238 (20.2)</td>
<td>406 (19.1)</td>
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<td>Military Status, n (p)</td>
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<td>Active Duty</td>
<td>19,520 (63.2)</td>
<td>1552 (72.9)</td>
</tr>
<tr>
<td>Retired</td>
<td>1588 (5.1)</td>
<td>83 (3.9)</td>
</tr>
<tr>
<td>Family Member/ Dependent</td>
<td>9506 (30.8)</td>
<td>474 (22.3)</td>
</tr>
<tr>
<td>Other/Unknown</td>
<td>396 (1.3)</td>
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</tr>
<tr>
<td>Service Branch, n (p)</td>
<td></td>
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</tr>
<tr>
<td>Army</td>
<td>12,812 (41.4)</td>
<td>950 (44.6)</td>
</tr>
<tr>
<td>Air Force</td>
<td>8773 (28.4)</td>
<td>658 (30.9)</td>
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<tr>
<td>Navy</td>
<td>5207 (16.8)</td>
<td>294 (13.8)</td>
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<tr>
<td>Marine Corps</td>
<td>2641 (8.5)</td>
<td>136 (6.4)</td>
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<td>1018 (3.3)</td>
<td>66 (3.1)</td>
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<td>Other/Unknown</td>
<td>459 (1.5)</td>
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<td>Rank, n (p)</td>
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<tr>
<td>Cadets</td>
<td>195 (0.6)</td>
<td>26 (1.2)</td>
</tr>
<tr>
<td>Junior Enlisted</td>
<td>18,621 (60.2)</td>
<td>1275 (59.9)</td>
</tr>
<tr>
<td>Senior Enlisted</td>
<td>6572 (21.3)</td>
<td>411 (19.3)</td>
</tr>
<tr>
<td>Junior Officer</td>
<td>2400 (7.8)</td>
<td>192 (9.0)</td>
</tr>
<tr>
<td>Senior Officer</td>
<td>2732 (8.8)</td>
<td>205 (9.6)</td>
</tr>
<tr>
<td>Other/Unknown</td>
<td>390 (1.3)</td>
<td>19 (0.9)</td>
</tr>
<tr>
<td>Distinct Episodes of Care Mean (SD) [median]</td>
<td>1.76 (1.1) [1.0]</td>
<td>1.9 (1.2) [1.0]</td>
</tr>
<tr>
<td>Frequency, n (p)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>17,268 (55.9)</td>
<td>1034 (48.6)</td>
</tr>
<tr>
<td>2</td>
<td>7604 (24.6)</td>
<td>573 (26.9)</td>
</tr>
</tbody>
</table>
The morbidity associated with more severe injuries such as fractures, a service member is likely to be more compelled to seek care following injury. This is stark contrast to ankle sprains, where self-management, injury minimization, and perceptions of “it is only an ankle sprain” is pervasive among service members.22

One key finding to highlight is the high prevalence of ankle sprain recurrence in this cohort. Almost half of all cases (44.1%), regardless of injury type, had at least one recurrence within one year following injury. This finding is likely attributed to persistent symptoms, ankle impairment, and activity limitation that persisted beyond 60 days following the index injury. Almost one in five (19.6%) cases had three or more care episodes, indicating that symptoms and disability persisted for at least 120 days following injury. These values align with reports in civilian populations showing that as high as 40% of individuals proceed to have chronic ankle instability.27 While the methodology employed in this study does not allow for determination of a chronic ankle instability diagnosis,13 it does provide the foundation to develop epidemiological approaches to define the condition when chronicity persists beyond 12 months following index injury, an effort that is currently underway. This highlights the idea that care seeking for recurrent ankle sprains within the first year of injury may be a useful indicator for predicting long term morbidity in service members. The cases that experienced recurrence most likely reflected a higher injury severity or persistence, reaching a threshold where

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total Ankle Injuries N=30,910</th>
<th>Isolated Lateral Sprain n=2128 (6.9%)</th>
<th>Isolated Medial Sprain n=513 (1.7%)</th>
<th>Medial and Lateral Sprain n=85 (0.3%)</th>
<th>Unspecified Sprain† n=21,135 (68.4%)</th>
<th>Sprain with Ankle Fracture n=7049 (22.8%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3541 (11.5)</td>
<td>292 (13.7)</td>
<td>60 (11.7)</td>
<td>15 (17.6)</td>
<td>2286 (10.8)</td>
<td>888 (12.6)</td>
</tr>
<tr>
<td>4</td>
<td>1643 (5.3)</td>
<td>160 (7.5)</td>
<td>30 (5.8)</td>
<td>3 (3.5)</td>
<td>1025 (4.8)</td>
<td>425 (6.0)</td>
</tr>
<tr>
<td>5+</td>
<td>854 (2.8)</td>
<td>69 (3.2)</td>
<td>22 (4.3)</td>
<td>3 (3.5)</td>
<td>532 (2.5)</td>
<td>228 (3.2)</td>
</tr>
<tr>
<td>Ankle-Related ED Visits, n (p)</td>
<td>430 (1.4)</td>
<td>6 (0.3)</td>
<td>2 (0.4)</td>
<td>0</td>
<td>101 (0.5)</td>
<td>321 (4.5)</td>
</tr>
<tr>
<td>Physical Rehabilitation, n (p)</td>
<td>12,963 (41.9)</td>
<td>1176 (55.3)</td>
<td>250 (48.7)</td>
<td>51 (60.0)</td>
<td>8066 (38.2)</td>
<td>3420 (48.5)</td>
</tr>
<tr>
<td>Time to Physical Rehabilitation Evaluation (days), Mean (SD) [median]</td>
<td>110.0 (158.6)</td>
<td>90.5 (145.6)</td>
<td>102.1 (150.0)</td>
<td>53.0 (59.6)</td>
<td>116.6 (170.0)</td>
<td>103.2 (135.5)</td>
</tr>
<tr>
<td>Time to Physical Rehabilitation Intervention (days), Mean (SD) [median]</td>
<td>72.6 (181.0)</td>
<td>58.8 (182.2)</td>
<td>42.2 (182.9)</td>
<td>60.2 (148.4)</td>
<td>71.5 (195.5)</td>
<td>82.3 (141.1)</td>
</tr>
<tr>
<td>Ankle Surgeries, n (p)</td>
<td>5072 (16.4)</td>
<td>389 (18.3)</td>
<td>61 (11.9)</td>
<td>16 (18.9)</td>
<td>2052 (9.7)</td>
<td>2554 (36.2)</td>
</tr>
<tr>
<td>Healthcare Cost per Patient-Year (USD), Mean (SD) [median]</td>
<td>$2725 (5052)</td>
<td>$3256 (4834)</td>
<td>$2807 (4231)</td>
<td>$3430 (3927)</td>
<td>$2188 (4368)</td>
<td>$4161 (6569)</td>
</tr>
</tbody>
</table>

ED, Emergency Department; SD, standard deviation.

Note: *Individuals are present only once in each category, which defaults to the more specific or more severe category (e.g., if someone had a lateral ankle sprain and a fracture, they were included only in the fracture count); †Unspecified can include both medial and lateral sprains, as well as syndesmotic sprains (high ankle). p= proportion within group.
Fractures and Chronic Recurrence are Commonly Associated with Ankle Sprains: a 5-year Population-level Cohort of Patients...
the limitations inherent with this type of data (variability in use of diagnostic codes, etc.). Many individuals could have sustained an ankle sprain and not sought care or not had the requisite of 12-month minimum follow-up required for inclusion. Therefore, the rates of ankle sprain injuries are likely much higher. The majority of ankle sprains were coded as non-specific, limiting the assumptions that can be made about subgroups, and highlighting the importance and need for more precise diagnostic coding by providers in the MHS. Comfort can be taken knowing lateral ligament injuries represent 92% of all ankle sprains.51 With the wax and wane of military operations and ongoing changes in healthcare delivery, the external validity of these findings may be limited and may not necessarily reflect the current and future burden of these injuries. However, there is no evidence to suggest that the problem of ankle sprain has changed much over the last decade, and in fact the most recent reports show it continues to be extremely pervasive.52 There is an inability to assess laterality of injury with ICD-9 codes. It is plausible that individuals experience a recurrence in the contralateral limb. While possible, these research findings are still substantial since bilateral deficits are common following ankle sprain.53 Estimates of burden in this study were derived from healthcare visits. Based on the prior evidence of self-management, injury minimization, and psychosocial determinants of care-seeking, it is likely that the burden is substantially greater than that reported in this study.22

CONCLUSION

Ankle sprains in a military population were primarily diagnosed using non-specific codes. Fractures were a common comorbidity, which warrants routine clinical examination (approximately 1 in 5 injuries included a fracture). Almost half of all patients (44.1%) had at least one recurrent episode following the initial injury. These recurrence rates approximate the 40% previously reported in individuals with first-time ankle sprain who progress to chronic ankle instability. Very few cases were seen in an urgent care setting (1.4%). For treatment 16.4% underwent surgical care and 41.9% had at least one associated physical rehabilitation procedure. Future epidemiological studies should consider reporting on subcategories of ankle sprain injuries to provide a more granular assessment of the distribution of severity. This can allow for assessment of treatment response variability within injury subgroups and improved precision for targeted interventions.

COMPETING AND CONFLICTING INTEREST

No authors have any competing or conflicts of interest to declare

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DISCLAIMER

The view(s) expressed herein are those of the author(s) and do not necessarily reflect the official policy or position of Brooke Army Medical Center, the U.S. Army Office of the Surgeon General, the Department of the Army, the Department of the Navy, the Defense Health Agency, the Department of Defense, nor the U.S. Government. The authors are military service members or employees of the U.S. Government, and this work was prepared as part of their official duties. Title 17, USC, §105 provides that 'Copyright protection under this title is not available for any work of the U.S. Government.' Title 17, USC, §101 defines a U.S. Government work as a work prepared by a military service member or employee of the U.S. Government as part of that person’s official duties. The study protocol was approved by the Brooke Army Medical Center Institutional Review Board in compliance with all applicable Federal regulations governing the protection of human subjects. Research data were derived from an approved Brooke Army Medical Center Institutional Review Board protocol, number C.2016.048n.

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REFERENCES


Background
Limitations in passive hip range of motion (PROM) may negatively affect pitching mechanics in baseball pitchers. Understanding the relationships between PROM and mechanics can assist in the development of injury prevention protocols.

Purpose
The purpose of this study was to examine the association of hip rotational PROM with pelvis and trunk rotation during pitching in high school baseball pitchers.

Study Design: Cross-sectional.

Methods
Twenty-five healthy high school baseball pitchers volunteered (15.9 ± 1.1 years; 180.4 ± 5.5 cm; 75.4 ± 9.3 kg). Seated passive hip internal rotation (IR) and external rotation (ER) PROM were measured using a digital inclinometer. Total PROM was calculated (IR+ER). Pitching biomechanical data were collected with a 3-dimensional electromagnetic tracking system while pitchers threw fastballs. Simple linear regressions were performed to examine the association between hip IR, ER, and total PROM with pitching kinematics at foot contact including stride length, pelvis rotation, and trunk rotation.

Results
Only one significant association in PROM and kinematics was observed. Drive leg hip IR PROM was associated with trunk rotation angle \( F(1,24) = 4.936, p = 0.036 \), with an \( R^2 = 0.177 \). Drive leg total PROM was not associated trunk rotation angle \( F(1,24) = 4.144, p = 0.053 \) with an \( R^2 = 0.153 \).

Conclusions
Increased drive leg hip IR PROM was associated with decreased trunk rotation towards home plate. Hip total PROM and ER were not related to pitching mechanics.

Level of Evidence
2
strength are critical in the transfer of energy from the lower extremities to the trunk, shoulder, elbow, wrist, and finally hand before ball release.\textsuperscript{1-3} At foot contact of the pitch, the stride foot should be planted slightly towards third base (for a right handed pitcher) and pointed slightly inward.\textsuperscript{4} Hip PROM may contribute to lower extremity positioning during pitching therefore it is important to examine the association between these variables. Improper stride foot positioning can cause the pelvis and trunk to rotate towards the catcher too early in the pitching motion, which leads to improper segmental sequencing.\textsuperscript{4} Improper segmental sequencing of the lower extremities can lead to compensations at the trunk and upper extremity that result in increased upper extremity forces.\textsuperscript{5} Lower extremity mechanical or functional deficits can result in compensation patterns in the trunk and upper extremity to maintain ball velocity.\textsuperscript{4,6} During pitching segmental power of trunk motion contributes to the development of ball velocity and elbow valgus load and ball velocity.\textsuperscript{5} High school pitchers have been reported to have different patterns of segmental sequencing compared to professional pitchers despite having similar elbow valgus load relative to size.\textsuperscript{5} Over time high shoulder and elbow loads may contribute to tissue breakdown and injury.\textsuperscript{7-9}

Hip PROM is one functional measure that can influence pitching mechanics. The repetitive nature of the pitching motion leads to adaptations in the hip joint tissues, often leading to changes in hip PROM.\textsuperscript{10-13} Rob et al. determined professional pitchers display less hip external rotation (ER), internal rotation (IR), and total PROM in the stride leg compared to the drive leg.\textsuperscript{10} The results also showed decreased stride leg total PROM was associated with lower trunk separation velocity while increased total drive leg PROM has been associated with a more open pelvis at foot contact.\textsuperscript{10} It has also been speculated in youth that decreased stride leg hip IR PROM contributes to insufficient trunk rotation during pitching and may lead to increased forces about the shoulder and elbow, contributing to tissue breakdown and pain.\textsuperscript{14,15}

A comprehensive understanding of the relationships between hip PROM and pitching mechanics is also needed in high school pitchers.\textsuperscript{10} The findings of this study can contribute to developing rehabilitation programs that target hip PROM deficits to improve pitching performance and decrease the risk of injury. The purpose of this study was to examine the association of hip rotational PROM with pelvis and trunk rotation during pitching in high school baseball pitchers. It was hypothesized pitchers with lower hip rotational PROM would have increased trunk and pelvis rotation towards home plate at foot contact.

METHODS

Twenty-five healthy high school baseball pitchers volunteered (15.9 ± 1.1 years; 180.4 ± 5.5 cm; 75.4 ± 9.5 kg; 8.3 ± 3.2 years of competitive baseball experience; n = 17 right-handed dominant). Two pitchers were tested in the spring (January-April), two were tested in the summer (May-August), and the rest were tested in the fall (September-December). Inclusion criteria consisted of no injury in the prior six months and no history of surgery to the lower or upper extremities. At the start of each data collection, testing procedures were explained and informed consent and parental assent were obtained. The study was approved by the Auburn University Institutional Review Board.

An a priori power analysis was conducted using G*Power3 to test the difference between two dependent means using a two-tailed test, an alpha of 0.05, and a power of 0.8. An effect size of 2.4 was calculated from previously reported total hip PROM data on the mean difference between the stride and drive leg (27.8°) and standard deviation (10.5°) in professional pitchers.\textsuperscript{10} It was estimated that a sample size of four participants would be needed.

After reviewing testing procedures, participant hip rotational PROM (IR and ER) was assessed. Hip rotational PROM was measured passively with the participant in a seated position. Their knees were flexed to 90° allowing the legs to comfortably hang off the edge of the table with their hands resting comfortably on the table to assist with trunk stabilization.\textsuperscript{10,16-18} The hip was positioned in 90° of flexion by placing a towel under the femur, and a digital inclinometer was aligned along the soft tissue contour of the participant's tibia (Figure 1). The examiner supported the femur to eliminate accessory motion and passively rotated the hip until capsular end-feel was achieved. At the point of a firm capsular end-feel without the production of accessory hip movement (hip hiking), the PROM measurement was recorded.\textsuperscript{10,11,17} Total PROM was calculated (IR+ER). The same examiner measured each participants PROM. Test-retest reliability for the examiner was established prior to the study. Excellent intra-rater reliability for the hip was observed (ICC\textsubscript{(3,k)} of 0.92 to 0.95 for all measurements). Minimal detectable change (MDC\textsubscript{0.05}) was 5.6° and 4.7°, respectively.

Fourteen electromagnetic sensors (trakSTAR, Ascension Technologies Inc.; Burlington, VT, USA) were placed on the skin using double-sided cohesive tape and were then wrapped in flexible adhesive tape to secure sensor position at the following sites: (1) posterior aspect of the first thoracic vertebrae, (2) posterior aspect of the pelvis at the first sacral vertebrae, (3-4) flat, broad portion of the acromion on the bilateral scapula, (5-6) lateral aspect of bilateral up-

Figure 1. Measurements of hip passive internal and external rotation range of motion.
per arm at the deltoid tuberosity, (7-8) posterior aspect of the bilateral distal forearm, (9-10) lateral aspect of bilateral upper leg centered between the greater trochanter and the lateral condyle of the knee, (11-12) lateral aspect of the bilateral lower leg centered between the head of the fibula and lateral malleolus, (13) dorsal aspect of the second metatarsal of the stride foot, and (14) dorsal aspect of the third metacarpal of the pitching hand. A fifteenth moveable sensor was attached to a plastic stylus and used for digitization of bony landmarks. The stylus was used to digitize the anterior superior iliac spine and posterior superior iliac spine of the pelvis and used Bell offsets to calculate hip joint centers. The rotation method was used to calculate shoulder joint centers. Ankle and knee joints were defined as the midpoint between the medial and lateral malleoli and femoral condyles respectively. The digitized space between C-7 and T12-L1 defined the spinal column and a validated rotation method, where the hip or shoulder is stabilized and rotated to 10 different positions in a circular motion, was used to estimate hip and shoulder joint centers.

Sensor position and orientations were collected at 240 Hz using thetrakSTAR, which was synchronized with The MotionMonitor software (Innovative Sports Training; Chicago, IL, USA). Sensor positions and orientations were transformed to locally-based coordinate systems for the captured body segments based on the recommended definitions of reporting human joint motions standardized by the International Society of Biomechanics. The world axis was defined with the positive Y axis pointing vertically, the positive X axis pointing in the direction of movement, and the positive Z axis orthogonal to X and Y and pointing to the right. Orientation for the pelvis and trunk were referenced to the world axis using a ZX’Y’ Euler rotation sequence. A 4th-order Butterworth filter with a cutoff frequency of 13.4Hz was applied independently to all raw data along each global axis. Data were analyzed at foot contact of the pitching motion (Figure 2).

Pitchers were allotted unlimited time to perform their pre-competition pitching warm-up. Warm-up routine and time was subjective to each pitcher and depended on their own individual routines to replicate game day performance. Pitchers instructed to warm-up so that they would be prepared to make maximal effort pitches once testing began. All pitchers included maximal effort pitches from a mound, at regulation distance, in their warm-up. After warming up, pitchers threw three maximal-effort four-seam fastballs, from a mound, to a catcher at regulation distance (18.5 m). Only pitches that were deemed to be strikes, by an investigator with prior baseball or softball experience, were used for analysis. The average data at foot contact, for the three trials, was calculated for each variable. The drive leg was defined as the ipsilateral hip to the throwing arm and the stride leg was contralateral to the throwing arm. Ball velocity was recorded by a calibrated radar gun (Stalker Pro II; Stalker Radar; Plano TX, USA).

STATISTICAL ANALYSIS

A paired sample t-test was used to assess differences in PROM between drive and stride legs. Simple linear regressions were performed to examine the association between hip IR, ER, and total PROM with pitching kinematics at foot contact including stride length, pelvis rotation, and trunk rotation. Statistical significance was set a priori at p < 0.05 and all analyses were performed using IBM SPSS Statistics Version 25.0 software (International Business Machines Corp., Armonk, NY, USA).

RESULTS

Mean ball velocity was 31.3 ± 2.1 m/s (70.1 ± 4.6 mph). Means and standard deviations can be found for kinematic data at foot contact and hip range of motion values in Table 1. Only one significant association in PROM and kinematics was observed. Drive leg hip IR PROM was associated with trunk rotation angle [F(1,24) = 4.936, p = 0.036], with an R² = 0.177 (Figure 3). Drive leg total PROM was not associated trunk rotation angle [F(1,24) = 4.144, p = 0.053] with an R² = 0.153. Lastly, no significant differences were found between drive and stride legs for IR, ER, and total hip PROM values.

DISCUSSION

The purpose of the study was to examine the association of hip rotational PROM with lower extremity and trunk kinematics at foot contact in high school baseball pitchers. The findings partially support the hypothesis that lower hip PROM would be associated with altered trunk rotation mechanics. Drive leg hip IR PROM in high school baseball pitchers predicted trunk rotation positioning at foot contact, where drive leg hip IR explained 17.7% of the variance in trunk rotation. Pitchers with increased drive leg hip IR PROM had decreased trunk rotation towards home plate. No other significant differences were observed between hip PROM and pitching kinematic parameters.

The drive leg functions to propel the body towards home plate and adequate hip internal rotation is needed to position the stride leg foot. Weight is transferred from the drive leg to the stride leg at stride foot contact and the stride leg acts to provide stability as the pitch progresses to a position of single-leg support. Adequate hip internal rota-
Table 1. Mean (SD) for kinematic data at foot contact and passive range of motion.

<table>
<thead>
<tr>
<th>Range of Motion</th>
<th>Stride Leg</th>
<th>Drive Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total PROM</td>
<td>57.0 (11.0)</td>
<td>58.2 (13.4)</td>
</tr>
<tr>
<td>IR PROM</td>
<td>24.2 (6.8)</td>
<td>25.1 (8.2)</td>
</tr>
<tr>
<td>ER PROM</td>
<td>32.9 (6.9)</td>
<td>33.1 (6.6)</td>
</tr>
</tbody>
</table>

Kinematics

<table>
<thead>
<tr>
<th>Pelvis Rotation (°)</th>
<th>Trunk Rotation (°)</th>
<th>Stride Length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-61.1 (11.9)</td>
<td>-98.4 (17.7)</td>
<td>1.2 (0.09)</td>
</tr>
</tbody>
</table>

Trunk & pelvis rotation: smaller values = greater rotation towards home plate (0° of rotation is facing home plate, 180° is facing centerfield).

Figure 3. The relationship between drive leg hip internal rotation PROM and trunk rotation angle. 0° indicates the shoulders open and facing the catcher.

Reduction of the stride leg is required to allow the trunk to properly rotate after pelvis rotation optimizing proximodistal energy transfer.\textsuperscript{11,26} Previous literature has speculated that decreased stride leg hip IR PROM contributes to insufficient trunk rotation during pitching and may lead to increased forces about the shoulder and elbow, contributing to tissue breakdown and pain.\textsuperscript{14,15} However, the current study determined increased drive leg hip IR PROM was associated with decreased trunk rotation towards home plate at foot contact. Less trunk rotation at foot contact may be beneficial since prior research suggests too much trunk rotation towards home plate at foot contact may result in the throwing arm lagging behind the body which is known to increase forces at the shoulder and elbow. Therefore, sufficient drive leg hip IR PROM may support proper trunk rotation mechanics at foot contact and potentially reduce injurious upper extremity forces.

Reducing injurious upper extremity forces requires an understanding of the kinematics and other potential factors that contribute to the increased forces. Early trunk rotation, increased shoulder ER, and decreased elbow flexion during pitching increase elbow valgus loads.\textsuperscript{9} The relationship between hip PROM and kinematics that contribute to increased elbow valgus loads has been examined in collegiate pitchers.\textsuperscript{27} Stride leg hip total PROM is associated with maximum shoulder ER and drive leg ER and total PROM is associated with trunk angular velocity during pitching.\textsuperscript{27} It is important to note that only seven collegiate pitchers were examined and the findings may have been due to chance because the study was underpowered. More research is needed to improve the understanding of the contribution of hip PROM to pitching kinematics, joint loads, and injury risk. By identifying potential injurious risk factors than targeted interventions can be developed to reduce injury.

The current study’s findings also showed hip IR, ER, and total PROM did not predict pelvis rotation during pitching.
The results differ from a study in professional pitchers that reported decreased hip total PROM led to altered pelvic rotation during pitching.¹⁰ The discrepancy may indicate that PROM adaptations are more likely to appear in older pitchers. Older pitchers have accumulated more pitching exposure and time to elicit musculoskeletal adaptations. It is also possible that the timing of the season that the pitchers were assessed contributed to the different results between studies. The current study examined PROM in most pitchers prior to the beginning of fall practices and it is unclear when the professional pitchers were tested. If pitchers were tested in season, PROM patterns may be different due to the physical demands of participating in baseball.Stride leg and drive leg hip IR and stride leg total PROM have been observed to decrease over the course of a season in collegiate pitchers.²⁸ Overall, total PROM in the current study (drive leg = 58.2°; stride leg = 57.0°) was approximately 46° less than data presented in professional pitchers (drive leg = 94.8°; stride leg = 67.0°). High school pitchers had approximately 37° less drive leg total PROM than professional pitchers, whereas there was not a large discrepancy in stride leg motion. Differences in hip PROM measurement methodology may have contributed to the lack of agreement between studies. Robb et al.¹⁰ assessed hip PROM with the pitchers prone, whereas the current study assessed motion with the pitchers seated on a table. Assessing hip motion in a seated position can result in lower values due to compressive forces on the hip joint, so the results should be compared with caution.¹⁰ In addition, the current study used a digital inclinometer versus a bubble goniometer to assess PROM. Although different testing positions may result in different PROM magnitudes, the within-pitcher PROM asymmetry between studies is intriguing. Professional pitchers had asymmetry between legs which may explain why there were significant correlations with pitching kinematics that were not observed in the current study. Total PROM in the current study was similar to pilot data that has been presented in collegiate pitchers where the measurements were taken in a prone position.²⁷ Drive leg total PROM in collegiate pitchers has been reported to range from 41.7°–50.3° while stride leg PROM ranges from 41.4°–50.6°.²⁷²⁸ Additional PROM measures such as hip flexion, extension, abduction, and adduction could contribute to compensation in frontal and sagittal plane trunk mechanics and should be evaluated in future studies. It is possible that the trunk rotates less, compensations including increased trunk flexion or lateral flexion may occur in pitchers with limited hip PROM. Future studies should also aim to delineate the role of hip strength and lumbo-pelvic control as it relates to pitching mechanics and performance.

This study did have limitations that should be considered when interpreting the results. Data were collected on high school pitchers from a few high schools in a small geographical area in the southeastern United States, and the results may not be generalizable to pitchers from other geographical regions. The sample size was small, but it was similar to previous investigations into baseball biomechanics.¹⁰,²⁷,²⁹,³⁰

CONCLUSION

Increased drive leg hip IR PROM was associated with decreased trunk rotation towards home plate. Hip total PROM and ER was not related to pitching mechanics. It is critical to continue identifying factors that contribute to altered mechanics to improve pitching performance and reduce injury rates. Range of motion is commonly measured by baseball organizations when performing player evaluations. If PROM was found to be related to altered pitching mechanics, training and rehabilitation programs could be developed to target specific deficits to improve performance and decrease injury susceptibility.

The Auburn University Institutional Review Board approved this study.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

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REFERENCES


Background
Ulnar collateral ligament injuries are rampant in the sport of baseball where kinetic chain impacts, stemming from misappropriation of stride length or changes that occur in competition due to fatigue, have not been evaluated for dynamic elbow stability effects.

Hypothesis/Purpose
To examine the relationship between clinical measures of grip strength and altered stride length in baseball pitchers. It is believed that shorter stride lengths would reduce grip strength in baseball pitchers.

Study Design
Crossover Study Design

Methods
A total of 19 uninjured pitchers (15 collegiate and 4 high school) (age 18.63 ± 1.67 years, height 1.84 ± 0.054 m, mass 82.14 ± 0.054 kg) threw two simulated 80-pitch games at ±25% of their desired stride length recorded by motion capture with two force plates and a radar gun to track each throw. A handheld grip dynamometer was used to record the mean change in grip strength after games from baseline measures. Pairwise comparisons at baseline and post-game denoted grip strength changes and dominant grip strength offsets for stride length conditions.

Results
Subjects with shorter stride lengths revealed a significant decline in grip strength in the dominant arm from baseline (pre-game; 45.1 kg vs. post-game; 43.2 kg, p=0.017, ES=0.28), however all other tests involving dominant grip strength changes and offset analyses were not statistically different for under-stride and over-stride length conditions.

Conclusions
Clinical evaluation of grip strength has the potential to identify altered lower body mechanics and may be considered as a safe and effective monitoring strategy to integrate with motion capture in determining optimal stride lengths for baseball pitchers.

Level of Evidence
Level 3
INTRODUCTION

Elbow valgus torque is the primary mechanism responsible for ulnar collateral ligament (UCL) failure where dynamic stability offered by elbow musculature is critical to stress shielding of the UCL.\(^1\,\,2\) Cadaveric research has shown the biceps, triceps and brachialis provide medial elbow stability at all degrees of forearm rotation.\(^1\) In addition to large, biarticular muscles, the flexor pronator mass appears to provide significant stability despite a deficient, anterior UCL bundle in a supinated wrist position, which is representative of the forearm position near peak valgus loading as the throwing arm lays back in the later stages of the cocking phase.\(^1,\,\,3\)

Optical motion capture provides further context into biomechanical limitations posed by cadaveric loading simulations. However, motion capture presents a challenge as kinetics are expressed as net joint moments combining osseous, connective tissue and muscular contributions to the varus moment and does not identify individual muscles' force applications. Musculoskeletal modeling from three-dimensional pitching analyses can elucidate the roles of specific, medial elbow, dynamic stabilizers that can be trained to apply greater varus torque to resist opening of the medial elbow.\(^4\) Pitching fatigue is the greatest contributor to injury, where electromyography-based modeling has shown how neural activation of forearm musculature is affected by workload and reinforces the need to study grip strength loss as a measure of functional forearm fatigue (FFF) of the flexor pronator mass.\(^5,\,\,6\)

Pitching workload fatigue has been examined through functional strength changes, yet muscular weakness impacting kinematics and kinetics are unknown.\(^7,\,\,8\) Similarly, biomechanical changes have been reported in pitching fatigue studies, yet the movement adaptations described cannot be considered compensations given velocity depreciation and was not maintained with increasing workload.\(^9-\,\,11\)

In other work, stride length has been shown to vary with increased pitch counts that may be accompanied by changes in momentum, timing, physiology and ground reaction force.\(^12-\,\,16\) Compensation to maintain velocity through a reduction in stride length entailed increased total body angular momentum as a result of reduced ground reaction force in the anterior-posterior direction, altering transfers from trunk to throwing arm.\(^14\) Related to this paradigm, Kibler\(^17\) mentioned that altered transfer of ground reaction force from the lower body can reduce kinetic energy of the hip and trunk and thereby increase rotational velocity at the shoulder. Increased throwing arm velocity as a result of lower body force deficits has the potential to increase dynamic stability effort for the forearm musculature making the flexor pronator mass more fatigable.\(^17\) Altered lower body function and its impact on forearm strength has not been extensively studied, yet has been shown to impact blood and salivary biomarkers, as well as visual analog scores related to fatigue.\(^13\) Therefore, this study is novel as it is aimed to model variation in stride length and its impact on FFF to illustrate the importance of clinical evaluation of grip strength in practice and competitive environments to infer less than optimal kinetic chain interactions. The purpose of the study was to examine the relationship between clinical measures of grip strength and altered stride length in baseball pitchers. We hypothesized that FFF of the medial elbow stabilizers will increase with shorter stride lengths (a surrogate for reduced ground reaction force production) to signify less than optimal stride length or pitching fatigue that alters lower body functioning.

METHODS

A cohort of 20 healthy and skilled competitive pitchers were recruited from collegiate and high school seasonal travel programs from across western New York. One pitcher withdrew owing to conflicts with collegiate baseball obligations. Of the remaining 19 participants, 15 were right-handed and four were left-handed (age 18.63 ± 1.67 years, height 1.84 ± 0.054 m, mass 82.14 ± 0.054 kg).\(^14,\,\,16,\,\,18\) None of the athletes had experienced a throwing arm injury that required surgery. All had at least five seasons of competitive experience, were injury free within two years prior to participation, or had fully recovered from all previous injuries and were medically cleared. Prior to participating informed consent was approved by the University at Buffalo's Children and Youth Institutional Review Board, and subject signatures were obtained or parental consent granted for minors.

Upon arrival to the laboratory, intake procedures were initiated which included informed consent review, recording height and weight measurements and collecting baseline grip strength measurements as described in other work.\(^19\) Two calcaneal markers were affixed to the athlete's athletic shoes to be able to discern stride length from three-dimensional (3D) motion capture data (Vicon Motion Systems, Denver, Colorado) and determine simulated game conditions. Stride lengths were determined as the horizontal distance along the global leading axis (horizontal distance from the first or third base perspective) between the drive foot calcaneus at peak knee height to the stride foot calcaneus at stride foot contact.

The instant of stride foot contact was identified by an unpublished pilot study involving force plates, undertaken by the principal investigator, that involved visual inspection of stride foot contact and its corresponding ground reaction force threshold. Pilot research indicated that a registered vertical ground reaction force that exceeded 5% body weight signified the minimum threshold to be considered foot contact. Also in the pilot study, the throwing hand and baseball were tracked with markers to indicate peak throwing hand velocities at the point of ball release.

Two force plates (Kistler Corp, Amherst, New York) were aligned in series with the area over the force plates marked to target drive foot and stride foot placement for each stride length intervention. Two subjects were taller than 1.95m and had longer stride lengths than what the arrangement could accommodate. As a result, the starting point was moved back for these athletes to ensure the stride foot could target the second force platform. These athletes alternated their drive foot placement on and off the first force plate, so that propulsive ground reaction recordings could be captured for every other pitch, and thus both drive leg and stride leg ground reaction force could be recorded (Figure 1).

A randomized cross-over design was used where pitchers
throwing from flat ground in two 80-pitch simulated games on separate days with 72 hours rest between conditions before performing the other condition; 1) at 25% increased stride (OS), and 2) at 25% reduced stride (US) from desired stride length (DSL). The \pm 25\% change from desired stride length, measured in meters, was determined a-priori and was designed to challenge throwing mechanics. The raw stride length difference equated to a 24\% difference in normalized stride length (% body height) between conditions and fell between 50-80\% body height (as measured during the warm-up), which is representative of collegiate and professional pitchers. \textsuperscript{10,20,21} The investigators used 50% and 80% body height stride length as limits in the stride length spectrum to attempt to identify forearm grip strength changes that could be seen between extremes. Previous authors have reported stride length measures for the respective over-stride and under-stride conditions in this study (1.40 \pm 0.15 and 0.95 \pm 0.14 m) and normalized stride lengths (0.76 \pm 0.07 and 0.52 \pm 0.08 \%body-height). \textsuperscript{13-16} Pitches adjusted throwing mechanics from the mean desired stride length (1.24 \pm 0.17m and 0.67 \pm 0.09 \%body-height). \textsuperscript{13}

Prior to simulated games, athletes underwent a standardized warm-up and were given time to prepare themselves with light throwing before initiating 25-30 warm-up pitches prior to simulated games that were recorded by motion capture. The last five warm-up pitches were thrown at 100\% effort at the desired stride length. The two warm-up pitches with the highest velocities were averaged and desired stride length was determined from the kinematic data. At the end of warm-up throwing, ten pitches were thrown for each OS and US game condition to acclimatize pitchers to each simulated game condition.

None of the deliveries were side arm and, therefore, twenty over the top throws at 100\% effort were completed per inning with a ratio of three fastballs to one change-up. The change-up was integrated into the simulated game to offload the throwing arm from delivering only fastballs. This workload allocation was determined from previous work examining short season, minor league baseball pitchers and conservatively estimated for high school, junior college and Division I baseball pitchers. \textsuperscript{22} With the use of a stopwatch, approximately 15 seconds of rest was allocated between pitches with a nine minute rest prescribed to simulate between inning rest periods. Five warm-up throws were allocated before each inning. Testing ceased after the 80\textsuperscript{th} delivery, with approximately 130-140 throws having been accumulated per testing condition. \textsuperscript{14,16,18} Ball velocities of all pitches thrown were tracked with a professional radar gun (Jugs Sports, Tualatin, OR).

Standard motion capture techniques involving eight cameras (VICON MX20 cameras, sampling at 240 Hz with Kistler force plates at 960 Hz) and Visual 3D (C-Motion, Germantown, MD) software were used to record and analyze stride length measurements. Trials were eliminated from analysis when the athlete did not target the force platform for the over or under-stride length condition. To account for the potential of lower body fatigue, an ensemble average of the two highest velocity pitches in the first inning and last inning (four pitches total), were used to calculate in-game stride length measurements.

Grip strength was used to evaluate FFF by measuring force in kilograms on a calibrated, Jamar hydraulic hand dynamometer (Lafayette Instrument, Lafayette, IN). The baseline grip assessment was performed prior to the first simulated game and then prior to the second simulated game after 72 hours of rest to provide a pre-pitching baseline. Grip strength was then recorded immediately after both game conditions. Grip strength procedures were adapted from the work of Kobesova et al. \textsuperscript{19} Athletes sat in a chair with their feet contacting the ground flat-footed, hips and knees flexed at 90 degrees and the testing arm flexed 90 degrees at the elbow that was confirmed by goniometric measurement while maintaining a 0 degree pronation-supination wrist position. Athletes were required to squeeze the hand dynamometer maximally for 5 seconds, with loud verbal encouragement provided by the investigator. A stopwatch indicated 30 seconds between trials to provide recovery for each subsequent trial. An average grip strength over three trials was used in statistical analysis for both the dominant and non-dominant flexor pronator mass musculature. A dominant arm strength offset was calculated for both baseline and post-pitching by subtracting the average non-dominant grip strength from the average dominant grip strength, where a positive value indicated more dominant arm grip strength, while a negative result indicated stronger grip strength for the non-dominant arm.

Statistical analyses were performed using the 2016 version of Excel (Redmond, WA, USA). Paired t-tests compared pre- and post-game grip strength for both the dominant and non-dominant arms for each condition to examine FFF. Pairwise t-tests were also used to determine differences between conditions at baseline and post-game for dominant arm grip strength offsets. Statistical significance, determined \textit{a priori}, was set at $p\leq 0.05$ for all statistical tests. Cohen’s d effect size (ES) was calculated for paired t-tests that met significance using a pooled standard deviation and were interpreted as trivial (0-0.19), small (0.20-0.49),
medium (0.50-0.79) and large (>0.80) effects. Results related to ground reaction force and ball velocity are reported in other work that indicated greater shear ground reaction forces in propulsion and braking with longer strides, yet no changes in ball velocity between stride length conditions.\textsuperscript{16,25}

**RESULTS**

Following an 80-pitch simulated game, significant differences in FFF were not found between baseline and post-pitching measures in the over-stride condition, nor differences in dominant grip strength offsets. In contrast, under-stride pitching revealed a significant decline in strength in the dominant arm from baseline; however, all other tests involving dominant grip strength offset analyses did not yield statistically significant differences (Table 1). All subject-specific data for grip strength for the dominant and non-dominant arm can be seen in Table 2. Potentiation effects, indicated by increased post-game grip strength for the dominant arm by 1kg or greater in force, were seen in some subjects for both conditions. Roughly 17% of subjects (3/19) saw increased post-game grip strength for the dominant arm for the over-stride condition versus 21% (4/19) who demonstrated greater dominant arm grip strength for the under-stride condition. Despite observed strength gains, most of the athletes in this study showed weaker dominant arm grip strength for both simulated games for over-stride and under-stride conditions.

**DISCUSSION**

Functional forearm fatigue of the medial elbow stabilizers increased during the condition of a simulated game outing with a shorter stride length, confirming the study’s hypothesis. Linked to other work, a reduction in stride length, which can be considered a surrogate for reduced ground reaction forces sustained during pitching, can potentially increase muscular effort of the dynamic stabilizers of the medial elbow joint.\textsuperscript{16} Overall, pitchers involved in this study showed weaker non-dominant strength versus the dominant arm at baseline and did not present a shift toward greater non-dominant strength compared to the dominant arm after pitch accumulation. Thus, to monitor FFF in games, one must assess the strength of the dominant arm’s flexor pronator mass as the non-dominant arm did not respond significantly to pitch accumulation.

Valgus stress testing has clearly elucidated the role of the medial elbow stabilizers offered by the flexor pronator mass. In an unloaded, loaded and loaded position with maximum grip force, isometric contraction of the flexor pronator mass saw the joint gap of the medial elbow close by 105mm and reduce opening by 21% with an effect size of 1.01, being a large effect related to isometric flexor pronator mass strength.\textsuperscript{24} Isometric strength of the flexor pronator mass is critical as moderate to high activity in the muscle group has been seen during the late cocking stage and acceleration, which is considered the critical instant in pitching with the highest kinetic properties.\textsuperscript{25,26} Wang et al\textsuperscript{27} performed a pre-fatiguing protocol to examine the effect of FFF on recruitment during pitching and found that the flexor carpi ulnaris increased neural activation by approximately 10% MVC. The fatigue protocol revealed that under fatigue, elevated recruitment of the flexor carpi ulnaris may contribute to elevated muscular effort by a principle medial elbow stabilizer while no changes were seen in elbow kinetics or ball velocity.\textsuperscript{27}

The results shed insight into a clinical opportunity to optimize stride length through grip dynamometry testing. The impacts of a shortened stride, or stride length that is not properly normalized to height, can propose a potential injury risk that could stem from an acute episode in an isolated game, but also exacerbated by high repetitive loads that can impact the recovery of the medial elbow stabilizers. Although strength loss was evident, what remains unknown (and was not measured in this study) was how stride length reduction increased variability in elbow valgus torque. Within-subject variability in elbow valgus load had been modeled where the addition of fatigue to reduce load capacity of the UCL, higher load variability, and pitch repetition, collectively lowered the injury threshold and increased theoretical risk.\textsuperscript{28} Combined with the current study’s results, identifying compensatory mechanisms that increase elbow valgus load variability and, in particular, altered mechanics that reduce one’s ability to withstand altered loading patterns through a reduction in grip strength, should be a principle focus of study in injury prevention. Current methods used to determine fatigue in games stem from the use of radar guns. Since previous work has identified no significant changes in ball velocity during an outing, and in some cases increases in ball velocity over a sea-

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**Table 1. Mean Pre and Post-Game Grip Strength Measures for Stride Length Conditions**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Over-Stride</th>
<th>Under-Stride</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Game Dominant Grip Strength (kg)</td>
<td>44.6</td>
<td>45.1*</td>
</tr>
<tr>
<td>Pre-Game Non-Dominant Grip Strength (kg)</td>
<td>43.4</td>
<td>44.9</td>
</tr>
<tr>
<td>Post-Game Dominant Grip Strength (kg)</td>
<td>43.4</td>
<td>43.2*</td>
</tr>
<tr>
<td>Post-Game Non-Dominant Grip Strength (kg)</td>
<td>43.8</td>
<td>44.0</td>
</tr>
<tr>
<td>Baseline Dominant Arm Grip Strength Offset (kg)</td>
<td>1.24</td>
<td>0.30</td>
</tr>
<tr>
<td>Post-Game Dominant Arm Grip Strength Offset (kg)</td>
<td>-0.41</td>
<td>-0.82</td>
</tr>
</tbody>
</table>

* Indicates that grip strength was reduced post-game versus baseline for the under-stride game condition (p =0.017, d = 0.28).
Table 2. Bilateral Strength Changes for All Subjects for Over-Stride and Under-Stride Simulated Game Conditions

<table>
<thead>
<tr>
<th>SUBJECTS</th>
<th>OVER-STRIDE</th>
<th></th>
<th>UNDER-STRIDE</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DOMINANT ARM</td>
<td>NON-DOMINANT ARM</td>
<td>DOMINANT ARM</td>
<td>NON-DOMINANT ARM</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre (kg)</td>
<td>Post (kg)</td>
<td>Δ</td>
<td>Pre (kg)</td>
<td>Post (kg)</td>
</tr>
<tr>
<td>1</td>
<td>44.0</td>
<td>51.8</td>
<td>7.9</td>
<td>40.7</td>
<td>50.4</td>
</tr>
<tr>
<td>2</td>
<td>39.5</td>
<td>39.0</td>
<td>-0.5</td>
<td>38.8</td>
<td>38.6</td>
</tr>
<tr>
<td>3</td>
<td>35.4</td>
<td>36.2</td>
<td>0.9</td>
<td>38.3</td>
<td>34.7</td>
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<tr>
<td>4</td>
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<td>-2.4</td>
<td>40.0</td>
<td>39.4</td>
</tr>
<tr>
<td>5</td>
<td>44.5</td>
<td>42.1</td>
<td>-2.4</td>
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<td>41.6</td>
</tr>
<tr>
<td>6</td>
<td>59.9</td>
<td>59.3</td>
<td>-0.6</td>
<td>59.6</td>
<td>59.1</td>
</tr>
<tr>
<td>7</td>
<td>37.3</td>
<td>37.6</td>
<td>0.3</td>
<td>40.8</td>
<td>39.3</td>
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<tr>
<td>8</td>
<td>57.8</td>
<td>51.6</td>
<td>-6.3</td>
<td>41.9</td>
<td>41.4</td>
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<td>9</td>
<td>54.9</td>
<td>59.7</td>
<td>4.8</td>
<td>51.9</td>
<td>59.9</td>
</tr>
<tr>
<td>10</td>
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<td>-1.0</td>
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</tr>
<tr>
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<td>44.7</td>
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<tr>
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</tr>
<tr>
<td>14</td>
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<td>-10.0</td>
<td>54.0</td>
<td>49.4</td>
</tr>
<tr>
<td>15</td>
<td>37.5</td>
<td>35.2</td>
<td>-2.3</td>
<td>35.6</td>
<td>43.9</td>
</tr>
<tr>
<td>16</td>
<td>47.7</td>
<td>43.7</td>
<td>-4.0</td>
<td>44.3</td>
<td>42.9</td>
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<td>17</td>
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<td>18</td>
<td>42.5</td>
<td>34.6</td>
<td>-7.9</td>
<td>44.1</td>
<td>36.0</td>
</tr>
<tr>
<td>19</td>
<td>49.4</td>
<td>47.5</td>
<td>-2.0</td>
<td>43.8</td>
<td>49.9</td>
</tr>
<tr>
<td>Mean</td>
<td>44.6</td>
<td>43.4</td>
<td>-1.3</td>
<td>43.4</td>
<td>43.8</td>
</tr>
<tr>
<td>Std</td>
<td>8.0</td>
<td>7.9</td>
<td>4.2</td>
<td>6.3</td>
<td>7.2</td>
</tr>
</tbody>
</table>

* Dominant arm grip strength was reduced by 1.9 kg post-game from pre-game baseline for the under-stride game condition (p < 0.017). Pre; Pre-Game, Post; Post-Game.

son, perhaps radar gun velocities may not be able to detect biomechanical compensations. Thus, clinical strength assessments of the flexor pronator mass to assess throwing arm fatigue post-game from baseline testing may be more valuable in order to understand changes in mechanical efficiency as determined by the percentage of strength retained from the baseline measurement. As an application of the findings of this work, grip strength losses greater than 1.9 kg may alert coaches to examine pitching mechanics and implement subsequent musculoskeletal tests for range of motion and strength changes in proximal segments.

There are a few limitations to the investigation. First, the research involved only 19 athletes with small, but significant effects (d=0.28). The small effect size calculation revealed that stride length may not have had a strong clinical influence on flexor-pronator strength loss, yet further research undertaken with greater statistical power could yield different results. The authors also cannot conclude that a decrease in grip strength is causally related to an increase in elbow valgus stress, as this study only focused on strength loss and its potential to reduce dynamic stability of the elbow. Joint mechanics were not explored in this work; therefore, FFF requires further investigation either with wearable technology or an optical tracking system to better understand how lower body mechanics influence joint loads in relation to grip strength loss. The results of this study are not generalizable to competitive game play, as stride length changes may not be as drastic, yet the model does provide an approach to inspire future work dedicated to stride length optimization, examining biomechanical responses along a variety of normalized body height spectrums. At the time of the completion of this work, the 20-second pitch clock rule had not been instituted in professional baseball; therefore, it is possible that the allocated rest times in this work could encourage additional fatigue by comparison to current conditions in minor league play. Responses seen between stride length extremes also cannot infer changes occurring from desired stride length, which is a goal of future study. A simple AB cross-over design (common in early phase studies) was utilized because the advantage is that each subject served as their own control and a smaller number of participants are required when compared to parallel-group designs. The disadvantage of this methodological design was the inability for comparing desired stride length data with the + 25% stride conditions. To enable comparison with desired stride length, more complicated crossover designs are necessary, perhaps the same desired stride length condition being administered in multiple different periods (e.g. ABAC or ABCABC designs) or to deploy a parallel-group design (ABC) requiring larger samples.
Maximum capacity flat ground pitching may have involved higher exertion levels than when throwing from a pitching mound, and other notable limitations include the absence of cleats, and "in contest" competition, however these facets are consistent with other laboratory studies. It is also important to note that related to game simulations being performed on flat ground, a small percentage of taller athletes required adjustment in throwing positions in order to target force plates. As such, given this work involved ground reaction force of the landing leg to determine stride length, only 40 pitches were available for taller pitchers to select the two fastest trials in the first inning and last inning for stride length determination. In the future, it is recommended that researchers evaluate laboratory constraints to ensure all 80 pitches are available for analysis. Similarly, effects may be different in studies that repeat the current methods by having pitchers throw from a mound without force plate adjustment. Although the results demonstrated a significant, strength loss of 1.9 kg (approximately 4 pounds) following simulated games with shortened stride lengths, the findings may not be considered clinically significant, where further work evaluating the presence of injury, or pain around such values is warranted.

CONCLUSION

Clinical evaluation of grip strength has the potential to identify altered lower body mechanics and may be considered as a safe and effective monitoring strategy to integrate with motion capture in determining optimal stride lengths for baseball pitchers.

CONFLICTS OF INTEREST

The authors of this work have no conflicts of interest to report.

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REFERENCES


Injuries in Quidditch: A Prospective Study from a Complete UK Season

Rachel Pennington, Ashley Cooper, Alastair C Faulkner, Alasdair MacInnes, Thomas S W Greensmith, Alistair I W Mayne, Peter S E Davies

1 St Andrews University, Scotland, 2 Psychiatry, Pennine Care NHS Foundation Trust, UK, 3 Trauma and Orthopaedics, NHS Tayside, Dundee, Scotland, 4 Trauma and Orthopaedics, County Durham and Darlington NHS Foundation Trust, UK, 5 Trauma and Orthopaedics, Belfast Health and Social Care Trust, UK

Keywords: quidditch, injury, gender, equality, concussion

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Background
Quidditch is a mixed-gender, full-contact sport founded in the USA in 2005, played worldwide by an estimated 25,000 players. It is one of the few mixed-gender full-contact sports, yet there remain few published studies regarding injury rates and patterns. A previous study suggested that the overall rate of injury in quidditch is in line with other contact sports, however raised concerns that female players were sustaining a higher rate of concussion when compared to male players.

Purpose
To examine injury rates and injury patterns in UK quidditch athletes over the course of a single season.

Study design
Prospective epidemiological study

Methods
Data were prospectively collected by professional first aid staff for the 2017-18 season spanning all major UK tournaments, involving 699 athletes. Anonymized player demographics were collected by an online survey. Time loss injury rates were measured per 1000 athletic exposures (AEs) and hours of play.

Results
The overall time loss injury rate was 20.5 per 1000 hours or 8.0 per 1000 AEs. The combined rate of concussion was 7.3 per 1000 hours or 2.8 per 1000 AEs. There was no statistical difference between time loss injuries in males (20.9/1000 hours and 8.1/1000 AEs) and females (13.9/1000 hours and 5.4/1000 AEs) (p=0.30) and no statistical difference between concussion rates in males (n=7) and females (n=4) (p=0.60).

Conclusions
Total time loss injury rates in quidditch appear to be comparable with other full-contact sports such as football. The rate of concussions for both males and females appear higher when compared to other contact sports.

Level of evidence
3
INTRODUCTION

Competitive quidditch is a mixed-gender, full-contact sport played worldwide.\(^1\) College students in the USA founded the real-life sport in 2005 after being inspired by the magical game of Quidditch created by JK Rowling in her Harry Potter novels.\(^2\) There are now at least 450 registered teams across the globe with 3500 registered athletes in the USA alone.\(^3\) Quidditch is played in over 40 countries by an estimated 25,000 players.\(^4\) The governing body of quidditch in the UK is QuidditchUK.\(^5\)

Rules are similar to the fictional game, involving two teams of seven players all mounted on a broomstick. Chasers aim to throw the quaffle (a deflated volleyball) through any of the three opposing hoops to score 10 points, but must negotiate their way past the keeper.\(^6\) Beaters can throw bludgers (a dodgeball) at opposing players, which temporarily suspends them from play. The snitch (a golden, winged, self-mobilizing ball in the novels) is an impartial player dressed entirely in yellow, shielding a tennis ball in a sock hanging from the back of their shorts. A seeker from each team aims to 'catch' the snitch (detach the tennis ball), which awards that team 30 points and ends the game. Players must have a broomstick between their thighs during play, but unlike in the wizarding world, are unable to levitate.

Quidditch is a fairly unique sport in that mixed-gender teams are mandatory with the rules stating that 'a team may not have more than four players who identify as the same gender in play at the same time'.\(^6\) Quidditch therefore promotes inclusion of players of all genders, including those who do not identify with the traditional binary genders. Consequently, it is a highly progressive and inclusive team sport. However, it also poses theoretical risks of increased injury rates due to its full contact and mixed gender nature.

The QuidditchUK season consists of the Northern and Southern Regional Cups as qualifiers for the British Quidditch Cup (BQC), alongside smaller events. The Quidditch Premier League (QPL) also takes place each year and is the biggest and most successful league championship played outside the national governing body. Players who play in the QuidditchUK season also compete in the QPL.

Undertaking injury surveillance is important to ensure that risk factors can be identified, enabling preventative strategies including rule evolvement as this new sport develops. A previous retrospective study of injuries in quidditch identified several areas of interest.\(^7\) The most significant of these was that female players reported an increased incidence of concussion compared to their male teammates. This prospective injury surveillance study was designed to examine these injury trends further, and to more accurately assess the risks posed by this emerging sport. Injuries can be considered significant if they are "time loss injuries" (TL injuries) meaning the athlete is not able to continue playing that day and has a period of recovery before being able to play again. The purpose of this study is to examine injury rates and injury patterns in UK quidditch athletes over the course of a single season.

METHODS

This was a prospective observational study undertaken over the 2017 – 2018 QuidditchUK season and the QPL. Self-reported demographic data consisting of age, sex, gender, height, weight, and player position were collected using a mandatory standardised anonymous pre-competition questionnaire. This questionnaire was completed through Google forms as part of the registration process. Every competing player provided consent for the study and was therefore included.

Injury data were prospectively collected by professional first aid staff present at the events, using a standardized player-injury form at the time of injury. Information about any injury that was assessed by a first aider was recorded, regardless of severity of the injury. Details of the injury included: injury type, body location of injury, level of assessment required, treatment required and whether the player could return to competition. Player self-reported demographics were recorded again as the pre-competition data were anonymous and could not be linked to injuries. Consent was taken to store information about their demographics and injury anonymously. All data were stored using Microsoft Excel (Version 2016 MSO).

The primary injury definition used for the study was a TL injury, which was defined as any injury which resulted in an inability to return to play that day. Players who sustained injuries which were treated but did not cause a loss of playing time (e.g. minor cuts) were not included in the analysis. Concussion was defined as a "head injury with significant impact force or shows an observable sign of concussion" or "reported symptoms of concussion", as per the Quidditch-UK concussion protocol (Appendix 1).

Injury rates were calculated as the incidence per 1000 hours of competitive play (/1000 hours) and per 1000 athletic exposures (/1000 AEs). The injury rates relate to match play only; no data from training sessions were included. The Pearson Chi squared test was used to compare the time loss injury rates and concussion rates between males and females using Microsoft Excel.

For the purposes of this study, sex was defined as either male or female as assigned at birth and gender was defined by the individual's self-identification. Individuals self-reported sex was used for analysis due to the wide variety of non-binary genders reported. This led to difficulties in maintaining confidentiality with small numbers of athletes in non-binary categories, and difficulty in comparing injury rates with other sports.

ETHICAL APPROVAL

The Health Research Authority online tool indicated that this study did not need National Health Service Research Ethics Committee (NHSREC) review for sites in England or Scotland. A local research ethics committee was also contacted for confirmation of this before data were collected.
Table 1. Player demographics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean Male (n=378)</th>
<th>Mean Female (n=315)</th>
<th>Mean Prefer not to say (n=6)</th>
<th>Total (n=699)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age years (years)</td>
<td>21.7</td>
<td>21.2</td>
<td>22.8</td>
<td>21.5</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>178.7</td>
<td>171.4</td>
<td>184.7</td>
<td>175.5</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>76.3</td>
<td>64.8</td>
<td>76.3</td>
<td>71.1</td>
</tr>
</tbody>
</table>

Table 2. Injuries seen over the course of the season

<table>
<thead>
<tr>
<th>Type of Injury</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concussion</td>
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</tr>
<tr>
<td>Head</td>
<td></td>
</tr>
<tr>
<td>Soft tissue injury e.g. sprain/ligament injury</td>
<td>9</td>
</tr>
<tr>
<td>Wrist/hand</td>
<td>3</td>
</tr>
<tr>
<td>Shoulder</td>
<td>1</td>
</tr>
<tr>
<td>Knee</td>
<td>2</td>
</tr>
<tr>
<td>Ankle</td>
<td>3</td>
</tr>
<tr>
<td>Suspected fracture / joint dislocation</td>
<td>6</td>
</tr>
<tr>
<td>Wrist/hand</td>
<td>2</td>
</tr>
<tr>
<td>Shoulder</td>
<td>1</td>
</tr>
<tr>
<td>Ribs</td>
<td>3</td>
</tr>
<tr>
<td>Haematoma / Bruise</td>
<td>3</td>
</tr>
<tr>
<td>Wrist/hand</td>
<td>1</td>
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<tr>
<td>Knee</td>
<td>1</td>
</tr>
<tr>
<td>Ankle</td>
<td></td>
</tr>
<tr>
<td>Wound – laceration</td>
<td>2</td>
</tr>
<tr>
<td>Lip</td>
<td>1</td>
</tr>
<tr>
<td>Head</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
</tr>
</tbody>
</table>

RESULTS

DEMOGRAPHICS

In the 2017 – 2018 quidditch season there were 56 teams competing in the four competitions studied, comprising 699 players. Self-reported player demographics are shown in Table 1.

The sex (as assigned to at birth) of 315 players were female and the sex of 378 players were male. Six players preferred not to disclose their sex, and thus have been excluded from the analysis. Of the 699 players, 302 identified as being a woman, 360 identified as being a man. Of these, 10 reported as being transgender (four women and six men). Twenty-nine players identified as being non-binary and eight preferred not to disclose their gender.

There were 3,868 athletic exposures equating to 1,509 hours of play. A total of 102 injuries required assessment, with 31 TL injuries identified. Of the players sustaining a TL injury, there were 9 females and 22 males. There were no significant differences in mean age, weight, height or BMI among injured athletes compared with non-injured athletes. In total, there were 11 concussions: four females and seven males. There were 12 injuries that required referral to the local accident and emergency department for assessment.

INJURY TYPE

Table 2 presents the breakdown of the injuries sustained. Head and extremity injuries were the most common injuries observed.

OVERALL INJURY RATE

The overall TL injury rate was 20.5/1000 hours or 8.0/1000 AEs. In males the TL injury rate was 20.9/1000 hours and 8.1/1000 AEs and in females it was 13.9/1000 hours and 5.4/1000 AEs. There was no statistical difference between TL injuries for males vs female (p=0.30), shown in Table 3.
Table 3. Injuries sustained by male and female subjects

<table>
<thead>
<tr>
<th></th>
<th>Injured</th>
<th>Uninjured</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>18</td>
<td>832</td>
<td>850</td>
</tr>
<tr>
<td>Female</td>
<td>9</td>
<td>633</td>
<td>642</td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
<td>1465</td>
<td>1492</td>
</tr>
</tbody>
</table>

*p=0.30, regarding difference between time loss injuries for males vs. females*

Table 4. Concussions sustained by male and female subjects

<table>
<thead>
<tr>
<th></th>
<th>Concussion</th>
<th>No concussion</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>7</td>
<td>843</td>
<td>850</td>
</tr>
<tr>
<td>Female</td>
<td>4</td>
<td>638</td>
<td>642</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td>1481</td>
<td>1492</td>
</tr>
</tbody>
</table>

*p=0.60, regarding difference between concussions in males and females.*

Table 5. Time loss injury rates in match play in other sports compared to quidditch

<table>
<thead>
<tr>
<th></th>
<th>Time loss injury rates / 1000 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Football</td>
</tr>
<tr>
<td>Male</td>
<td>18.8</td>
</tr>
<tr>
<td>Female</td>
<td>16.4</td>
</tr>
</tbody>
</table>

CONCUSSION RATE

The combined rate of concussion was 7.3/1000 hours or 2.8/1000 AEs. There was no statistical difference in concussion rate between males and females (p=0.60), which is shown in Table 4.

MECHANISM OF CONCUSSION

Of the 11 players that sustained a concussion injury, nine were reported as due to a tackle/body block, and two due to contact with the ground.

DISCUSSION

Quidditch is a sport that is progressive in terms of gender equality, with increasing popularity throughout the world. The nature of the sport is full-contact between mixed sexes and genders, ages and abilities. This study is the first prospective, longitudinal study looking at an entire season of competitive quidditch and will inform the governing body and participants of the sport.

It is important to note that individuals self-reported sex was used for analysis due to the wide variety of non-binary genders reported. This led to difficulties in maintaining confidentiality with small numbers of athletes in non-binary categories, and difficulty in comparing injury rates with other sports.

OVERALL INJURY RATE

Injury rates in quidditch appear to be comparable with other widely played full contact sports. For comparison, a large study undertaken by Hootman et. al. looking at the epidemiology of collegiate sporting injuries is summarized in Table 5, showing that in other sports, TL injury rates are higher. Hootman focused on analyzing data for injuries that occurred during participation in an organized intercollegiate practice or contest.

CONCUSSION RATE

A previous retrospective study suggested high rates of concussion in quidditch warranting further investigation. A systematic review undertaken by Prien et. al. looking at the epidemiology of concussions in contact team sports has been summarized in Table 6, to provide comparison to the rates of quidditch from this current study. Concussion rates in quidditch are higher than that of rugby, a sport which is often considered high risk for concussion. Reassuringly, the rates of concussion appear similar between males and females and do not suggest that allowing full contact between males and females is problematic in terms of head injuries. The previous study was based on a retrospective self-reporting questionnaire and is subject to bias in self-reporting between sexes. Broshek et. al. suggested that there were self-reporting differences in concussion between sexes which further complicates concussion reporting in mixed-
Table 6. Concussion rates in match play compared to quidditch.

<table>
<thead>
<tr>
<th></th>
<th>Football /1000 hours</th>
<th>Rugby /1000 AE</th>
<th>Ice Hockey /1000 hours</th>
<th>Quidditch /1000 AE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>0.44</td>
<td>1.07</td>
<td>3.89</td>
<td>3.00</td>
</tr>
<tr>
<td>Female</td>
<td>1.76</td>
<td>1.48</td>
<td>1.58</td>
<td>2.11</td>
</tr>
</tbody>
</table>

A conference paper by Tran et. al. profiled concussion in quidditch players in Major League Quidditch, a semi-professional league based in the USA and Canada. In this study, twenty-five percent of players reported to have sustained a medically confirmed concussion during play. This was higher than the concussion rates found in this study. However, this study was based on an emailed retrospective self-reported survey, had a response rate of 34%, and is yet to be published in a peer-reviewed journal.

Previous research led to QuidditchUK introducing a Concussion Policy, which demonstrates the sport is evolving to improve safety for participants (Appendix 1). This policy provides protocols for the diagnosis and management of suspected head injuries including the requirement of a medical opinion to authorise return to play where a diagnosis of concussion is suspected. All concussions identified in this study were TL injuries, indicating that the protocol was followed and patients with concussion were removed from play. The present study confirms relatively high rates of concussion within the quidditch community. By following the concussion policy, players are removed from play and are protected from more significant head injuries.

The finding of no significant difference in overall injury and concussion rates between males and females is reassuring. This study suggests that mixed sex contact sports can be safe for all, however further work is required to confirm this is the case in other mixed-gender full-contact sports.

LIMITATIONS

Few players sustained TL injuries, and only injuries sustained during competitive play were captured. To improve the quality of data, a larger study designed to capture data over multiple seasons and including training data would likely give the truest picture of injuries in quidditch. Players developing chronic TL injuries who did not present for assessment would not have been captured by the study methodology. We did not follow players up to determine days of sport lost due to their injury, and as such are unable to report on this outcome.

Despite these limitations, the present study offers a robust description of the incidence and nature of injuries occurring during quidditch matches in the United Kingdom.

CONCLUSION

Quidditch is an exciting, inclusive emerging sport which is rapidly growing in popularity throughout the world. This study has highlighted that although overall injury rates do not appear alarming, the rate of concussion is high compared with other sports. We have introduced a clear concussion policy to prevent further head injury in patients sustaining concussion.

It is important to identify injury patterns to raise the question of the need for rule changes to improve athlete safety. Incorporating the findings of the present study in the ongoing development of quidditch will be important to ensure its successful ongoing evolution as a safe sport.

COMPETING INTERESTS

We declare that we have no competing interests.

Submitted: November 09, 2020 CDT, Accepted: August 24, 2021 CDT
REFERENCES


Appendix 1. Concussion Protocol

The Effect of a Novel Training Program to Improve Trunk Stability Push Up Performance in Active Females: A Pilot Study

Kate Schwartzkopf-Phifer, Suzanne Leach, Katie Whetstone, Kevin Brown, Kyle Matsel

1 Department of Physical Therapy, University of Evansville, 2 Rehabilitation and Performance Institute, PSC, 3 Rehabilitation and Performance Institute

Keywords: females, trunk stability, functional movement

https://doi.org/10.26603/001c.28055

Background
Trunk stability is a risk factor commonly associated with lower extremity injuries, particularly in females. Performance on trunk stability tasks, such as the Trunk Stability Push Up (TSPU), is less than optimal in females. Current corrective programs include few females, and clinically, improvements for females have been minimal.

Purpose/Hypothesis
The purpose of this pilot study was to determine the effectiveness of a novel trunk stability intervention program in improving TSPU performance in a cohort of active female participants. It was hypothesized that ≥60% of participants would improve their TSPU scores to ≥2 via Functional Movement Screen™ (FMS™) criteria following a novel six-week intervention program.

Study Design
Pilot Cohort Study

Methods
Participants were screened for pain with lumbar and shoulder clearing tests and hypermobility was assessed using Beighton scores. Additional testing included a breathing screen, the FMS™, Y-Balance Test-Lower Quarter and Y-Balance Test-Upper Quarter. Participants who scored a 1 on the TSPU received a home exercise program instructed by student physical therapists. Exercises focused on improving awareness of lumbar spine position and thoracic spine mobility. Participants returned for follow-ups after two and four weeks for instruction in exercise progression, which increased postural demand on the lumbar spine and upper extremities, and utilized closed-chain, multiplanar stability strategies.

Results
Nine of 20 participants (45%) scored ≥2 on the TSPU at posttest. Due to the COVID-19 pandemic, only 12 participants were able to complete all posttest outcome measures. No significant differences were noted in the remaining outcome measures. Conclusion: The results of this study indicate that a multiplanar exercise approach, combining anti-extension and anti-rotation training, was beneficial for inducing trunk stability improvements in some active females.

Corresponding Author:
Kate Schwartzkopf-Phifer, DPT, PhD, OCS
Department of Physical Therapy
University of Evansville
Evansville, Indiana 47708 USA
Fax number: 833-345-3918
Phone number: (812) 468-2453
Email: ks148@evansville.edu
Level of Evidence

INTRODUCTION

The susceptibility of the lower extremity (LE) to musculoskeletal injury in sports can vary based on biological sex differences. LE injuries in active adults can occur in either sex, however, females tend to have higher injury incidences compared to their male counterparts. When compared to male counterparts, female collegiate and high school athletes are greater than two times more likely to sustain an anterior cruciate ligament (ACL) injury. Additionally, LE stress fracture rates in high school female athletes outpace rates in males by nearly two-fold. Likewise, the prevalence of chronic low back pain is 50% higher in females over the age of 18 relative to males. The impact of LE injuries in active females has significant financial implications directly related to health care utilization and costs. Specifically, females aged 15–44 with LE injuries accounted for more than $90,000 visits to the emergency department in 2010, with an average cost of over $1,700 per visit.

Several risk factors have been identified to explain the disproportionate LE injury rates, such as altered neuromuscular control and landing mechanics at the knee, anatomic differences, and impaired postural trunk stability. Though trunk stability is an important risk factor to address in females, it is inherently difficult to measure; no standardized definition of trunk stability currently exists, therefore, no standard measurement exists. Examples of trunk stability measures include isometric strength tests of the trunk and hip, trunk endurance holds, and planking or bridging activities. Due to the variability in testing methodology, it may be more practical to utilize a measurement that captures all these factors simultaneously.

One test which has been theorized to measure core function is the Trunk Stability Push Up (TSPU). The TSPU is a component of the Functional Movement Screen™ (FMS™) which consists of seven fundamental movement patterns designed to quickly screen for major movement limitations and pain. Multiple authors have reported that poor performance on the FMS™ is associated with increased injury risk in active male and female populations. Specifically, the scoring of the TSPU test demonstrates excellent inter-rater reliability (kw=0.82) and fair to good intra-rater reliability (k=0.68). Furthermore, the TSPU can be easily administered in any setting without additional equipment requirements. Thus, the TSPU may be a functional, field-expedient alternative to capture the construct of trunk stability.

In adolescents, a significant difference (p=0.000) in TSPU performance was noted by Abraham et al, with males outperforming females. Anderson et al reported 69% (n=20/29) of high school females failed the TSPU (defined as scoring a 1 using the FMS™ scoring criteria) compared to only 13% (n=4/31) of males. This gender difference has been observed in collegiate athletes as well, with females scoring significantly lower than males (p<0.001). The gender difference persists into adulthood, with more than 60% (n=65/108) of active females failing the TSPU compared to less than 10% (n=10/101) of active males. Collectively, this evidence suggests that poor performance on the TSPU develops early and persists into adulthood, even in healthy and active populations.

Several intervention programs designed to improve performance on the FMS™ exist in the literature. Nearly all are effective at improving composite scores on the FMS™ within four to six weeks, in varied populations including firefighters, mixed martial arts athletes, professional football players, and Reserve Officer Training Corps (ROTC) cadets. However, there are several limitations that hinder a direct transfer of the results of these programs to the clinical treatment of trunk stability, as measured by the TSPU, in females. First, the populations studied are predominantly male. Only one study had greater than 4% of the sample represented by females, and three studies did not include any females. In a cluster randomized cohort, Basar et al compared standardized group warm up exercises to individualized programs to determine effectiveness at improving FMS™ scores and Army Physical Fitness Test performance. While 41% of subjects were female (n=18), no analysis based on gender was performed. Secondly, most studies that report improvement in FMS™ scores after exercise intervention programs only report changes in the overall composite score, thus leaving it unclear as to which component screen of the FMS™ changed and led to the observed improvement.

Current recommendations for exercises to improve TSPU performance include single plane, anti-extension exercises. Such recommendations have excellent face validity, as anti-extension exercises encourage maintenance of neutral lumbar spine positioning, particularly during anteriorly directed forces. This neutral lumbar spine position and control appear necessary to prevent the anterior pelvic tilt and trunk lag commonly observed in females while performing the TSPU (Figure 1). Despite the sound rationale, clinicians continue to observe suboptimal improvements in TSPU performance in females. It is likely that the exercise programming should be more comprehensive to see improved trunk stability as measured by the TSPU in this population.

Given the elevated incidence of LE injury, deficits in hip and trunk control, and high proportion of poor or failing scores on the TSPU, it is necessary to determine if trunk stability, measured by the TSPU, can be improved in active females. Development of a comprehensive program to improve performance on the TSPU may provide crucial information for clinicians struggling to improve trunk stability in their active female clients. Therefore, the primary purpose of this pilot study was to determine the effectiveness of a novel trunk stability exercise program in improving TSPU performance in a cohort of active female participants.

It was hypothesized that >60% of participants would improve their TSPU scores following six weeks of intervention. The secondary purpose was to examine the program’s effect on additional measures of movement quality, and trunk and dynamic stability. It was hypothesized that significant
improvements in these additional measures would be observed at posttest compared to baseline testing.

METHODS

Female participants, between the ages of 18 and 45, were recruited via flyer and e-mail from faculty and student clubs at the University of Evansville and the Stone Family Center for Health Sciences, which houses allied health programs from multiple universities. Female participants were eligible if they self-reported meeting physical activity guidelines by the American Heart Association31 for the last four consecutive weeks. Rolling recruitment of subjects occurred from October 2019–March 2020, with all participants belonging to either a fall or spring cohort. This study was approved by the Institutional Review Board at the University of Evansville.

Participants were screened for lumbar and shoulder pain by completing a prone press up and Yocum impingement test, respectively. If the subject reported pain with either test, she was excluded from the study. Additional exclusion criteria included: limitations of >50% in shoulder mobility or active straight leg raise (based on American Academy of Orthopaedic Surgeons32 definitions), history of lumbar or shoulder surgery, history of anterior shoulder instability or recurrent shoulder dislocations, current pregnancy, and any non-musculoskeletal issue resulting in exercise restrictions from a healthcare provider.

Participants signed an informed consent then provided demographic information including age, height, weight, injury history, and current activity level. All data collection procedures were completed by three licensed physical therapists, two with board certifications (in orthopedics and sports) and one orthopedic physical therapy resident, with thirteen, eleven, and one years of experience with all data collection procedures respectively. Subjects were first assessed for generalized joint hypermobility, a factor that has impacted dynamic stability measures in other active female populations,33 using the Brighton score. The Brighton score is a common clinical assessment scored on a nine-point scale, with operationally defined mobility assessments of the following (all movements performed bilaterally): extension of the 5th metacarpophalangeal, elbow, and knee joints; forward bending; apposition of the thumb. Brighton scoring has substantial intrarater reliability (kappa=0.7534) with a score of four or more representing hypermobility.34,35

All participants completed the FMS™, which qualitatively screens fundamental movement patterns in people without known musculoskeletal pain. The FMS™ has been described previously1 and studied extensively, demonstrating good reliability (ICC= 0.84–0.87) among novice to experienced raters.36 The main outcome measure, the TSPU, is a subcomponent of the FMS™. All movement patterns for the FMS™ have established criteria and are scored on an ordinal scale from 0–5: 0 represents pain with the movement, 1 represents inability to perform the movement, 2 represents completion of the movement with compensations, and 3 represents completion of the movement without compensations. Because the purpose of this study was to improve TSPU performance, subjects scoring 2 or greater were considered to “pass” the TSPU component of the FMS™ and were therefore excluded. Subjects scoring a 1 were considered to “fail” the TSPU and could be included in the intervention.

All participants completed a breathing screen, which included a mini-questionnaire and a breath hold test using the protocol established by Kiesel et al.37 The breathing screen captures dysfunctional breathing, which has been linked to trunk musculature function.38,39 The mini-questionnaire has four items (Appendix 1) which are scored on an ordinal scale of 0–4 (0=never, 1=rare, 2=sometimes, 3=often, 4=very often). Breath hold time following a normal exhalation (functional residual capacity) was then measured using a digital timer. A rating of 3–4 on any of the mini-questionnaire items in combination with a low breath hold time (<25 seconds) results in a sensitivity of 0.89 for identification of dysfunctional breathing in adults.37

Finally, the anterior reach of the Y-Balance Test-Lower Quarter (YBT-LQ) and the superolateral reach of the Y-Balance Test-Upper Quarter (YBT-UQ) were performed to capture a continuous measurement of dynamic trunk stability. These reaches were chosen because they are the most robustly studied directions, have excellent reliability, and are most associated with neuromuscular control deficits.40–42

In the anterior reach of the YBT-LQ, the subject must maintain single limb stance on the test kit, while using the opposite leg to push a slide box into the anterior direction. This is repeated on the opposite leg, with the maximum distance reached in three trials being used for analysis. In the super-

Figure 1. Illustration of a Trunk Stability Push Up (TSPU) failure. A. Start position for the TSPU. Hands are positioned under the shoulders, with thumbs at the height of the clavicles. B. Subjects were instructed to push up from the floor as a unit, keeping shoulders and hips level. C. End position for the TSPU.
Table 1. Results of paired t-tests for secondary, continuous outcomes.

<table>
<thead>
<tr>
<th>Test</th>
<th>n</th>
<th>Pretest μ (SD)</th>
<th>Posttest μ (SD)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breath Hold Test</td>
<td>20</td>
<td>14.12 (4.5)</td>
<td>15.96 (7.6)</td>
<td>0.22</td>
</tr>
<tr>
<td>Anterior Reach—Right</td>
<td>12</td>
<td>58.6 (6.4)</td>
<td>58.6 (7.5)</td>
<td>0.99</td>
</tr>
<tr>
<td>Anterior Reach—Left</td>
<td>12</td>
<td>60.3 (5.1)</td>
<td>58.7 (5.6)</td>
<td>0.41</td>
</tr>
<tr>
<td>Superior Lateral Reach—Right</td>
<td>12</td>
<td>63.00 (9.8)</td>
<td>62.7 (10.6)</td>
<td>0.89</td>
</tr>
<tr>
<td>Superior Lateral Reach—Left</td>
<td>12</td>
<td>66.3 (7.1)</td>
<td>65.4 (9.0)</td>
<td>0.64</td>
</tr>
</tbody>
</table>


RESULTS

Twenty-two females consented to participate in the study, however, two were excluded due to a history of shoulder instability. Therefore, twenty subjects participated in the study (Figure 2); mean age was 22.06 (1.8) years, mean height was 66.15 (2.9) inches, and mean weight was 143.50 (21.5) pounds. Due to the COVID-19 pandemic, only one subject in the spring cohort was able to perform posttests in person. Therefore, only tests that could be completed by visual assessment and required no equipment (breathing screen, breath hold test, and TSPU) were collected on the other eight subjects in the spring cohort. The planned secondary analyses were performed for all outcome measures using the remaining 12 subjects with completed posttest data.

At pretest, all subjects screened for inclusion in the study failed the TSPU. Beighton scores ranged from 0-9, with 10 subjects scoring 0. The range of FMS™ scores was 9-16, with a median score of 14. A frequency count of breathing screen mini-questionnaire responses is available in Appendix 2. Sixty-five percent of subjects responded to at least one of the mini-questionnaire items as "often" or "very often". At pretest, 30% (n=6/20) of participants selected "often" or "very often" in response to the question "Do you notice yourself breathing through your mouth at night?". Mean breath hold time was 14.12 seconds (4.5).

At posttest, nine of the 20 subjects (45%) passed the TSPU (χ²=1.876; p=0.171). The breathing screen question with the largest percentage of "often" or "very often" responses was "Do you feel tense?" at 25%, though no significant differences were observed (p=0.06-0.77). No significant differences were observed in breath hold time [Mean 15.96 seconds (7.6); p=0.217]. Aside from the TSPU (p=0.013), no significant differences were observed in remaining secondary analysis for the YBT-LQ or YBT-UQ (p=0.56-0.89; Table 1) or the FMS™ (p=0.180-1.0; see Figure 3).
DISCUSSION

Current research indicates that large proportions of active, healthy females are unable to complete the TSPU, a fundamental movement pattern, without compensations. This is the first study to explore interventions designed to improve TSPU performance in females. Although the COVID-19 pandemic resulted in poorer home exercise compliance and loss of posttest data points, 45% of females had passing TSPU scores at posttest. Additionally, this study had the second largest female representation in an FMS™ corrective exercise program with twelve subjects completing all FMS™ components compared to previous intervention studies which included four and eighteen females.

The primary goal of this study was to explore the effectiveness of a six-week trunk stability exercise program at improving the TSPU test. While the improvement observed in this study fell short of the hypothesis, 45% (n=9/20) represents a larger proportion of successful performance on the TSPU compared to other literature in female populations. Commonly utilized approaches for improving TSPU performance includes static exercises (ie planks), single plane movements, or strength training. While these studies have shown improvements in total FMS™ score, most of the subjects were males and multiple dynamic trunk stability are largely unaddressed. The intervention program utilized in the current study incorporated a combination of both anti-extension and anti-rotation exercises, progressing in postural demand, to train the trunk from a more comprehensive and functional perspective. Many participants demonstrated more coordinated movement between the upper body, trunk, and pelvis at posttest, however, they were only able to rise one to two inches from the floor, resulting in a failing score on the TSPU. Additionally, all subjects scored a 3 bilaterally on the shoulder mobility pattern, suggesting that upper quarter mobility restrictions are not present and, therefore, are unlikely to contribute to poor performance on the TSPU. Thus, additional contributing factors, such as upper body strength, need to be explored to create an effective program to improve TSPU performance in females.

Though the secondary purpose explored the program’s impact on additional continuous outcome measures of trunk and dynamic stability, such as breath hold time and dynamic balance, this study was underpowered. Posttesting for the spring cohort was performed virtually for all but one subject due to the COVID-19 pandemic. These virtual follow-ups were not conducive to collection of several outcome measures, such as the YBT-LQ and YBT-UQ, and 6 of 7 of the FMS™ patterns, which led to a loss of several posttest data points; therefore, only 12 participants had completed all outcome measures for secondary analysis. Due to low power, no significant differences in these secondary outcome measures were observed.

One of the more interesting relationships observed was between participants with high Beighton scores and TSPU performance. Because systemic hypermobility impacts ligamentous integrity, poor global stability can be observed. However, a greater proportion of subjects with high Beighton scores passed the TSPU at posttest compared to subjects with low scores (0-3) (Figure 4). This is an encour-

LIMITATIONS

This study was impacted substantially by the COVID-19 pandemic. Forty percent (n=8) of subjects in the spring cohort were unable to receive face-to-face instruction for the final exercise progression and were unable to attend in-person posttest data collection. Only eight subjects returned exercises logs at posttest; zero were from the spring cohort. Anecdotally, the spring cohort subjects reported a failure to perform the corrective exercises after they were dismissed from campus. Therefore, compliance and follow up for the second cohort was poor, potentially limiting success with prescribed interventions. Additionally, the age range in this sample of active females was 20-25 years old, though the target was 18-45. Thus, generalization to other populations and ages is limited.

CONCLUSION

The results of this study indicate that a multiplanar approach may be beneficial for improving trunk stability in active females, though additional contributing factors should be explored. Because males consistently outperform females on measures of trunk stability, even after intervention, there appears to be a need for a new approach to training trunk stability in female populations. This pilot study offers information regarding a novel program.
Figure 3. Comparison of pretest versus posttest performance on individual Functional Movement Screen™ component scores. Points falling above the line indicate a decrease in component score at posttest, while points below the line indicate improvement in scores at posttest. SLR=Straight Leg Raise. *=statistically significant

CONFLICTS OF INTEREST

The authors report no conflict of interest.

Submitted: January 13, 2021 CDT, Accepted: August 23, 2021 CDT

Figure 4. Frequency of Beighton scores and Trunk Stability Push Up (TSPU) performance.
REFERENCES


SUPPLEMENTARY MATERIALS

Appendix 1. Breathing screen mini-questionnaire and frequency of responses.

Appendix 2.
Case Reports

Traumatic Hip Dislocation in an NCAA DI Football Player with Occult Sequelae: A Case Report

Daniel W Safford1,2, Marisa Pontillo2, Brian J Sennett2

1 Department of Physical Therapy, Arcadia University; Good Shepherd Penn Partners, Penn Therapy & Fitness, 2 Department of Orthopedic Surgery, University of Pennsylvania Health System

Keywords: return to sport, trauma, football, hip dislocation

https://doi.org/10.26603/001c.28229

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Background and Purpose
American football generates the most sports-related injuries in the United States, with tackling as the leading injury mechanism. Overall injury rate at the collegiate level has been reported as 8.61 per 1,000 athlete exposures (AEs) – twice the rate of high school levels; competition injury rates are reported as high as 36.94/1000 AEs. Traumatic hip dislocation is an uncommon injury typically arising from high-energy axial impact with only 2-5.5% occurring during sports activities.

Case Description
A 22-year-old NCAA Division I football defensive back who experienced extreme left hip pain following contact with another player with his hip flexed during a game was diagnosed with a type 1 posterior hip dislocation, a grade 1 medial collateral ligament sprain with concomitant posterior thigh and hip muscle strains. Key impairments were limited left lower extremity motor performance, range of motion deficits, left hip pain, and diminished function and weight-bearing ability.

Outcomes
The athlete reintegrated into typical defensive back off-season training approximately four to five months post injury without restrictions, however presented with new anterior hip pain seven months post injury revealing occult sequelae requiring surgical intervention. He was able to return to full play the following football season.

Discussion
This case report describes the successful return to sport of a Division I football player who sustained a traumatic posterior hip dislocation and complicated course including surgical intervention secondary to associated sequelae.

Level of Evidence
5

BACKGROUND AND PURPOSE
American football generates the most sports-related injuries in the United States, with tackling as the leading injury mechanism.1 Overall injury rate at the collegiate level has been reported as 8.61 per 1,000 athlete exposures (AEs) – twice the rate of high school levels;1 competition injury rates are reported as high as 36.94/1000 AEs.2 These injuries can be difficult to manage secondary to potential uncommon diagnoses, multiple concurrent diagnoses, and the paucity of literature describing management, especially regarding later phases of rehabilitation and return to sport criteria.

Traumatic hip dislocation is an uncommon injury ty-
ially arising from high-energy axial impact. The most common cause is motor vehicle accident accounting for between 70-84% of such injuries, followed by falls, with only 2-5.5% occurring during sports activities. Posterior dislocations have been reported to represent 85-92% of these injuries, generally occurring with the hip in a flexed and adducted position. Associated local compounding injuries may include acetabular, femoral, or pelvic fractures, femoral head cartilage damage, vascular or ligamentous injury, soft-tissue disruption, and neural involvement, all of which may negatively impact prognosis. Sequelae of posterior dislocations of particular concern are avascular necrosis (AVN) and post-traumatic arthritis, which have reported incidences as high as 40% and 55%, respectively. Higher rates are associated with increased severity of injury and delayed joint reduction (over 12 hours from injury).

Multiple classification systems exist for posterior hip dislocation. Two common systems are the Thompson-Epstein and Milford and Stewart classifications, based on radiologic and functional stability findings respectively (Appendix).

Upon suspected hip dislocation, acquisition of anterior to posterior radiographic plain films is indicated to confirm the diagnosis. Some debate exists on whether oblique or Judet films are routine, however they help elucidate the presence of a posterior acetabular wall fracture which is the most common acetabular fracture in posterior dislocations.

In the absence of femoral neck and acetabular fractures, closed reduction is immediately indicated. If closed reduction is not possible, then open reduction is indicated. Following relocation, confirmatory repeat radiographs should be performed in conjunction with computed tomography to assess for femoral head integrity and intra-articular loose bodies. Magnetic resonance imaging (MRI) may be warranted to further assess for soft-tissue involvement. MRI has demonstrated limited ability to identify onset of avascular necrosis acutely, but may be effective and appropriate to be repeated at 6-12 weeks after injury. Arthroscopic intervention may be warranted pending severity of findings for capsular or labral involvement, intra-articular loose bodies, or chondral lesions.

Minimal description of conservative management and rehabilitation for football athletes following traumatic hip dislocation exists in the literature. Cooper et al. reported the case of a professional running back who experienced a hip subluxation with posterior acetabular fracture with onset of avascular necrosis identified by MRI six weeks after injury. He was able to return to play after eight months of conservative management, however there is minimal detail presented in the report of said conservative care. Yates et al. described a single case of a high school football player that experienced a posterior hip dislocation who completed conservative care in five months and successfully completed the following football season. Philippeon et al. reported on 14 cases of professional athletes that required arthroscopic intervention after hip dislocation (12 posterior), all of whom returned to full play. Of those cases, five were football players, and three of them did not undergo surgery until greater than 90 days after injury, implying failed conservative management. However, their conservative care course was not described. While a number of postsurgical hip dislocation rehabilitation protocols exist, the authors were unable to find any other published detailed rehabilitation progressions for football players post closed reduction hip dislocation.

**CASE DESCRIPTION**

The subject of this case is a 22-year-old NCAA Division I football defensive back who experienced extreme left hip pain following contact with another player with his hip flexed during an early season game. The subject was informed that data collected regarding the case would be submitted for publication.

The on-field medical team transported the subject to a nearby emergency room where plain film radiographs revealed a posterior left hip dislocation (Figures 1A-B), negative for fracture, along with mild pre-existing femoral head CAM deformities bilaterally, thus, the diagnosis was consistent with a type 1 dislocation.

The left hip was reduced (Figures 2A-B) and the subject was instructed to be non-weight-bearing on the left lower extremity with bilateral axillary crutches for two weeks, followed by adding 25% weightbearing each week thereafter to weight bearing as tolerated while maintaining standard posterior hip precautions (no hip flexion greater than 90°, no hip adduction, no hip internal rotation) for a total of six weeks. Magnetic resonance imaging was also performed of the left knee and findings indicated a "low grade" left medial collateral ligament sprain.

Three weeks after injury the subject had a chief complaint of ongoing limited function and left hip, knee, and posterior thigh pain. Primary personal goals were full re-

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**Figure 1A. Plain film radiograph of left hip demonstrating posterior dislocation**

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*International Journal of Sports Physical Therapy*
Table 1. Range of motion measurements at initial examination.

<table>
<thead>
<tr>
<th>Range of Motion</th>
<th>Active Range of Motion, Left</th>
<th>Active Range of Motion, Right</th>
<th>Passive Range of Motion, Left</th>
<th>Passive Range of Motion, Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip flexion</td>
<td>15°-107°</td>
<td>0°-120°</td>
<td>20°, painful</td>
<td>40°</td>
</tr>
<tr>
<td>Hip External Rotation at 90°</td>
<td>30°</td>
<td>40°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee flexion</td>
<td>0°-130°</td>
<td>0°-137°</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Grey indicates not tested.

Table 2. Manual muscle test findings at initial examination.

<table>
<thead>
<tr>
<th>Manual Muscle Test (out of 5)</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip Extension</td>
<td>4-</td>
<td>5-</td>
</tr>
<tr>
<td>Hip Flexion</td>
<td>4-</td>
<td>4+</td>
</tr>
<tr>
<td>Hip Abduction</td>
<td>3+</td>
<td>4-</td>
</tr>
<tr>
<td>Hip External Rotation at 90°</td>
<td>4-</td>
<td>4</td>
</tr>
<tr>
<td>Knee Extension</td>
<td>4+</td>
<td>5</td>
</tr>
<tr>
<td>Knee Flexion</td>
<td>4+ painful</td>
<td>5</td>
</tr>
</tbody>
</table>

EXAMINATION

The subject presented to the clinic approximately three weeks after the injury ambulating with bilateral axillary crutches and apparently weight-bearing at approximately 75% on the left lower extremity (LLE), although he had been instructed to be no greater than 25% weight-bearing at that time. He reported 2/10 on the numeric pain rating scale (NPRS) at rest, located in the anterior left hip region, and 5/10 at worst with mild rotational movements in the left hip, knee, and posterior thigh. The subject demonstrated limited left lower extremity range of motion (ROM) and motor performance detailed in Tables 1 & 2.

The subject reported medial left knee pain with active end range left knee flexion, and had an empty endfeel secondary to pain with gentle left hip internal rotation, flexion, and extension. The subject presented with positive grade 1 left knee valgus stress test (mild pain, no gapping apparent), and tenderness to palpation in the left psoas, distal biceps femoris, and medial collateral ligament. Resisted left knee flexion reproduced the subject’s posterior mid-thigh complaint. The subject’s static right lower extremity balance was within normal limits, however the left was not tested in consideration of precautions. He presented with a positive trace left knee effusion as assessed by sweep test and recorded a 51/80 on the Lower Extremity Functional Scale. Dermatomal light touch was intact and deep tendon reflexes were 1+ throughout bilateral lower extremities.

CLINICAL IMPRESSION

The subject presented with impaired left lower extremity motor performance, range of motion deficits, pain, and diminished function and weight-bearing ability consistent with status post traumatic posterior dislocation of the left hip, with secondary soft tissue injury around the hip joint, a grade 1 left MCL sprain, and a grade 1 hamstring strain.

INTERVENTION

The subject was progressed through a phased formal physical therapy program, averaging two visits per week over 14 weeks with multi-modal care including weekly consults...
with the team physician and the athletic department. Following the 14 weeks, full return to sport was facilitated by the athletic program’s athletic training and strength and conditioning staff. Loading of the left hip and lower extremity was carefully controlled throughout the course of care utilizing rating of perceived exertion, percentage of pre-injury 1-repetition-maximum (1RM), and a rolling acute to chronic workload ratio for prescribed resistance exercise, return to run, and plyometric activities.

ACUTE PHASE (0–6 WEEKS) *(Table 3)*

This phase emphasized pain reduction, appropriate healing of affected tissues, strengthening of LLE in protected ranges, and re-introduction of weight-bearing (WB) activity with normalization of gait. The subject was instructed by his physician to be non-weightbearing (NWB) on the LLE until two weeks post-reduction, and then to progress to weightbearing as tolerated (WBAT) at six weeks. The subject demonstrated poor adherence to WB precautions in non-clinical areas and was educated at evaluation and thereafter about appropriate percentage of WB. Posterior hip precautions were placed until six weeks post-reduction. Initial treatment included instrument-assisted soft tissue mobilization (IASTM) to the left hamstrings and medial knee region, and manual techniques to reduce left psoas spasm. Progressive resistance exercise (PRE) was prescribed in NWB positions emphasizing left hip external rotators and extensors while avoiding hip ROM precautions, and eccentric training of left knee flexor musculature. As precautions allowed, the subject was encouraged to begin WB with lateral shifting in standing and protected leg press activity, progressing to partial squatting on stable and unstable surfaces. Gait training was performed to normalize gait and progress from bilateral axillary crutch use to single crutch, and then no assistive device. Aerobic and upper extremity conditioning were achieved with progressive moderate intensity upright cycling and seated UE resistance exercise supervised by strength and conditioning staff. After six weeks the subject demonstrated normalized gait, normalized left hip ROM (hip flexion 0–115°, IR 30° at 90° flexion), reported minimal pain at rest and with prescribed activities, and demonstrated improved left hip motor performance, exhibited by hand-held dynamometer and manual muscle tests.

INTERMEDIATE PHASE 1 (6–10 WEEKS) *(Table 4)*

This phase emphasized progressive loading of the left lower extremity and reintroduction of non-contact impact activity. The subject performed progressive unilateral leg press beginning at 50% pre-injury 1-repetition-max (1RM), elevated conventional barbell deadlift of 50% pre-injury 1RM,
and kettlebell goblet squats beginning at 20lb progressing up to 100lb by 10 weeks post-injury. He was prescribed progressive elliptical and pool running aerobic activity for two weeks, followed by initiation of a gradual return to run program beginning with two bouts of 2 minutes of running on the treadmill. Core and hip strengthening interventions included various planks, bridging with physioball, half-kneeling cable column chops, and sidestepping and kickbacks with elastic bands at the ankles. Gentle stretching was prescribed for the left hip flexors and knee flexors. Balance training was performed with single leg stance on unstable surfaces and multi-directional rebounder ball toss on stable surfaces. The subject was barred from performing plyometrics, Olympic lifts, and any agility activities. After 10 weeks the subject was able to asymptotically perform multiple bouts of five minutes of easy pace running on treadmill and artificial turf, 60% preinjury 1RM elevated conventional deadlift and left single leg press, and single leg stance on stable surfaces with external perturbation.

INTERMEDIATE PHASE 2 (10–14 WEEKS) (TABLE 5)

This phase emphasized return to plyometric impact activity, agilities, and non-contact sport-specific movement. The subject was prescribed low-intensity single plane agilities without cutting movements, progressing to multiplanar tasks with greater intensity, such as T- and pro-agility style drills with integration of non-contact sport-specific movements. Low-intensity double leg plyometrics were initiated progressing to single leg plyometrics with an emphasis on left hip external rotation control. He initiated a progressive sprinting program during this phase, and performed varied single leg static balance exercises on unstable surfaces with external perturbations. At the end of this phase the subject was able to asymptotically perform lateral single leg jumps into alternate direction sprint starts, 36-inch double leg box jumps, single leg stance on unstable surfaces with perturbation, 70% of pre-injury 1RM PRE all non-Olympic lifts. Sets of 40yd x 8 sprints and non-contact drills prescribed.

RETURN TO SPORT PHASE

The subject completed the return to sport phase with the athletic training and strength and conditioning staff. Formal physical therapy care was ended since he had asymptotically performed the majority of non-contact sport

Table 4. Intermediate Phase 1, 6-10 Weeks, 2 visits per week

<table>
<thead>
<tr>
<th>Goal</th>
<th>Intervention</th>
<th>End of Phase Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strengthen Left Lower Extremity Musculature</td>
<td>Unilateral leg press &amp; elevated conventional barbell deadlift (50% pre-injury 1-repetition max), kettlebell goblet squats (&lt;100lb) – 3 sets to 6-7 RPE, 1.1-1.2 ACWR progression</td>
<td>Multiple 5 min bouts of running without pain</td>
</tr>
<tr>
<td>Introduce Impact Activity</td>
<td>Elliptical &amp; Pool Running x 2 weeks Return to run program (2min x2 at start) after successful pool running</td>
<td>60% preinjury 1-repetition max unilateral leg press &amp; elevated conventional deadlift</td>
</tr>
<tr>
<td>Kinetic Chain Stability</td>
<td>Varied planks, physioball bridges, half-kneeling chops, sidestepping and kickbacks with bands – performed 2-3 sets to fatigue</td>
<td>Single leg stance on stable surface with ball toss</td>
</tr>
<tr>
<td>Proprioceptive Training</td>
<td>Single leg stance on unstable surfaces, single leg stance with multi-directional rebounder ball toss – 3x30sec ea, 10-15 minutes per visit</td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Intermediate Phase 2, 10-14 Weeks, 1-2 visits per week

<table>
<thead>
<tr>
<th>Goal</th>
<th>Intervention</th>
<th>End of Phase Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase Plyometric Ability &amp; Impact Activity Tolerance</td>
<td>Progressive double-leg to single-leg plyometrics (e.g., box jumps and lateral jumps – initiated at 12-inch height), progressive sprinting program</td>
<td>Lateral single leg jumps with sprint start</td>
</tr>
<tr>
<td>Increase Agility with Non-Contact Sport-Specific Movement</td>
<td>Progression from single plane to multiplanar agilities (e.g., T and pro-agility drills) with incorporation of sport-specific movement and stimuli/cues Position-specific non-contact drills</td>
<td>36-inch double leg box jumps</td>
</tr>
<tr>
<td>Continue to Increase Hip Strength &amp; Control</td>
<td>Continue progressive resistance exercise and increase perturbations during single leg stance activity</td>
<td>Single leg stance on unstable surfaces with perturbation, 70% pre-injury 1RM PRE all non-Olympic lifts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sets of 40yd x 8 sprints</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-contact drills</td>
</tr>
</tbody>
</table>
activity and his athletic program staff provided extensive monitoring and care to continue guiding his return to full participation. He successfully returned to a normal training schedule without restrictions for that point in the off-season.

OUTCOME

Three months following initial injury the subject was asymptomatically performing the majority of non-contact sport activity and training. He was restricted from contact, >80%1RM lower extremity PRE, and Olympic lifts (e.g., clean variations, snatch, jerk). Following a one to two week visit to home the subject returned and continued care with athletic training and strength and conditioning staff. He reintegrated into typical defensive back off-season training approximately four to five months post injury without restrictions.

At seven months post injury, the subject returned to his team physician with report of "pinching" in his anterior left hip with rotational agilities and movements. The physician noted normal strength and range of motion of the left hip, but positive clinical tests for acetabular or labral involvement. A magnetic resonance arthrogram was ordered, which revealed an osteochondral lesion of the superomedial femoral head with underlying intense subchondral marrow signal abnormality and overlying near-full to full thickness cartilage defect of 12x5 mm. There was additional full thickness cartilage delamination with chondral flap posterior and inferior to the osteochondral lesion of 6x6 mm along with a partial thickness, non-detached tear of the anterior labrum, which extended superiorly to the anteroinferior labrum (Figures 3A-B). Mild incipient subclinical avascular necrosis was identified in weightbearing regions of the femoral head.

In consideration of imaging results the subject was recommended the options of a trial of intra-articular corticosteroid injection with prescribed rest or surgical intervention including cartilaginous debridement. The subject selected the surgical option and underwent the surgical procedure almost immediately, which consisted of 10 to 2 o'clock left labral repair with cam osteoplasty and acetabular chondroplasty including; femoral head chondral debridement, iliofemoral capsular thermal plication, loose body removal with anterior inferior iliac spine decompression, and injection of plasma rich platelets and Supartz™ (synthetic joint lubrication).

The subject successfully completed the initial post-surgical protocol at a third-party facility, passed the Vail Hip Sports Test,21 completed a transitional period of physical therapy at the collegiate facility, and was cleared for reintegration into sport approximately four months post operatively. He was able to return to full play in the following football season. Figure 4 details the full course from injury to return to sport the next season.

DISCUSSION

This case report describes the successful return to sport of a Division I football player who sustained a traumatic pos-

terior hip dislocation and complicated course secondary to associated sequelae. Avascular necrosis, chondral lesions, and local soft tissue injury are common sequelae following posterior dislocation,3–6 while AVN is often asymptomatic in its early stages. This subject denied pain symptoms throughout the rehabilitative process and may have experienced an asymptomatic onset. He was closely monitored by a multidisciplinary team including the Chief of Sports Medicine for the school’s associated medical system; two experienced, board-certified physical therapists; the athletic training and strength and conditioning staff; along with coaches, teammates, and family. Thus, it would be surprising if the subject was experiencing symptoms with-
out detection from this team. However, the subject was in a position of team leadership with inherent pressures to perform, demonstrated a consistently positive overall affect and strong work ethic, and was highly motivated. The subject did not report symptoms until they limited his activity – typical of elite athletes – and these psychosocial aspects speculatively may have contributed to a delayed report of onset.

Interestingly, the subject had idiopathic, pre-existing bilateral femoral cam deformities, with alpha angles of 60 degrees. Cam deformities have been noted to potentially contribute to likelihood of posterior dislocation, and may predispose an individual to a greater incidence of femoral acetabular impingement and labral tears that was later diagnosed in this subject. As such, the cam deformity was reduced during surgery via cam osteochondroplasty.

Magnetic Resonance Arthrogram is an appropriate imaging choice for this subject’s presentation after return of symptoms. Similar patients should be referred to their physician upon recurrence or worsening of apparent intraarticular hip pain following posterior dislocation. In consideration of potential occult processes intermittent repeat imaging to examine for potential osteochondral and soft tissue pathology may be warranted in later stages of rehabilitation.

There is almost no published guidance available for conservative rehabilitation of football athletes following posterior hip dislocation. However, the authors were relatively confident that this subject was appropriately progressed using an algorithmic approach to loading based upon pre-injury 1RM’s with observance of consensus safe acute to chronic workload ratios for PRE and impact activity, in conjunction with consideration of expected tissue healing time and monitoring of subject symptom irritability. A case presented by Yates et al included a five-month rehabilitation progression initiated with primarily non-weight-bearing progressive resistance exercise (PRE) followed by pool activity to protected squat and leg press training in the second month. That subject was progressed to functional training and low intensity plyometrics in the third month after injury. Running, sprinting, and agility activities were added the following month after demonstrating normalized hop testing. Criteria for release from formal care and return to sport included no pain or difficulty with exercise program and an 80 out of 80 on the Lower Extremity Functional Scale (LEFS). The conceptual progression described in this case report was in agreement with the case study by Yates et al, but certain aspects were at a higher level due to the nature of this subject’s ability. A rolling acute to chronic workload ratio of 1.1–1.2 was used for progression of PRE and impact activity. Impact was reintroduced using less than body-weight aquatic therapy activities before double to single leg plyometric progressions.

Additionally, patients presenting with type 1 injuries without fracture with expedient closed reduction – as in this case – have a better prognosis. Dumont et al recommend a structured physical therapy rehabilitation program and that general return to play after 10 weeks is “reasonable” if the patient is asymptomatic. The subject in this case was cleared for return to sport more conservatively at greater than 14 weeks after injury. However, despite the optimistic initial prognosis, cautious and meticulously progressed management, and close multidisciplinary monitoring, the subject experienced common sequelae upon full return to activity requiring surgical intervention.

This report was limited by several factors. Minimal information was available regarding the subject’s training during the approximately four-month period between ending the initial physical therapy course of care and discovery of occult sequelae leading to surgery. The subject’s activity level outside of the clinical and athletic training environments is relatively unknown except based on subject report. Minimal information regarding post-operative care is available. The outcome of this report may not be generalizable to others secondary to the individual characteristics of this subject.

CONCLUSION

This case highlights the plan of care for a 22-year-old NCAA Division I football defensive back who sustained a traumatic posterior hip dislocation and required surgery to address occult sequelae discovered seven months after the injury. The subject was able to return to full play the following season demonstrating that return to play for an elite contact-sport athlete following traumatic posterior hip dislocation is possible.
CONFLICTS OF INTEREST
None

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REFERENCES


Appendix 1

Pelvic tilt refers to the spatial position or motion of the pelvis about a frontal horizontal axis on the rest of the body in the sagittal plane. It is relevant for several musculoskeletal conditions commonly seen in physical therapist practice, particularly conditions affecting the hip and groin. Despite the relevance of pelvic tilt identified in biomechanical studies, and the historical precedence for assessing pelvic tilt, there is a lack of clarity regarding the utility of clinical measures that are practical in a rehabilitation setting. There are several options available to assess pelvic tilt which are discussed in detail in this commentary. All of these options come with potential benefits and considerable limitations. The purpose of this commentary is to provide an overview of the relevance of understanding pelvic tilt in the pathology and rehabilitation of conditions affecting the hip joint, with a focus applying evidence towards identifying clinical measures that may be useful in the rehabilitation setting and considerations that are needed with these measures.

**Level of Evidence**

5

**INTRODUCTION TO PELVIC TILT**

Assessment of the position and mobility of the pelvis may be relevant for a variety of conditions that a physical therapist might encounter, particularly musculoskeletal conditions of the lumbar spine, pelvis, hip, and knee. This is thought to be due to the interrelationship between the pelvis and adjacent segments of the body during movement. Assessment of pelvic tilt has long been a part of physical therapy practice, and the relevance of pelvic tilt has become increasingly studied in laboratory-based biomechanical and in surgical research. Compared to biomechanical and surgical research, there is comparatively less description or interpretation of clinical measures of pelvic tilt that are practical in a rehabilitation setting.

There are several definitions used to describe pelvic tilt. For the purposes of planning surgical interventions, pelvic tilt is assessed statically via plain radiographs, with several different descriptions existing without a consensus gold standard. In research, 'pelvic tilt' is usually describing the position or movement of the pelvis in the sagittal plane, but is occasionally referred to as movement of the pelvis in the frontal plane. In the physical therapy setting, pelvic tilt typically refers to the angle formed from a horizontal line and a line bifurcating the anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS) in the sagittal plane. It is commonly assessed in a static manner, such as the pelvic tilt of an individual in a relaxed standing position. It is also sometimes assessed in an active manner, such as the ability of an individual to actively move through as much pelvic motion as possible in an upright position. It may also be assessed during a functional movement, such as the change in pelvic tilt angle during a step-down task. While there are different descriptions of pelvic tilt, for the purposes of this commentary pelvic tilt refers to the spatial position or motion of the pelvis in the sagittal plane about a horizontal frontal axis. Anterior pelvic tilt is when the ASIS is either lower than the PSIS in the sagittal plane (position) or rotating inferiorly relative to the PSIS (motion). Posterior pelvic tilt is when the ASIS is higher than the PSIS in the sagittal plane (position) or rotating su-
pelvis, any alteration to the lumbar spine, pelvic, and knee, but most notably in regards to conditions affecting the hip. At the hip joint, differences in pelvic tilt are correlated with symptomatic femoroacetabular impingement (FAI) and non-specific groin pain as compared to asymptomatic controls. Differences in pelvic tilt in subjects with a symptomatic hip have manifested during kinematic assessment of a variety of basic functional movements, such as walking, a single leg step-down, and squatting. Significant differences of pelvic tilt during athletic activities such as cutting have also been identified in populations with a symptomatic hip condition. The majority of these studies demonstrate either a reduction in posterior tilt or an increase in anterior tilt in symptomatic patients with hip and/or groin pain, with one study identifying reduced anterior tilt in patients with symptomatic FAI.

Across all of these studies there is some variance regarding whether symptomatic individuals demonstrate an increase or decrease in pelvic tilt, and to what magnitude. It has been proposed that altered pelvic tilt in individuals with FAI could be contributing to an increase in symptoms, such as during performance of a squat maneuver or a step down with increased anterior tilt. These scenarios would initiate earlier impingement at the hip joint which could potentially exacerbate symptoms. In other cases, altered pelvic tilt could be an adaptive maneuver to avoid symptom-producing mechanics, such as an individual with FAI reducing the amount of anterior pelvic tilt during walking to increase the available amount of motion at the hip. The reasoning behind the differences in pelvic tilt in persons with symptoms are unclear and likely diverse among different populations. Indeed, differences have been found in pelvic kinematics in males and females following hip arthroscopy, with increases in anterior pelvic tilt during walking evident only in females compared to healthy controls after at least 1 year post-arthroscopy. Alterations in pelvic tilt have been found to influence clinical hip range of motion measurements. In particular, anterior pelvic tilt has been shown to reduce the available range of motion at the hip until impingement occurs, and may contribute to range of motion losses that are sometimes seen in patients with symptomatic femoroacetabular impingement. Because of the ability of pelvic tilt to affect the available functional range of motion at the hip, it has been proposed that specifically assessing and targeting modifiable factors that affect pelvic tilt during rehabilitation may be of benefit.

In addition to being associated with musculoskeletal pathology and hip range of motion, pelvic tilt may influence other objective measurements and common physical therapy interventions as well, regardless of the location of symptoms or pathology. Changes in pelvic tilt have been found to influence the muscle activation during assessment and common exercises at not only the hip and pelvis but also the lumbar spine and even the shoulder girdle.

CLINICAL MEASURES OF PELVIC TILT

In contrast to laboratory measures of movement, there is less information available to describe clinical measures of pelvic tilt common in physical therapy practice. In the rehabilitation setting, there is no consensus on the optimal method of assessing pelvic tilt. The most commonly described ways of assessing pelvic tilt in an outpatient rehabilitation setting include: visual assessment, use of a hand-held inclinometer, use of a specific caliper-based inclinometer, and use of a smartphone application. Table 1 summarizes the available research on the validity and reliability of each of these options. Each of these are described in more detail below.

Visual assessment is commonly described in physical therapy examination textbooks. The patient stands in a relaxed stance position, and the practitioner observes from the side. The practitioner visually observes the angle formed by an imaginary line bifurcating the ASIS and the PSIS. The resting posture is compared to a predefined "normal" posture. The practitioner can palpate the aforementioned bony landmarks in attempt to confirm their assessment. The ASIS being lower than the PSIS in the sagittal plane is defined as an anterior pelvic tilt, and the ASIS being higher than the PSIS in the sagittal plane is defined as a posterior pelvic tilt. If they are level, it is defined as "neutral." There have been no known attempts to assess the reliability, validity, or clinical usefulness of this method. Visual assessment of lumbar lordosis, a postural measure in close proximity and directly related to pelvic tilt has fair intrarater reliability and poor inter-rater reliability.

Use of a hand-held inclinometer to assess pelvic tilt has been described. To assess pelvic tilt, the practitioner aligns the inclinometer in the sagittal plane and places it firmly on the sacrum. The angle is interpreted as the amount of pelvic tilt, with higher numbers corresponding to
greater anterior pelvic tilt and vice versa. When assessing anterior, posterior, and total pelvic tilt in males and females, reliability has been found to be moderate to excellent (ICC: 0.60 – 0.94). There have not been any studies on the validity for assessing pelvic tilt with a hand-held inclinometer as compared to a gold standard or identification of normative values.

More recently, applications that utilize the inclinometer functions within a smartphone have been developed and used to assess pelvic tilt. The device is used and interpreted in the same fashion as a hand-held inclinometer and demonstrates excellent (ICC= 0.97) intra-rater reliability. Van Goeverden and colleagues identified significant deficits in active pelvic tilt in athletes with groin pain using a smartphone application, although it should be noted that they used an alternative method which involved placing the smartphone in a strap that is secured around the subject’s waist.

Caliper-based inclinometers, described as pelvic inclinometers, have been developed to specifically assess pelvic tilt. Pelvic inclinometers have adjustable arms to facilitate direct contact with the bony landmarks in question. To assess pelvic tilt, the clinician aligns the adjustable arms to the ASIS and PSIS. This is most often described with the digital pelvic inclinometer (DPI, Performance Attainment Associates, St. Paul, MN). The digital pelvic inclinometer has good inter-rater (ICC: 0.81-0.88) and validation (ICC:0.93) with a pelvic inclinometer as compared to a roentgenographic measure. Subsequent devices have been developed which are comparable in physical construct, such as the digital pelvic inclinometer (DPI, Sub-4 Limited, UK) and the palpation meter (PALM, Performance Attainment Associates, St. Paul, MN).

Further, applications that utilize the inclinometer functions within a smartphone have been developed and used to assess pelvic tilt. The device is used and interpreted in the same fashion as a hand-held inclinometer and demonstrates excellent (ICC= 0.97) intra-rater reliability. Van Goeverden and colleagues identified significant deficits in active pelvic tilt in athletes with groin pain using a smartphone application, although it should be noted that they used an alternative method which involved placing the smartphone in a strap that is secured around the subject’s waist.

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Table 1. Summary of Research on Methods to Assess Pelvic Tilt in a Rehabilitation Setting.

<table>
<thead>
<tr>
<th>Method</th>
<th>Reliability</th>
<th>Validity</th>
</tr>
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<tbody>
<tr>
<td>Visual Assessment</td>
<td>• Fedorak et al (2003) found fair intra-rater (kappa= 0.50) and poor intra-rater reliability (kappa= 0.16) for visual assessment of lumbar lordosis with analysis of photographs of individuals with and without low back pain.</td>
<td>No studies</td>
</tr>
<tr>
<td>Hand-held inclinometer</td>
<td>• Prushansky et al (2008) found good intra-rater reliability (ICC=0.87; SEM 0.9-2.26) for measuring anterior pelvic tilt, neutral pelvic tilt, posterior pelvic tilt, and total pelvic tilt in the standing position, and moderate inter-rater reliability (ICC=0.60; SEM=2.59) for the total pelvic tilt in male subjects with 30 healthy subjects (15 f; age 25.4 +/- 1.7) using a digital inclinometer (Fennel, Germany). They found no significant differences between testers indicating inter-rater reliability (p&lt;0.05) for total pelvic tilt and all pelvic tilt measures in females.</td>
<td>No studies</td>
</tr>
</tbody>
</table>
| Caliper-based pelvic inclinometer | • Herrington (2011) found good intra-rater reliability (ICC=0.87; SEM=1.1) using the PALM palpation meter pelvic inclinometer with 120 healthy subjects (55 f; age 23.8 +/- 2.1) for measuring the standing pelvic position.  
  • Crowell et al (1994) found excellent intra-rater (ICC=0.92-0.96) and inter-rater (ICC=0.95) reliability when using a non-commercialized caliper-based inclinometer and assessing 26 healthy males (average age 45) in a standing position.  
  • Beardsley et al (2016) found good inter-rater reliability (ICC=0.81-0.88), good test-retest reliability within a single session (ICC=0.88-0.95) and moderate to good reliability for test-retest reliability between sessions (ICC=0.65-0.85) when using a digital pelvic inclinometer and assessing 18 healthy subjects (6 females, age 23.6 +/- 4.7) in a standing position.  
  • Hagins et al (1998) found excellent intra-rater (ICC=0.98) and good inter-rater (ICC=0.89) reliability and a high SEM (12.6) using the PALM palpation meter pelvic inclinometer with 24 healthy subjects (15 female; age 27) in a standing position. The measurements in this study were done over clothing. | No studies                   |
| Smartphone Application      | • Koumantakis et al (2016) found excellent intra-rater reliability (ICC=0.87; SEM=1.41) using an Android smartphone with the ‘iHandy Level‘ application with 183 healthy subjects (100 f; age 26.1 +/- 10.04) for measuring the standing pelvic position.  
  • Herrington (2011) found high degree of agreement as compared to a roentgenographic measure (ICC=0.93) when using a non-commercialized caliper-based inclinometer and assessing 26 healthy males (average age 45) in a standing position.  
  • Hayes et al (2016) found good correlation between pelvic tilt measurements with the PALM palpation meter and radiographic measures in 50 healthy subjects (age 18-79, sex not reported) for total pelvic tilt (r=.509; p<0.001) and changes in anterior pelvic tilt (r=.676; p=0.001) but poor correlation for changes in posterior pelvic tilt (r=.298; p=0.036). | No studies                   |

tilt and total amount of pelvic tilt.\textsuperscript{47} Normative values for pelvic tilt using the palpation meter show a significant degree of variance among asymptomatic populations with the majority of individuals presenting with some degree of anterior pelvic tilt.\textsuperscript{20,21,46}

**DISCUSSION**

Laboratory-based studies describe alterations in pelvic tilt associated with several common musculoskeletal conditions during a variety of functional and athletic movements. There are comparatively much fewer attempts to identify differences in clinical measures of pelvic tilt when comparing symptomatic to asymptomatic individuals, despite the historical usage of such measurements. The vast majority of available research on clinical measures of pelvic tilt is on healthy subjects. There is a large gap between what available research suggests and current physical therapy practice standards. This may cloud clinical decision making.

While it is not known what the most frequent methods of assessing pelvic tilt are in a practice setting, anecdotally it is the author’s perspective that visual observation is commonly utilized. Visual assessment of pelvic tilt is typically subjectively interpreted on a three-point categorical scale: “posterior pelvic tilt,” “neutral,” or “anterior pelvic tilt.” Because of the variance among normal asymptomatic populations, with the majority of asymptomatic individuals presenting with some degree of anterior pelvic tilt,\textsuperscript{19–21,46} use of this rudimentary scale may lead to misguided clinical decisions. This is further confounded by the fact that kinematic assessment of functional movements shows a precise quantifiable difference in the quantity of pelvic tilt (example: a 5 degree difference in the amount of anterior pelvic tilt between symptomatic and asymptomatic populations).\textsuperscript{15,23–28} This is in contrast to an absolute categorical difference (example: anterior pelvic tilt, neutral, or posterior pelvic tilt) which is how visual observation is interpreted. Further, variations in the pelvic morphology within a normal population may further confuse a simple visual or manual assessment.\textsuperscript{16} Visual assessment of pelvic tilt may not only be overly simplistic but may be especially prone to inaccurate clinical interpretations given the subjectivity.

Assessment of pelvic tilt using an inclinometer, whether it is hand-held, caliper-based, or smartphone application based, allows for increased precision. In addition to using an interval scale, this also reduces the subjectivity of the measurement and may be more sensitive to measure change over a treatment plan.\textsuperscript{46} These measurements have shown moderate-to-excellent reliability.\textsuperscript{45,46,51} Caliper-based inclinometers have established validity for assessing the degree of anterior pelvic tilt and the total amount of pelvic tilt.\textsuperscript{44,47} With the currently available evidence, inclinometers may be a better option for assessment of pelvic tilt due to acceptable reliability and validity, as well as the enhanced precision for measurement that might be needed to identify relevant changes. For caliper-based inclinometers only, there is normative data available which may add additional value, although these values are variable which may limit the clinical usefulness.\textsuperscript{20,21,46}

There is scarce research using any of these clinical measures to assess pelvic tilt on clinical populations. With this consideration, there are additional and more fundamental questions that have not yet been addressed. There is a poor and inconsistent link between basic static standing measurements and symptoms at the knee,\textsuperscript{52} lumbar spine,\textsuperscript{53} and shoulder girdle.\textsuperscript{54} The lack of clinical usefulness for static standing measurements elsewhere in the body raises doubts that assessing static standing pelvic tilt will add any clinical value regardless of the accuracy. Active pelvic tilt may offer more value as differences in pelvic tilt in symptomatic individuals seem to manifest during active tasks. As there are multiple potential limiting factors for active pelvic tilt, consideration of the symptom-provoking positioning or individual functional limitations when determining the best position of measurement may be beneficial. Active pelvic tilt can be assessed in the traditional standing position (Figures 1A and 1B),\textsuperscript{47} or in a position that may be closer to mimicking positions of function,\textsuperscript{15} such as a split stance position (Figures 2A and 2B).

Despite many studies finding significant differences in pelvic tilt during laboratory-based assessments of functional movements in symptomatic individuals, it is not known if there is a correlation between kinematic movement assessments and of the use of a basic clinical measure with an inclinometer during basic static or dynamic standing posture. Very limited research suggests that there may not necessarily be a relationship between measurements at...
Clinical Measures of Pelvic Tilt in Physical Therapy

The introduction of simplified clinical measures and more athletic movements. Assessment of pelvic tilt during functional activities specific to the patient, provided it is done in a precise manner using validated and reliable measures may be most useful. The diagnosis, the biomechanics, when symptoms occur, and the performance goals are all worthy of consideration. Measuring the amount of pelvic tilt that occurs during a functional motion can be considered, such as assessing the amount of pelvic tilt during a step down with a smartphone-based inclinometer (Figure 3). This method is not be practically feasible for challenging or athletic movements. For example, as one part of an expanded understanding of the individual and the entire movement system, it may be beneficial to assess anterior pelvic tilt occurs during terminal stance of high-speed running for an athlete recovering from an anterior hip or groin injury, as reduced anterior pelvic tilt may lead towards increased tensile loading to these structures in this task. Conversely, adequate posterior tilt during terminal swing of high-speed running may be of great interest for an athlete recovering from FAI or a hamstring injury, as reduced posterior tilt may lead towards earlier impingement in the hip joint and greater tensile loading on the posterior hip muscles. These are both active processes that require complex dynamic movement and control from the patient, and an understanding of the total task-specific pelvic tilt may be most clinically useful. A valid and reliable 3-D motion capture analysis system may be required if the goal is to understand pelvic excursion during high-speed athletic tasks due to the nature of the movement and precision required. This may not be practical for smaller clinics with a limited budget based upon currently available options.

There is limited research demonstrating an association between improving pelvic tilt during sporting maneuvers and a successful recovery from a musculoskeletal injury. It is not clear if the change in pelvic tilt leads to the reduction in symptoms or the other way around. It is also not known what interventions, if any, can be attributed to the change in pelvic tilt. Increased hip extensor strength is correlated with improved pelvic mobility during functional tasks which may suggest a potential intervention target. Core muscle function has also been associated with the ability to control pelvic tilt. Improving hip flexor flexibility has also been proposed as a target, although limited research suggests that addressing hip flexor flexibility in isolation does not lead to carryover in functional tasks. Training specific movements with improved pelvic motor control may be of benefit, however generalized strength and flexibility interventions may produce similarly beneficial patient-reported outcomes and more research is needed in this area. While there are several potential targets, it is not established if pelvic tilt can be changed because of a specific or generalized rehabilitation plan, or if specifically tracking the change in pelvic tilt might be a useful prognostic factor for a successful outcome.

In consideration of the limitations, the physical therapist or other rehabilitation clinician may consider assessing pelvic tilt in order to individualize assessment and treatment. There appears to be some variability among those who are symptomatic and not, with some presenting with a pelvic tilt that theoretically could be contributing to an increase in symptoms and some presenting with a pelvic tilt that may reflect an adaptive movement strategy to reduce symptoms. Assessment of pelvic tilt may be best performed in a manner that has the potential to capture the subtle differences between symptomatic and asymptomatic population, and for this reason visual assessment alone would not be helpful to guide clinical decisions. Caliper-based pelvic inclinometers offer a valid, reliable, and precise measurement and may be a superior option, although the full clinical usefulness is not known and the practicing clinician should apply critical thought with interpretation. Comparisons may be best limited to within-subjects only, as opposed to a predefined normal value, due to variability between subjects in a normal asymptomatic population. A clinician should consider standardization of how they measure pelvic tilt due to pelvic morphology potentially skewing results if different sides are compared. Measuring active pelvic tilt and pelvic tilt during a movement specific to the patient’s presentation may be more useful.

CONCLUSIONS

Having a basic appreciation for pelvic tilt may be of benefit to the physical therapist, particularly for conditions related to the hip. Despite the importance of understanding pelvic...
tilt, there are some inherent limitations in the currently available methods for assessing pelvic tilt in the rehabilitation setting that bring caution to clinical interpretations. Further research investigating assessment methods should seek to identify any relationship of basic clinical measures of pelvic tilt to patient-specific functional movements, investigating clinically feasible methods of accurately assessing pelvic tilt during functional movements, the responsiveness to treatment, and the relevance of clinical assessment of pelvic tilt for a successful recovery.

CONFLICTS OF INTEREST

The author reports no conflicts of interest.

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Figure 3. Assessment of pelvic tilt during a step-down maneuver. A smartphone with an application that can assess change in spatial angulation (such as iHandy Level) is secured onto the subject’s sacrum via a running belt. The initial angle is recorded, and the change in angle at the lowest point of the step-down is recorded. The difference between the two angles is the change in pelvic tilt during the stepdown.
REFERENCES


International Journal of Sports Physical Therapy
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Return to Pre-injury Level of Play

<table>
<thead>
<tr>
<th></th>
<th>With InternalBrace (in weeks)</th>
<th>Standard repair (in weeks)</th>
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<tr>
<td></td>
<td>13.3</td>
<td>17.5</td>
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</table>

Postoperative management is patient-specific and dependent on the treating professional’s assessment. Individual results will vary and not all patients will experience the same postoperative activity level or outcomes.

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