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Perceptions of Rehabilitation and Return to Sport Among High School Athletes With Anterior Cruciate Ligament Reconstruction: A Qualitative Research Study

The rate of anterior cruciate ligament reconstruction (ACLR) has nearly doubled over the past 10 years, with individuals under the age of 20 years experiencing the highest rates of ACLR and the greatest increase during that time.[9,18] The common course of care following ACLR involves the completion of a finite set of rehabilitation sessions, after which an individual may be cleared for a return to physical activity and sport participation.[1,16]

BACKGROUND: Adolescent athletes struggle to return to sport following anterior cruciate ligament reconstruction (ACLR) for physical and psychosocial reasons. The ability to integrate contextual evidence obtained directly from patients with the growing body of quantitative rehabilitation research may aid clinicians in taking an evidence-based approach to rehabilitation and return to sport within the adolescent population.

OBJECTIVES: To assess perceived barriers to return to sport, as well as positive and negative factors influencing recovery, among high school athletes with recent history of ACLR.

METHODS: This phenomenographic cross-sectional study included a sample of 10 high school–aged individuals (7 female, 3 male; mean ± SD age, 16.8 ± 1.1 years; time since surgery, 5.5 ± 1.4 months) who underwent ACLR and had not returned to sports. Participants completed a semi-structured interview focused on attitudes related to return to sport, perceived physical or psychosocial barriers to physical activity and return to sport, and rehabilitation characteristics that may facilitate or hinder return to sport.

RESULTS: Participants reported psychosocial barriers to return to sport with greater consistency than physical barriers. Consistently reported barriers included the feeling that sport-based activities were now associated with injury, a persistent sense of uncertainty regarding full recovery, and the sense that comparison to others with ACLR by parents or coaches hindered their ability to make progress in rehabilitation.

CONCLUSION: Early identification of athletes at risk for persistent psychosocial barriers, such as fear of reinjury and uncertainty regarding full recovery, and establishment of peer mentoring groups to facilitate psychosocial support throughout the rehabilitation process may be key components of a gradual, patient-centered approach to improving mental and physical readiness for return to sport. *J Orthop Sports Phys Ther 2018;48(12):951-959. Epub 22 Jun 2018. doi:10.2519/jospt.2018.8277*

KEY WORDS: *ACL, pediatrics, psychological aspects of injury, qualitative research*

Unfortunately, a majority of individuals do not return to preinjury levels of sport or activity after ACLR, and some individuals do not even attempt a return.[1,3] This is troubling because participation in sport has been reported to be the primary mode of physical activity engagement among adolescents and young adults.[15] Developing a clear, patient-centered understanding of objective and perceived barriers to return to sport among adolescent individuals with ACLR may aid clinicians in better identifying those at risk for developing an inactive lifestyle.

Prolonged periods of sedentary behavior associated with the rehabilitative process,[3] coupled with a disengagement from sport-related physical activity early in the lifespan, may increase the risk of adopting a physically inactive lifestyle. Further, this drop in physical activity engagement may have significant negative psychosocial effects during a key period of development.[1,22,25] Factors such as fear

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of reinjury,[12,22] perceived functional limitations,[1,12] decreased quality of life,[11,12,23] and changes in social roles[22,23] have been shown to negatively impact the rehabilitation process and reduce the likelihood of return to preinjury levels of sports participation.

However, this research has been conducted with adults and may not translate to the adolescent high school athlete.[9,18] The effects of school-based sport engagement, access to care from school-based medical professionals, and social pressures associated with disengagement from sport-related activities may play key roles in determining the success of the ACLR rehabilitation process. Therefore, a key focus of this study was to identify the characteristics and considerations unique to the high school sports setting.

There are clear differences in contextual and environmental factors between adults and high school–aged individuals who are progressing through the rehabilitation and return-to-sport process following ACLR.[1] Identifying perceptions of the positive and negative aspects of the rehabilitation and return-to-sport process specific to adolescent athletes with recent ACLR may provide key contextual evidence for the re-evaluation of clinical practices. Thus, the primary purpose of this study was to develop an understanding of positive and negative perceptions of the rehabilitation and return-to-sport process among adolescent individuals who had not yet returned to sports following ACLR.

METHODS

This was a qualitative research study using in-person semi-structured interviews of adolescent individuals who had not yet been cleared for sports following ACLR. The study protocol was created in accordance with the Consolidated Criteria for Reporting Qualitative studies (COREQ) checklist.[27] An initial contact script was prepared for recruitment via electronic communication (e-mail and phone). Potential participants were contacted following receipt of permission to contact from the sports medicine clinics at both recruitment sites; no participants dropped out or declined to participate in the study. Participants 18 years of age or older provided informed written consent. Participants younger than 18 years of age provided written assent, and their legal guardians provided written consent to participate. All interviews took place in the Institute for the Study of Youth Sports research lab at Michigan State University. Only the participant and the lead interviewer (ie, the primary author) were present for each interview. This study was approved by the Michigan State University Biomedical and Health Institutional Review Board.

Participants

A total of 10 participants between the ages of 15 and 18 years enrolled in the study (**TABLE 1**). Participants were included in the study if they were in high school, participated on a sports team prior to their anterior cruciate ligament (ACL) injury, had an ACLR no more than 12 months prior, were ambulatory without crutches, and had not been cleared by a physician for unrestricted sports participation. Participants were injured in a variety of sports: basketball (n = 2), soccer (n = 2), football (n = 2), volleyball (n = 1), skiing (n = 1), ice hockey (n = 1), and lacrosse (n = 1). Participants who otherwise met inclusion criteria were excluded from the study if they were beyond 12 months from surgery, had any serious surgical complications, or had any general or previous medical condition that existed before surgery that may have affected their ability to engage in physical activity.

Patient-Reported Outcome Measures

Participants completed 4 patient-reported outcome measures prior to the semi-structured interview (**TABLE 2**). Knee-related function was assessed using the Knee injury and Osteoarthritis Outcome Score (KOOS).[21] The KOOS consists of 42 items divided among pain, symptoms, function in daily living, knee-related quality of life, and function in sport and recreation.[21] After completion, each subscale is normalized to a 100-point scale, where a score of 100 represents no symptoms and a score of 0 represents the worst possible symptoms.[21]

Participants also completed the Tegner activity scale in order to quantify peak physical activity level prior to ACL injury.[5] Last, kinesiophobia and fear avoidance were evaluated using the Tampa Scale of Kinesiophobia and the Athlete Fear Avoidance Questionnaire, respectively.[10,26]

TABLE 1 Participant Characteristics

Participant Number	Sex	Graft Type	ACLR Type	Age, y	Height, cm	Mass, kg	Time Since Surgery, d
1	Female	HSA	Primary	17	165.1	65.8	35
2	Male	HSA	Primary	15	172.7	84.1	43
3	Male	HSA	Primary	18	172.7	105.3	131
4	Female	BTB	Primary	16	182.9	79.5	53
5	Female	BTB	Primary	18	170.2	63.6	50
6	Female	QTA	Primary	15	178.0	83.6	42
7	Male	HSA	Retear	17	190.5	111.1	28
8	Female	HSA	Primary	18	165.1	72.7	44
9	Female	BTB	Primary	18	177.8	72.7	149
10	Female	BTB	Primary	18	172.7	72.7	66

Abbreviations: ACLR, anterior cruciate ligament reconstruction; BTB, bone-patellar tendon-bone autograft; HSA, hamstring autograft; QTA, quadriceps tendon autograft.

Semi-structured Interview

Following their completion of the patient-reported outcome measures, each participant completed a single semi-structured qualitative interview, which was conducted by the first author (J.D.). Both the primary interviewer (J.D.) and third author (K.E.) had studied qualitative methodology extensively and are experienced researchers in this domain, while all other members of the research team (C.L., D.B., M.S., C.K.) are active in sports medicine research and practice. Participants had no prior relationship with any member of the research team.

An initial round of pilot interviews was conducted prior to initiation of the study, which aided in the construction of the final interview guide. This interview guide was designed to prompt both broad and specific responses related to the guiding purposes of this study (**APPENDIX**).

The interview process began with an initial rapport-building phase, in which participants discussed their sport history in general, how their injury occurred, and their current recovery status. Participants were then given a brief overview of the nature of this study and asked about any barriers they had encountered while progressing through rehabilitation, as well as pertinent characteristics of their rehabilitation program and setting (eg, program strengths and weaknesses, who was involved, what they would change, etc).

While the interview guide served as a tentative framework, the researchers emphasized that the interviews were participant driven, and participants had the freedom to explore additional topics as they saw fit. Data generation ended when participants indicated that they had no additional information to contribute and confirmed that they wished to conclude the interview. Each interview was audio-recorded in its entirety, with brief field notes taken by the lead interviewer in the event of recording failure. Participant recruitment continued until general conceptual saturation was reached, as defined through consensus of the research team.

TABLE 2 Patient-Reported Outcomes

	KOOS*							
Participant	Pain	Symptoms	ADL	Sport	QoL	Tegner†	TSK-11‡	AFAQ§
1	64	54	71	65	38	7	27	29
2	100	68	96	85	69	7	26	28
3	94	86	96	55	31	9	23	31
4	94	100	99	85	44	9	19	20
5	94	96	96	90	50	8	25	29
6	97	93	100	75	88	7	16	18
7	97	96	99	90	56	9	25	16
8	64	39	88	30	13	10	28	42
9	86	82	96	55	50	9	24	21
10	83	79	99	55	63	9	24	17

Abbreviations: ADL, activities of daily living; AFAQ, Athlete Fear Avoidance Questionnaire; KOOS, Knee injury and Osteoarthritis Outcome Score; QoL, quality of life; TSK-11, Tampa Scale of Kinesiophobia-11.
**Scale from 0 to 100, where a score of 100 represents no symptoms and a score of 0 represents the worst possible symptoms.*
†Scale from 0 to 10, where 0 is "on sick leave/disability" and 10 is "participation in competitive sports such as soccer at a national or international elite level." Graded prior to anterior cruciate ligament injury.
‡The TSK-11 consists of 11 items with a potential score ranging from 11 to 44, with higher scores indicating greater fear of movement and injury or reinjury due to pain.
§Scale from 0 to 50.

Analysis Approach

After completion of each interview, the accompanying audio file was transcribed verbatim by a research assistant. Though transcripts were not returned to participants, within-interview strategies (ie, continuous echoing, asking for correction and further information) were employed to facilitate participant correction of researcher interpretation.[24] Thematic analysis of interview content was then conducted by the research team.[4]

First, an initial reading allowed for broad, higher-order themes to be identified. Next, the research team completed in-depth, line-by-line inductive coding of the transcriptions to identify emergent lower-order themes. Lower-order themes were subsequently nested within the higher-order framework, and excerpts that demonstrated the key themes were identified.[4]

RESULTS

Patient-reported knee function, postinjury physical activity, and psychosocial outcomes varied greatly among the participants in this study (**TABLE 2**). Participant interviews ranged in length from 20 to 53 minutes, with 28 minutes the median time to completion.

Development of Interview Themes

Results of the qualitative analysis yielded 3 primary, higher-order themes that helped describe the experiences of these athletes recovering from ACLR: types of barriers for returning to physical activity, positive recovery factors, and negative recovery factors. Lower-order themes were nested within each of these 3 factors; a detailed breakdown of the results of full thematic coding is presented in the **FIGURE**.

Barriers to Returning to Physical Activity

Physical The first type of barrier frequently cited by participants may be the most obvious: the physical nature of recovery. Participants frequently mentioned that they struggled with fatigue, stiffness, pain, and discomfort that limited their strength and mobility.

Psychological Participant interviews highlighted the insufficiency of using physical markers exclusively to evaluate progress during rehabilitation after ACLR. Rather, they emphasized the impact of psychological barriers that arose during the recovery of these athletes. Several participants experienced restlessness with being inactive and struggled to maintain patience during their lengthy recovery.

"They told me to do certain exercises. I felt like they were just taking forever to get to the advanced ones, so then I just didn't want to do the regular ones. And then I felt regression, and I [thought] I need to do more, and they wouldn't give me more, so ... I just felt stuck." (Participant 6)

Participants struggled with uncertainty about their progress throughout their rehabilitation, because their recovery was, at times, nonlinear, with day-to-day improvements not always evident. These mental challenges contributed to a lack of motivation to engage in physical therapy. Individuals in this study were injured during participation in sport, and the authors expected that they would be eager to partake in any activity that allowed them to engage in physical activity.

However, this was often not the case, as participants commented that the activities involved in physical therapy were incongruent with the sports activities they previously found motivating. Further, the rudimentary nature of the exercises in physical therapy served as a reminder of the long road ahead before their return to full health. Additionally, activities taken for granted suddenly became atypical, and these young athletes were now forced to adjust to their inability to perform activities of daily living.

"I didn't notice it before but it's ... the little things ... [for example] I was at the zoo the other day, and my dad and sister were running to the car and I [thought] I can't run. They weren't trying to be cruel or anything. But I can't run. It's ... the small things that I ... want to get back. I don't like the fact that I am still technically injured. I just want it to be how it was." (Participant 1)

As participants approached the end of their physical therapy and prepared to return to physical activity, it was very common for them to experience fear of reinjury. Though the intensity and manifestation of this emotion varied, individuals in this study acknowledged that to some extent, they had to overcome this fear.

"It's not necessarily that ... I'm terrified of injuring myself again; I also just think how fluky my step was ... I planted my foot, and I tore my ACL. So, to think about that ... is a little bit nerve-wracking." (Participant 8)

Last, though participants spent an enormous amount of time and effort rehabbing their injury, there was still a major psychological gap to be bridged between postrehabilitation and return to physical activity. Uncertainty about their recovery led to hesitancy to re-engage, as well as more tentative sport-related movement that the athletes perceived as a way to reduce the risk of reinjury.

". . . I'm more concerned about the right tearing . . . I'm just worried that I am not going to be as competent as I was and that's going to reflect in my playing, because I feel if you're really timid in your playing, then you're going to get hurt again." (Participant 1)

Social Rehabilitation settings typically feature multiple people rehabbing at the same time, which invites interpersonal comparison. This can be particularly unsettling when participants are progressing at disparate rates, or if

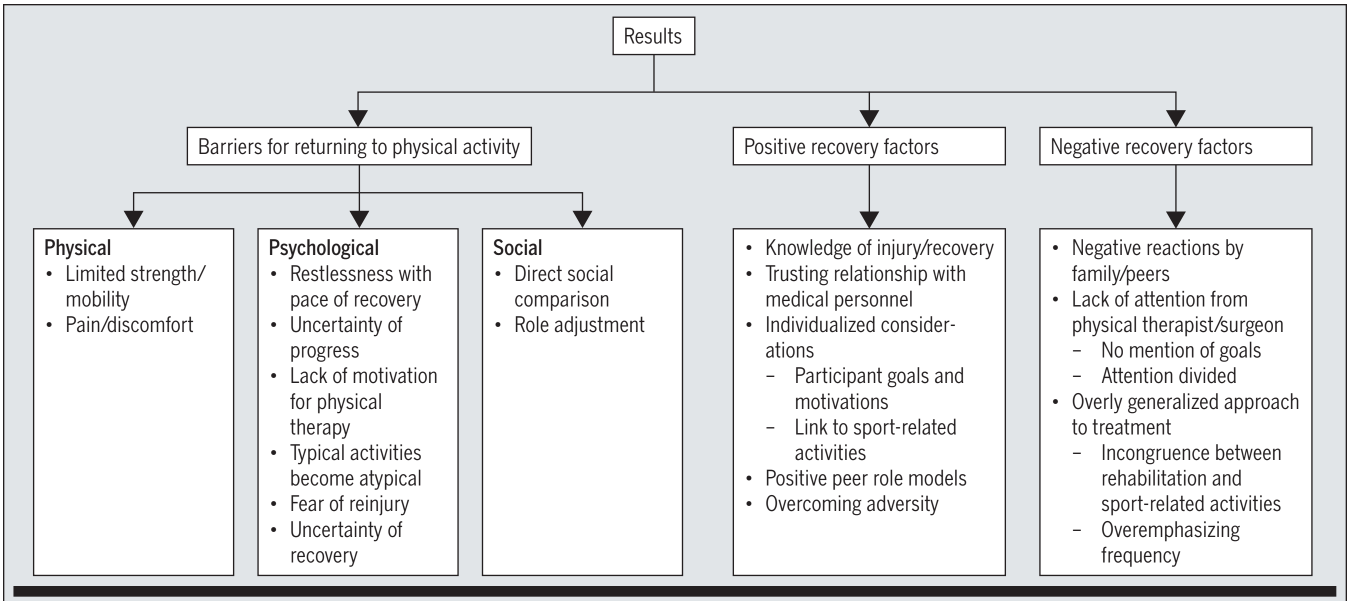

FIGURE. Visual depiction of key themes derived from participant interviews.

they have different motivations for their rehabilitation.

"I [think] . . . it would be really discouraging because not everybody is on the same recovery track … if I were to see [others and think] …, 'Oh, I'm supposed to be here, and these are all the milestones … I need to work up to,' but I can't even take the first one, like running, like … so many milestones that I should be achieving that I haven't [yet], … that would be really discouraging." (Participant 1)

Participants also experienced the social barrier of role adjustment. Transitioning from being a thriving, physically active person to the "injured one" in their peer groups changed the way they interacted and involved themselves in activities.

"If I'm in a situation where I'm just sitting, hanging with my friends, and they want to get up and go shoot some hoops or something, I'm all for it. But then I realize that I can't do extreme activities like driving or pivoting or anything that may cause me to turn or jump or land the wrong way." (Participant 2)

Positive Recovery Factors

The first positive strategy found throughout participant testimony was building knowledge about the recovery process. Participants who were well informed about the details of their injury and the expected timeline of their rehabilitation and were able to anticipate challenges were more likely to maintain a healthy mindset throughout and take a more active role in their rehabilitation. For example, athletes who were given activities that they could complete on their own experienced less uncertainty during the time between therapy sessions and were more informed day to day.

"Not only were they telling me to make sure I was doing my exercises … and holding me accountable to do [them there], but I also knew that I had to do them at home … because I didn't want to go back [to physical therapy] and not look stronger." (Participant 9)

A trusting relationship with the physical therapist or athletic trainer proved to be another positive factor for these athletes. Clinicians readily available to answer any question built participants' knowledge and had a positive impact on their experience. A unique aspect for high school athletes is the availability of on-site athletic trainers at their schools, who were viewed as key contributors to recovering athletes' emotional stability.

"I would go straight to our school athletic trainer and she was there for me emotionally, physically; she helped me through exercises. [She also] told me you need to get it together. It's okay to feel this way and that way, but you just got to push through it and get better." (Participant 2)

Demonstrating these individualized considerations for the participant's goals, motivations, and personal characteristics aids the participant's perceptions of personal relevance and treatment effectiveness. One example of this strategy was to link sport-specific activities to rehabilitation exercises to clearly demonstrate how their inclusion would aid in return to sport.

"I think everybody for the first . . . 3 or 4 months, to get back to a somewhat normal level, should be [working on] the same concepts. But if you can put in some sport-related things toward the end of that time period and then advancing into the return-to-sport period, I think [that] would be a big help." (Participant 8)

Though it was previously mentioned that rehabilitation settings may create social barriers, some participants viewed comparison to others as a positive aspect of recovery. This was especially the case when participants were paired with other athletes who were very clearly further along in their recovery, allowing them to serve as positive peer role models.

One way this was done effectively was through a program that segmented recovery into "stages," allowing participants to be motivated by those ahead of them without directly comparing their progress. Further, participants drew positive social support through connecting with athletes who had already completed the process and were back to normal function. Participants often mentioned that they benefited greatly from someone who could sincerely empathize with their challenges during rehabilitation.

"I think it would help a lot to have some sort of support system . . . with somebody else [who] has done it and has recovered in … similar conditions as you … so like for me, it would be nice the first time I tore my ACL to have, say, a basketball player [who is] now playing college or something like that who has torn his ACL, [been through] the recovery process, and is back to playing. Just for me to see that it works." (Participant 7)

Finally, participants in the study were more likely to see their recovery in a positive light when they viewed the process as "overcoming adversity." Rather than feeling isolated and frustrated by day-to-day challenges and incremental improvements, athletes possessing this optimistic attitude believed their experiences made them stronger as people overall.

"It's interesting though, because . . . the emotional side I feel … is what has enabled me to grow from this whole experience … I tie in the support, … gaining new friends, and meeting new people, and having this huge community [of] support … that has definitely enabled me to grow." (Participant 10)

Negative Recovery Factors

Participants mentioned that they perceived negatively those social interactions where people were overly sympathetic or treated their eventual return to sport with hesitation and caution. This was especially true when these messages came from those closest to the athletes, such as family and friends.

"[My parents] are really supportive, but at the same time they didn't really know what I was going through. Since soccer has always been such a huge part of my life, I want to get back to it, but my mom is more the protective helicopter mom . . . she doesn't want to see us get hurt again. [She says] 'I miss seeing you play soccer, but at the same time it isn't worth seeing you go through this again.' . . . So I think it was hard for her, but at the same time it was hard for me . . . I don't want to go against what my parents say, but at the same time, I need to get back to sports." (Participant 1)

Participants were also more likely to have a negative experience when they thought they were receiving insufficient attention and guidance from the physical therapist or surgeon. This reaction occurred when there was little mention of the participant's individual goals for recovery and ultimate return to play, or when attention from the physical therapist or surgeon seemed to be divided.

"I feel . . . it could've been a little more hands on, as opposed to . . . 1 person assigned to 2 different people at a time. . . . If it was just . . . one on one . . . and [we were] not surrounded by so many other people and other instructors telling other people what to do. There's just so much going on around me." (Participant 2)

In addition, participants viewed an overly generalized approach to treatment as negatively affecting their recovery. Standard therapeutic exercises were considered too basic and insufficiently motivating because they were perceived as incongruent to the sport-related activities to which participants ultimately wanted to return.

Finally, when the high frequency of this injury is overemphasized, the patient often reacts with agitation.

"It was rough. I just didn't like it. [I] was like okay, it's so common. Then, why does it . . . have to happen to me?" (Participant 3)

DISCUSSION

Functional and physiological measures of recovery have dominated the injury rehabilitation literature.[2,8,13] However, the results from this study highlight that an athlete's psychological well-being is equally important. Though participants in this study seemed to use improved knee function as the key marker of their progression throughout recovery, psychosocial factors appear to have critical importance during recovery transition points. Providing the participant with more detailed information about each of these transitions may help the participant to feel better prepared for what comes next.

Previous research has demonstrated that athletes who have undergone ACLR and returned to sport are at greater risk for suffering a knee injury than those in healthy control groups.[19,20] In this sample, participants frequently mentioned fear of reinjury after re-engaging in physical activity—and the lengthy recovery from ACLR only exacerbated this concern.[11,12] This disconnect from the potential reduction in injury risk that occurs with prolonged rehabilitation (greater than 9 months) may be positively addressed through patient education early in the rehabilitative process.[14]

Connecting currently recovering participants with athletes who have successfully completed rehabilitation and returned to sports was consistently viewed as a positive strategy by the study sample. This was particularly effective when the fully recovered athlete shared congruent participation history and personal characteristics with the athlete now progressing through recovery. These partnerships could arise organically in the school environment or be facilitated via connection with a network of previous clinical patients for those who do not have a mentor readily available.

The potential for both positive and negative influence exists, but how a participant interprets the comparison is key. A negative social comparison may persist when an athlete is not meeting his or her perceived rehabilitation goals in comparison to social peers. However, positive social comparison can help to facilitate improved patient motivation and clearer understanding of the key stages of the rehabilitation process.

Rehabilitation clinicians should actively work to normalize differential rates of progress when there is the risk of negative social comparison by developing individualized treatment plans to isolate patients' personal recovery experiences. There may also be benefits in discussing how social comparison may affect the participant's motivation and attitudes prior to commencing physical therapy, as those with a stronger ego orientation (ie, those who like to compare themselves to others) may actually benefit from working with another individual.

Aside from the social comparison aspect, the abrupt shift in social dynamics of a participant's daily life should also be considered; participants frequently indicated frustration with becoming the "injured one" who cannot participate in their social group's shared physical activities. Practical strategies to combat this phenomenon should be detailed further in future research and practical settings.

Sports may comprise a major part of identity for high school–aged individuals, and the abrupt removal of this involvement can have a major negative impact on their well-being.[7] Furthermore, it is important to recognize that interscholastic athletes have (at maximum) 4 years to compete, and the lengthy duration of ACLR rehabilitation may lead to their athletic career being drastically shortened, or even terminated, at an earlier stage than anticipated.[6] In this sample, athletes approaching the end of their high school sport involvement possessed a greater sense of urgency for recovery when they had the opportunity to return to competitive settings; on the contrary, athletes whose timetables would keep them from continuing sport participation experienced a significant decrease in their motivation.

One element of the high school sport setting that was viewed as a major benefit of this context was the availability of an on-staff athletic trainer. These individuals typically provide social support, as well as the ability to offer guidance and answer any questions that the injured athlete may have. High school–aged athletes who do not have this resource available should be given special consideration to ensure they are able to receive this day-to-day support elsewhere, and educating high school athletic trainers regarding their critical role in this process is highly recommended, based on the participant testimony in this study.

Finally, participants felt better about their recovery when the physical therapist, surgeon, and those involved in their recovery were perceived as knowledgeable about this process. Educating patients so that they possessed knowledge of their specific injuries and the recovery process was also viewed as beneficial. More knowledge allowed for a greater sense of control by participants. The ability of participants to conduct some rehabilitation activities and progress on their own was also considered by many to be positive.

Additionally, participants were more likely to view this process favorably when their rehabilitation plan and goals were self-determined or created in collaboration with their physical therapists. When participants thought that their therapists took the time to learn their backgrounds, personalities, and future intentions, they were more likely to view these relationships as positive and their therapists' services as effective.

CONCLUSION

PHYSICAL BARRIERS EXIST DURING the ACLR recovery process, and these were generally anticipated prior to surgery. However, patients' psychological well-being influenced how they handled these physical challenges. The experiences of these participants allowed for the identification of adaptive (and maladaptive) strategies and approaches to rehabilitation. The major themes and considerations of this paper highlight potential ways of guiding athletes to this adaptive outcome, and medical professionals should continue to build on the positive practices mentioned, while taking care to prioritize injured athletes' mental health. ◉

KEY POINTS

FINDINGS: High school–aged participants with anterior cruciate ligament reconstruction reported several key barriers to return to sport that were alleviated or worsened based on the presence of positive or negative recovery factors. Social comparison was found to be both a key positive and negative recovery factor, depending on the context and environment in which the comparison was made.

IMPLICATIONS: Based on feedback from this study's participants, clinicians may find that their practice benefits from including more specific and incremental goals in rehabilitation plans, prioritizing sport-specific rehabilitation exercises throughout the recovery process, and being mindful of the context and environment in which social or peer comparisons are made between patients with recent anterior cruciate ligament reconstruction.

CAUTION: The findings of this study are derived from a small sample of young individuals who had not yet attempted to return to sport. Based on these findings, it is unclear whether and how their perceptions of rehabilitation and the return-to-sport process would have evolved as they progressed in their recovery.

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APPENDIX

SEMI-STRUCTURED INTERVIEW GUIDE

Barriers to Physical Activity After Anterior Cruciate Ligament (ACL) Injury: Interview Guide

Purpose of Study

Any injury can have a major impact on a person's physical activity habits; in this interview, we hope to better understand how your ACL injury may have influenced (or not) your exercise and physical activity, both in terms of behavior and in the way that you view being physically active.

Introduction (develop rapport and help participant feel comfortable talking)

- Please tell me a bit about the role that physical activity has played in your life.
- Please briefly describe how your injury occurred.
- Please briefly describe your rehab process so far.

Physical Activity (before and after)

- How have your feelings toward physical activity changed, if at all, after sustaining this injury?
  - How do you feel versus how does it affect what you actually do?
  - Probe on motivation.
- How have your behaviors related to physical activity changed, if at all, after sustaining this injury?
  - Within the constraints of your rehab, do you feel you are more or less active than you could be? Why?

Future Intentions (these typically come up throughout the other sections, but worth looking into)

- What are your goals for this rehab process?
  - Probe on physical activity specifically.
- What do you feel are realistic expectations of this rehab process for you?
  - Probe on physical activity specifically.
- What would be the ideal, "best-case-scenario" outcome of this rehab process for you?
  - Probe on physical activity specifically.

Rehab Experience (moving quickly through this section)

- Please briefly describe the current state of your knee (positive progress, symptoms, complaints, etc).
- Please briefly describe your experience in your current rehab process.
- What aspects of rehab have been most/least helpful for you? Why?
- What aspects of the rehab have you *liked* the most/least? Why?

Barriers to Physical Activity (main focus: emphasize)

- What, if anything, has made it difficult to do physical activity since your injury? (alternate phrasing: "… gets in the way of physical activity …")
  - Probe at individual level (eg, worries, coping styles, pain, etc).
  - Probe at social level (eg, social support, socializing habits, etc).
  - Probe at environmental level (eg, inconvenience, access, facilities, resources, etc).
- What, if anything, about this particular injury (ie, as opposed to another type of injury) might affect the way that you view the rehab process and physical activity?
- What strategies, if any, have you found helpful to address these difficulties or motivate you throughout the rehab process so far?
  - Probe on physical activity specifically.
  - End on a positive note.

Intervention Delivery Mode Preferences

- What aspects of the *delivery* of your current rehab program have been most beneficial for you? Would you make any changes?
- If you were to be involved in a program to help you be as physically active as you'd like, would you prefer it to be:
  - In person versus by phone versus through text/social media/online? (Strong preference? Why?)
  - (*If text/social media/online mentioned favorably*): Which social media/online platform would be preferable (eg, e-mail, text, Facebook, Snapchat, etc)? (Top 3? Strong preference? Why?)
  - Individual versus partner/paired versus group structure? (Strong preference? Why?)
  - Frequency of communication/contact and why.

Open Finish

- If you could give a word of advice to someone about to begin the same rehab process as you, what would it be?
- Is there anything more that you would like to add that you think would be beneficial for our understanding of your physical activity following ACL injury?

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Reliability of the Mechanical Diagnosis and Therapy System in Patients With Spinal Pain: A Systematic Review

Mechanical Diagnosis and Therapy (MDT), also known as the "McKenzie method," has been widely used by physical therapists as an individual-based approach for patients with musculoskeletal disorders.[5,9-11,35] Initially, the focus of MDT was on the diagnosis and treatment of patients with low back pain (LBP).[24] Subsequently, MDT was adapted for patients with neck and thoracic pain, as well as upper- and lower-limb disorders.[25,28] Overall, MDT aims to make patients as independent as possible, giving them skills to self-manage their pain through education as well as postural and specific exercises.[26] Mechanical Diagnosis and Therapy treatment is based on findings from an assessment that includes a patient's history and a specific physical examination.[9,10,26]

BACKGROUND: An updated summary of the evidence for the reliability of the Mechanical Diagnosis and Therapy (MDT) system in patients with spinal pain is needed.

OBJECTIVE: To investigate the evidence on the intrarater and interrater reliability of MDT in patients with spinal pain.

METHODS: Searches in MEDLINE, CINAHL, Embase, PEDro, and Scopus were conducted for this systematic review. We included any study design as long as reliability of the MDT method was tested in patients with spinal pain. We collected data on the reliability of MDT to identify main and subsyndromes, directional preference, the centralization phenomenon, and lateral shift. The methodological quality of studies was assessed using the Quality Appraisal of Diagnostic Reliability and the Guidelines for Reporting Reliability and Agreement Studies checklists.

RESULTS: Twelve studies were included (8 studies on back pain, pooled n = 2160 patients; 3 studies on neck pain, pooled n = 45 patients; and 3 studies recruited mixed spinal conditions, pooled n = 389 patients). Studies investigating patients with back pain reported kappa estimates ranging from 0.26 to 1.00 (main and subsyndromes), 0.27 to 0.90 (directional preference), and 0.11 to 0.70 (centralization phenomenon). Kappa estimates for studies investigating neck pain ranged from 0.47 to 0.84 (main and subsyndromes) and 0.46 (directional preference). In mixed populations, kappa estimates ranged from 0.56 to 0.96 (main and subsyndromes).

CONCLUSION: The MDT system appears to have acceptable interrater reliability for classifying patients with back pain into main and subsyndromes when applied by therapists who have completed the credentialing examination, but unacceptable reliability in other therapists. We found conflicting evidence regarding the reliability of the MDT system in patients with neck pain or mixed pain locations. *J Orthop Sports Phys Ther 2018;48(12):923-933. Epub 22 Jun 2018. doi:10.2519/jospt.2018.7876*

KEY WORDS: *back pain, McKenzie method, neck pain, reproducibility*

The physical examination includes postural observation, neurological tests, repeated movements, and sustained positions.[26] Symptomatic and mechanical responses are recorded during the assessment to provide a provisional classification: derangement, dysfunction, postural syndrome, or other (ie, chronic pain syndrome).[26,27] A provisional syndrome classification is usually made during the first treatment session, which can be confirmed or modified during further sessions.[27] Based on the syndrome classification, a specific intervention approach is selected.[27] Thus, the reliability of the syndrome classification is very important, as this is critical to the treatment approach selected.[27]

Therefore, it is important for any trained MDT therapist to be able to reliably classify patients in order to make appropriate clinical decisions.[21] If interrater reliability and intrarater reliability are poor, then management decisions following the classification system would be based on unsound judgments.[37] There have been 2 previous systematic reviews on the reliability of different classification systems (including but not limited to MDT) for patients with LBP,[8,20] and another systematic review that aimed to

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investigate the reliability of MDT for extremity problems.[36]

These previously published systematic reviews[8,20] included 4 studies investigating the reliability of MDT for classifying patients with LBP.[3,14,31,32] One of the previous reviews found conflicting evidence regarding reliability of the MDT classification system for identifying syndromes and subsyndromes. The authors predetermined a kappa of 0.85 or greater to represent satisfactory reliability. The second systematic review[8] included the same 4 studies and concluded that there is substantial reliability among certified MDT clinicians for classifying patients into McKenzie's main syndromes. This agreement was lower for subsyndromes and among noncertified clinicians. Given that the most recent of the previous reviews was published 7 years ago, an updated summary of the evidence for the reliability of the MDT system is needed. Furthermore, no previous systematic review has specifically focused on the reliability of the MDT system in patients with spinal pain (neck pain, thoracic pain, and LBP). The aim of this systematic review was to summarize the evidence on the intrarater and interrater reliability of the MDT system when used in the assessment of patients with spinal pain.

METHODS

Search Methods for Identification of Studies

Electronic Database Search Strategy Systematic searches were conducted in MEDLINE, Embase, CINAHL, PEDro, and Scopus, including publications since the inception of these databases until February 23, 2018, without language restrictions. The PEDro database was selected after considering that some reliability data could be reported jointly with a clinical trial result. The search terms were adjusted for each of the databases used. We combined search terms related to neck pain, thoracic pain, and LBP; reliability; and MDT. Detailed search strategies used in each database are described in the **APPENDIX** (available at www.jospt.org).

Searching Other Resources In addition to the electronic databases searched, other potentially eligible studies were identified by reviewing the reference lists of the eligible articles. We also screened the reference list from the McKenzie Institute International (http://www.mckenzieinstitute.org/). We first selected the section "research," then "reference list," and screened titles from the sections "lumbar: studies into assessment, diagnosis and procedures" and "cervical: studies into assessment, diagnosis and procedures."[23]

Inclusion and Exclusion Criteria

Types of Studies We included any study design as long as reliability of the MDT method was tested.

Types of Participants We included studies that recruited adult participants of either sex with neck pain, thoracic pain, and/or LBP (with or without radiation to the upper and lower limbs, respectively).

Types of Outcome Measures We considered the reliability of the MDT system (reported by intraclass correlation coefficients [ICCs] for continuous variables,[34,37] kappa for categorical variables, and percentage of agreement[16,34]) to identify the main syndromes and subsyndromes as the main outcomes of this review. We also collected data on the reliability of the MDT system to identify directional preference, the centralization phenomenon, and lateral shift.

1. Main syndromes: derangement (identified by the abolition, decrease, or centralization of symptoms, and/or an increase in restricted range of movement in response to repeated movement tests), dysfunction (identified by intermittent pain produced at the end of range of movement), postural (only produced by sustained positions and abolished after correct posture), and other (ie, postsurgery and chronic pain syndrome)[26,27]
2. Subsyndromes: refers to subsyndromes of derangement (anterior, posterior, central, or unilateral) and dysfunction (flexion or extension)[26,27]
3. Directional preference: used to classify patients into syndromes and direct treatment strategies. Indicates the direction of movement required to improve pain (abolish, relieve, or centralize) and increase the range of movement[19,26,27]
4. Centralization phenomenon: there is an abolition of distal-limb symptoms in response to the application of repeated movements or sustained postures. Can be used to classify patients into syndromes and determine treatment strategies[19,26,27]
5. Lateral shift: defined as a lateral displacement of the patient's trunk in relation to the pelvis. This clinical finding is determined during the postural examination and is presented in patients with derangement syndrome[2,26]

Data Collection and Analysis

Selection of Studies Two of 4 review authors (A.G., F.S., M.A., or A.A.) independently screened all studies for eligibility. Disagreements were resolved by discussion or by arbitration by 1 of the remaining 2 review authors. The study-selection process included (1) screening the titles and abstracts and (2) screening the full text of articles. If an eligible study was published in a language other than those that the authors could read (English, Portuguese, and Spanish), all possible efforts were made to get a translation. When that was not feasible, the articles were excluded.

Data Extraction and Management Two of 4 review authors independently extracted data from all included papers. Disagreements were resolved by arbitration by one of the remaining review authors. Review authors used a customized data-extraction sheet, which was piloted prior to use. We extracted the following data: (1) year of publication, (2) authors, (3) country of origin, (4) source of patient sample, (5) number of participants, (6) mean age and sex of participants, (7) health condition (neck pain, thoracic pain, and/or LBP), (8) clinician characteristics (training level), (9) procedure used to assess reliability, and (10) reliability results reported. We investigated whether reliability was influenced by clinician training level and the procedure used to assess reliability. When any of this information was not reported in the original paper, the paper's authors were contacted by e-mail to request the additional information.

Quality of Studies We carried out 2 quality measures for included studies: (1) methodological quality and (2) reporting quality. The methodological quality was assessed using the Quality Appraisal of Diagnostic Reliability (QAREL) checklist.[18] The QAREL checklist consists of 11 items that explore 7 principles: (1) spectrum of subjects, (2) spectrum of examiners, (3) examiner blinding, (4) order effects of examination, (5) suitability of the time interval among repeated measurements, (6) appropriate test application and interpretation, and (7) appropriate statistical analysis.[18] In this review, the reviewers reached agreement beforehand on how to handle items of the checklist that needed a consensus.

Reporting quality was measured by the Guidelines for Reporting Reliability and Agreement Studies (GRRAS).[15] The GRRAS contain issues that should be addressed when reliability and agreement are investigated.[15] Both quality ratings were performed independently by 2 of 4 reviewers, and in cases of disagreement, a consensus was reached by discussion or by arbitration by 1 of the remaining 2 review authors.

Data Analysis

In this study, acceptable reliability was operationally defined as kappa and ICC estimates of at least 0.6.[16,22] It was not possible to perform a meta-analysis of the studies due to the large heterogeneity among them. For this reason, our results were reported descriptively.

We interpreted the overall quality of evidence across all appraised studies by considering quality and number of studies.[30] The QAREL checklist does not use an overall numeric scoring system, and there is no consensus regarding a single accepted cut point for defining study quality.[30] The analyses were undertaken by using different cutoff points for defining a high-quality study at 50% or greater, 60% or greater, and 70% or greater of applicable QAREL checklist items scored as "yes."[30] Thus, we established 5 levels of evidence, which were previously applied in a systematic review of interexaminer classification reliability of the McKenzie method for extremity problems[36]: (1) strong evidence: consistent findings from 3 or more high-quality studies; (2) moderate evidence: consistent findings from 1 or more high-quality and 1 or more low-quality studies; (3) limited evidence: consistent findings in 1 or more low-quality studies or only 1 study available; (4) conflicting evidence: inconsistent evidence in multiple studies, irrespective of study quality; and (5) no evidence: no studies found. The GRRAS scores were not used in rating methodological quality of the included studies. We simply described the percentage of items scored as "yes" for each included study. The higher the proportion of "yes" items, the higher the reporting quality.

RESULTS

Search Results

The initial electronic database search yielded a total of 1521 potentially eligible studies. Fifty-one records were identified through the list from the McKenzie Institute International. After screening citations by title and abstract, we considered 77 potentially eligible studies for inclusion and retrieved full-text articles. Twelve published studies[1-4,6,13,14,31-33,38,39] met the inclusion criteria and were included in this review. No additional studies were found in the references of the selected studies. There was no disagreement after examination of eligibility through inspecting full texts between the review authors. The flow diagram of the screening and study-selection process is presented in the **FIGURE**.

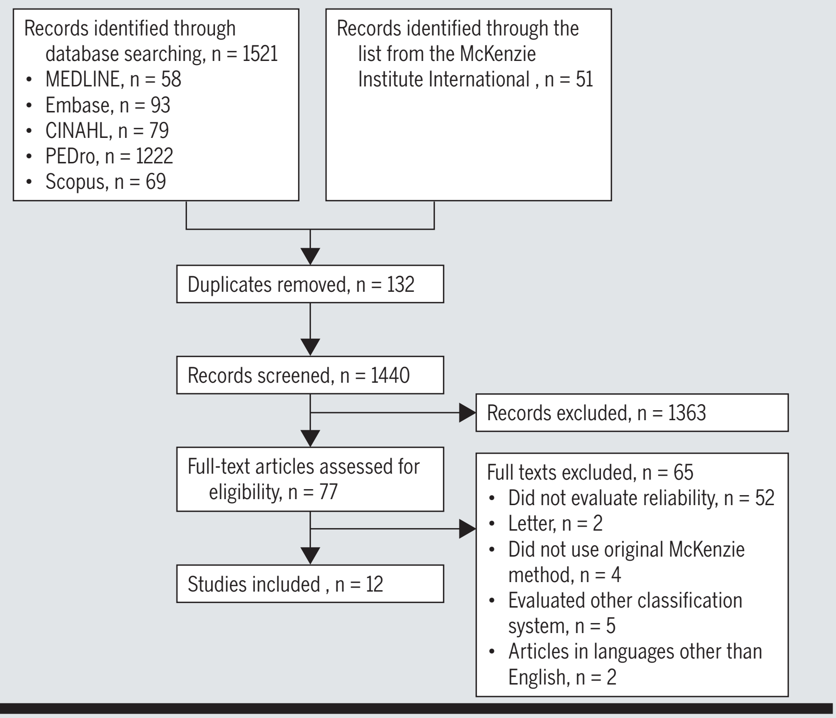

FIGURE. Study flow diagram.

Characteristics of Included Studies

Twelve studies were included in this review (pooled sample of 2544 participants).[1-4,6,13,14,31-33,38,39] Interestingly, 1 study represented 62% of the pooled sample (1587 participants).[39] The studies from Dionne et al[6] and Bybee and Dionne[1] used the same sample (patients selected for videotaping) with different aims. Dionne et al[6] investigated the interrater reliability of the MDT system as assessed by physical therapists who had received MDT training, and Bybee and Dionne[1] investigated the interrater reliability of the MDT system assessed by students recently trained in MDT. The sample size of the studies ranged from 15 to 1587 participants (median, 45; interquartile range, 40). The studies were conducted in 6 different countries: 3 were conducted in the United States,[32,33,38] 5 in Australia,[1-4,6] 1 in Finland,[14] 1 in Canada,[31] 1 in England,[13] and 1 in Israel.[39] All studies were published in English. Eight included patients with LBP (pooled n = 2160),[2,3,13,14,31-33,39] 3 studies included patients with neck pain (pooled n = 45),[1,3,6] and 3 included patients with spine pain from mixed locations (pooled n = 389).[3,4,38] One study[3] included patients with both neck and back pain and presented the data for each region separately, and also for all regions combined. For this reason, this study was counted for neck pain, LBP, and spine pain from mixed locations. A comprehensive description of each included study is provided in **TABLE 1**. Demographic data not reported in some papers[1,4,6,13,14] were requested from authors by e-mail unsuccessfully.

Methodological Quality Assessment

Methodological quality assessment was conducted using the QAREL checklist (11-item scale). We also assessed the reporting quality using the GRRAS. Item 4 of the QAREL checklist is related to intrarater reliability and was considered as "not applicable" for the 11 studies that only investigated interrater reliability. Item 5 refers to the reference standard, and it was classified as "not applicable" for all studies because there is no reference standard for the MDT system. Item 6 refers to whether raters were blinded to clinical information. The MDT system used a combination of clinical information and physical examination. For this reason, we also considered this item as "not applicable" for all studies. Item 8 is related to the varied order of examination, and it was considered as "not applicable" in 3 studies that used forms mailed[4] to the subjects and or videotaping.[1,6] We adjusted the number of items, excluding those that were not applicable,

TABLE 1 Characteristics of the MDT Reliability Studies Included in the Review

Study	Country of Origin	Source of Sample	Patients, n	Mean ± SD Age, y	Sex, n (%)	Health Condition
Bybee and Dionne[1] Dionne et al[6]	Australia	Outpatient physical therapy clinics and clinical laboratory in a physical therapy academic setting	20	...	Female, 13 (65); male, 7 (35)	Acute, subacute, and chronic patients with neck pain
Clare et al[2]	Australia	Private physical therapy clinic	45	50.6 ± 13	Female, 26 (58); male, 19 (42)	Acute, subacute, and chronic patients with LBP, with or without radiation to the leg
Clare et al[4]	Australia	Private practice and hospital	50 (25 neck pain and 25 LBP)	...	...	Neck pain and LBP
Clare et al[3]	Australia	Private physical therapy clinic	50 (25 neck pain and 25 LBP)	48.6 ± 12	Female, 24 (48); male, 26 (52)	Acute, subacute, and chronic patients with neck pain or LBP, with or without radiation into the limb
Kilby et al[13]	England	Physical therapy department	41	...	Female, 23 (56); male, 18 (44)	LBP
Kilpikoski et al[14]	Finland	Kuopio University Hospital	39	...	Female, 15 (38); male, 24 (62)	Acute, subacute, and chronic patients with nonspecific LBP
Razmjou et al[31]	Canada	Outpatient department at the Orthopaedic and Arthritic Hospital	45	47 ± 14	Female, 25 (55.5); male, 20 (44.5)	Acute, subacute, and chronic patients with LBP
Riddle and Rothstein[32]	United States	Clinics for evaluation and treatment of LBP	363	41.8 ± 12.5	Female, 189 (52); male, 174 (48)	LBP
Seymour et al[33]	United States	Physical therapy department	15	...	...	LBP
Werneke et al[38]	United States	Medical center for physical therapy services	289	37.9 ± 9.8	Female, 146 (50.5); male, 143 (49.5)	Acute neck pain or LBP, with or without referred symptoms
Werneke et al[39]	Israel	Physical therapy outpatient clinics	1587	51 ± 15	Female, 904 (57); male, 683 (43)	LBP, with or without referred lower extremity symptoms

Abbreviation: LBP, low back pain.

to calculate the total score on the QAREL checklist for each study.

All studies achieved a "yes" score of greater than 50% and greater than 60%, and 9 studies achieved greater than 70%, on the QAREL checklist and were considered as having high methodological quality. The methodological quality of LBP studies and those of mixed populations varied from 62.5% to 87.5%. The methodological quality of neck pain studies was 85.7%. Regarding the reporting quality as assessed by the GRRAS checklist, the percentage of items scored as "yes" for all studies ranged from 66.6% to 93.3%. The most common issues were related to "how the sample size was chosen" (item 6) and "sampling method" (item 7). **TABLES 2** and **3** present the QAREL and GRRAS scores of the included studies.

Reliability of LBP Studies

Main Syndromes A total of 6 studies (pooled n = 2100) investigated interrater reliability in patients with LBP (75.6% of the pooled sample was derived from a single study) (**TABLE 4**).[39] There was conflicting evidence of interrater reliability of the MDT system for identifying the main syndromes (kappa estimates ranging from 0.26 to 1.00), with percentages of agreement ranging from 39% to 100%. From these 6 studies, 3[3,14,31] (n = 109) found acceptable reliability and included only physical therapists who had completed the MDT credentialing examination and physical therapists who had an MDT diploma. In 2 out of 3 studies, the reliability was assessed in real time only once, and in the other study the reliability was assessed in real time twice.

Two studies[32,39] (n = 1950) found unacceptable reliability and included physical therapists who had received some MDT training but were not credentialed. The reliability was tested in real time twice (the time interval between assessments was 10 minutes[39] and 15 minutes[32]). One of these 2 studies assessed whether interrater reliability was influenced by level of MDT education[39] and found that there was no difference between clinicians across all levels of training. One study[13] (n = 41) reported only percentage-of-agreement estimates (58.5%), and reliability was tested by physical therapists who had received MDT training and was assessed in real time only once.

Subsyndromes Based on 3 studies, it was found that there was strong evidence of acceptable interrater reliability of the MDT system for identifying the subsyndromes (kappa estimates ranging from 0.70 to 0.96), with percentages of agreement ranging from 74% to 97% (n = 109).[3,14,31] In all 3 studies, the reliability was tested by physical therapists who had either completed the MDT credentialing or had an MDT diploma.[3,14,31] All of these studies assessed the reliability in real time; 2 studies assessed patients only once (one was the observer and

TABLE 2 Summary of Methodological Quality of MDT Reliability Studies Measured by the QAREL Checklist*

	Item†										
Study	1	2	3	4	5	6	7	8	9	10	11
Bybee and Dionne[1]	Y	Y	Y	NA	NA	NA	U	NA	Y	Y	Y
Clare et al[2]	Y	Y	Y	U	NA	NA	U	Y	Y	Y	Y
Clare et al[4]	Y	Y	Y	NA	NA	NA	U	NA	Y	Y	Y
Clare et al[3]	Y	Y	U	NA	NA	NA	U	U	Y	Y	Y
Dionne et al[6]	Y	Y	Y	NA	NA	NA	U	NA	Y	Y	Y
Kilby et al[13]	Y	Y	Y	NA	NA	NA	U	Y	Y	N	Y
Kilpikoski et al[14]	Y	Y	Y	NA	NA	NA	U	Y	N	Y	Y
Razmjou et al[31]	Y	Y	Y	NA	NA	NA	U	Y	Y	Y	Y
Riddle and Rothstein[32]	Y	U	Y	NA	NA	NA	U	Y	U	Y	Y
Seymour et al[33]	Y	Y	Y	NA	NA	NA	U	Y	Y	Y	Y
Werneke et al[38]	Y	Y	Y	NA	NA	NA	U	U	Y	U	Y
Werneke et al[39]	Y	Y	Y	NA	NA	NA	U	Y	U	Y	Y

Abbreviations: MDT, Mechanical Diagnosis and Therapy; N, no (did not satisfy the criteria); NA, not applicable; QAREL, Quality Appraisal of Diagnostic Reliability; U, unclear; Y, yes (satisfied the criteria).
Used with permission from Lucas et al.[18]
†*QAREL checklist items: 1, Was the test evaluated in a sample of subjects who were representative of those to whom the authors intended the results to be applied? 2, Was the test performed by raters who were representative of those to whom the authors intended the results to be applied? 3, Were raters blinded to the findings of other raters during the study? 4, Were raters blinded to their own prior findings of the test under evaluation? 5, Were raters blinded to the results of the accepted reference standard or disease status for the target disorder (or variable) being evaluated? 6, Were raters blinded to clinical information that was not intended to be provided as part of the testing procedure or study design? 7, Were raters blinded to additional cues that were not part of the test? 8, Was the order of examination varied? 9, Was the stability (or theoretical stability) of the variable being measured considered when determining the suitability of the time interval between repeated measures? 10, Was the test applied correctly and interpreted appropriately? 11, Were appropriate statistical measures of agreement used?*

the other the assessor)[3,31] and 1 study assessed patients twice (independent raters).[14] Two studies[3,31] considered the following as subsyndromes: direction of dysfunction (flexion, extension, lateral, or rotation), types of derangement (ie, 1 to 7), derangement irreducible, and other (nonmechanical). The other study[14] considered the direction of derangement (posterior or anterior) and dysfunction (flexion or extension) as subsyndromes.

Directional Preference Based on 2 studies, we found conflicting evidence of interrater reliability of the MDT system for identifying directional preference.[14,39] One study found acceptable interrater reliability[14] (κ = 0.90; percent agreement, 90%; n = 39) and the other found unacceptable interrater reliability, regardless of the MDT training level of the clinicians[39] (kappa estimates ranging from 0.27 to 0.39, with a percentage of agreement ranging from 77% to 82%; n = 1587). The interrater reliability was tested by physical therapists who had received different levels of MDT training in one study[39] and by physical therapists who had received an MDT diploma in the other study.[14] These studies assessed the reliability in real time (twice, with independent raters).

Centralization Phenomenon Based on 2 studies, we found conflicting evidence of interrater reliability of the MDT system for identifying the centralization phenomenon.[14,39] One study reported acceptable interrater reliability[14] (κ = 0.70; percent agreement, 95%; n = 39), whereas the other reported unacceptable interrater reliability for all MDT levels of education (kappa estimates ranging from 0.11 to 0.39; percent agreement ranging from 72% to 81%; n = 1587).[39] The interrater reliability was tested by physical therapists who had received different levels of MDT training[39] and by physical therapists who had received an MDT diploma.[14] These studies assessed the reliability in real time (twice, with independent raters).

Reliability of Lateral Shift Two studies investigated the interrater reliability of judgments of lateral shift,[2,33] and 1 study also investigated the intrarater reliability.[2] This study[2] proposed to investigate whether intrarater reliability and interrater reliability were influenced by level of education in the MDT method (first-year undergraduate physical therapy students with no clinical experience or training in MDT, graduate physical therapists with some clinical experience but no formal training in MDT, and graduate physical therapists who had clinical experience and had completed a minimum of 70 hours of formal training in MDT). The reliability was assessed only once, using photographs. In the other study,[33] the interrater reliability was tested twice by physical therapists who had received A and B levels of MDT training.

We found limited evidence of unacceptable intrarater reliability, regardless of the level of education in the MDT method

TABLE 3 Summary of Quality of Reporting of MDT Reliability Studies Measured by the GRRAS Checklist*

Study	Item†														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Bybee and Dionne[1]	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N
Clare et al[2]	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	Y	Y	N
Clare et al[4]	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	Y	Y	Y	N
Clare et al[3]	Y	Y	Y	Y	Y	N	Y	N	Y	Y	Y	Y	Y	Y	N
Dionne et al[6]	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N
Kilby et al[13]	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	Y	N	Y	N
Kilpikoski et al[14]	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N
Razmjou et al[31]	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N
Riddle and Rothstein[32]	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	N
Seymour et al[33]	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	Y	N
Werneke et al[38]	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N
Werneke et al[39]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N

Abbreviations: GRRAS, Guidelines for Reporting Reliability and Agreement Studies; MDT, Mechanical Diagnosis and Therapy; N, no (did not satisfy the criteria); Y, yes (satisfied the criteria).
**Used with permission from Kottner et al.[15]*
†GRRAS checklist items: 1, Identify in title or abstract that interrater/intrarater reliability or agreement was investigated; 2, Name and describe the diagnostic or measurement device of interest explicitly; 3, Specify the subject population of interest; 4, Specify the rater population of interest (if applicable); 5, Describe what is already known about reliability and agreement and provide a rationale for the study (if applicable); 6, Explain how the sample size was chosen. State the determined number of raters, subjects/objects, and replicate observations; 7, Describe the sampling method; 8, Describe the measurement/rating process (eg, time interval between repeated measurements, availability of clinical information, blinding); 9, State whether measurements/ratings were conducted independently; 10, Describe the statistical analysis; 11, State the actual number of raters and subjects/objects which were included and the number of replicate observations which were conducted; 12, Describe the sample characteristics of raters and subjects (eg, training, experience); 13, Report estimates of reliability and agreement, including measures of statistical uncertainty; 14, Discuss the practical relevance of results; 15, Provide detailed results if possible (eg, online).

(ICCs ranging from 0.48 to 0.59; n = 45). Based on 2 studies, conflicting evidence of identifying interrater reliability of judgments of lateral shift (ICC estimates ranging from 0.49 to 0.64; n = 45 and κ = 0.56; percentage of agreement, 73%; n = 15).

Reliability of Neck Pain Studies

Main Syndromes Based on 3 studies on neck pain (pooled n = 45), there is conflicting evidence of interrater reliability of the MDT system for identifying the main syndromes[1,3,6] (kappa estimates ranging from 0.50 to 0.63; percentage of agreement ranging from 67% to 92%) (**TABLE 4**). Two studies[1,6] used video recordings for clinical examination. In these studies, the initial examinations were performed by 1 experienced clinician with MDT diploma training. Then, raters (students formally trained in MDT[1] and physical therapists who had received MDT training[6]) viewed the videotaped MDT examinations independently and rated the main syndrome. One study[3] assessed the reliability in real time (one was the observer and the other the assessor) and included only physical therapists who had completed the MDT credentialing examination and physical therapists who had received an MDT diploma.

Subsyndromes Based on 2 studies, we found conflicting evidence of interrater reliability of the MDT system for identifying subsyndromes in patients with neck pain[3,6] (kappa estimates ranging from 0.47 to 0.84; percentage of agreement ranging from 63% to 88%). One study[3] assessed the reliability in real time (only once; one was the observer and the other the assessor) and included only physical therapists who had completed the MDT credentialing examination and physical therapists who had received an MDT diploma. This study considered the following as subsyndromes: direction of dysfunction (flexion, extension, lateral, or rotation), types of derangement (1 to 7), derangement irreducible, and other (nonmechanical). Another study[6] used video recordings for clinical examination. In that study, the initial examinations were performed by 1 experienced clinician with MDT diploma training. That study considered directions of derangement (posterior and anterior) as subsyndromes.

Directional Preference Based on only 1 study,[6] we found limited evidence of unacceptable interrater reliability of the MDT system for identifying directional preference in patients with neck pain (κ = 0.46; percent agreement, 70%; n = 20). No studies assessed the centralization phenomenon in patients with neck pain.

Reliability of Spine Pain From Mixed Locations

Main Syndromes Based on 3 studies, we found conflicting evidence of interrater reliability of the MDT system for identifying main syndromes in patients with pain from mixed locations[3,4,38] (kappa estimates ranging from 0.56 to 0.96; percentage of agreement ranging from 91% to 96%; n = 389) (**TABLE 4**). One study included only physical therapists who had completed the MDT credentialing examination,[4] 1 included physical therapists who had completed the MDT credentialing examination and physical therapists who had an MDT diploma,[3] and 1 study included physical therapists who had received MDT training and physical therapists who had an MDT diploma.[38] The interrater reliability was performed in real time (only once; one was the observer and the other the assessor).

Subsyndromes Based on 2 studies, we found moderate evidence of acceptable kappa values derived from the MDT system for identifying subsyndromes in patients with pain from mixed locations[3,4] (kappa estimates ranging from 0.68 to 0.87; percentage of agreement ranging from 76% to 90%; n = 100). One study included only physical therapists who had completed the MDT credentialing examination,[4] and the other included physical therapists who had completed the MDT credentialing examination and physical therapists who had an MDT diploma.[3] These studies assessed the reliability in real time. In 1 of the studies,[4] the assessment forms were mailed to the physical therapists, along with an instruction sheet and classification forms, and they were required to classify patients into 1 of the subsyndromes. In the other study,[3] one was the observer and the other the assessor. These studies[3,4] considered the following as subsyndromes: direction of dysfunction (flexion, extension, lateral, or rotation), types of derangement (1 to 7), derangement irreducible, and other (nonmechanical). No studies assessed directional preference and the centralization phenomenon in patients with spine pain from mixed locations.

DISCUSSION

Statement of General Findings

There are relatively few studies[1-4,6,13,14,31-33,38,39] that have investigated the reliability of the MDT system to assess patients with spinal pain. Most of the included studies investigated the interrater reliability in patients with LBP. There is a lack of evidence on interrater reliability in patients with neck pain and no evidence on interrater reliability in patients with thoracic pain. We found acceptable interrater reliability for identifying main syndromes and subsyndromes in patients with LBP when testing was performed by credentialed MDT therapists and physical therapists who had an MDT diploma. We found conflicting evidence for identifying directional preference and the centralization phenomenon in patients with LBP, lateral shift in patients with LBP, main syndromes and subsyndromes in patients with neck pain, and main syndromes in patients with mixed pain locations. Finally, we observed moderate evidence of acceptable interrater reliability for identifying subsyndromes in patients with mixed pain locations, and limited evidence for identifying directional preference in patients with neck pain.

Interpretation of the Study

All included studies were considered to have high methodological quality, ac-

TABLE 4 Intrarater and Interrater Reliability of the MDT System, Rater Characteristics, and Procedure of Reliability Assessments

Reliability Studies	Rater Characteristics (Training Level)	Procedure of Assessment	Kappa*	Percentage of Agreement
Low back pain				
Main syndromes classification				
Clare et al[3]	Credentialed MDT therapists and physical therapists who received an MDT diploma	In real time (once)	1.00 (0.35, 1.00)	100
Kilby et al[13]	Physical therapists who had received MDT training	In real time (once)	...	58.5
Kilpikoski et al[14]	Physical therapists who had an MDT diploma	In real time (twice)	0.60	95
Razmjou et al[31]	Credentialed MDT therapists and physical therapists who received an MDT diploma	In real time (once)	0.70	93
Riddle and Rothstein[32]	Physical therapists who had received MDT training	In real time (twice)	0.26	39
Werneke et al[39]	Physical therapists who had received MDT training	In real time (twice)	0.40 (0.28, 0.50)[†], 0.44 (0.32, 0.56)[‡], 0.37 (0.24, 0.49)[§]	87[†], 91[‡], 86[§]
Subsyndromes				
Clare et al[3]	Credentialed MDT therapists and physical therapists who received an MDT diploma	In real time (once)	0.89 (0.66, 1.00)	92
Kilpikoski et al[14]	Physical therapists who had an MDT diploma	In real time (twice)	0.70	74
Razmjou et al[31]	Credentialed MDT therapists and physical therapists who received an MDT diploma	In real time (once)	0.96	97
Directional preference				
Kilpikoski et al[14]	Physical therapists who had an MDT diploma	In real time (twice)	0.90	90
Werneke et al[39]	Physical therapists who had received MDT training	In real time (twice)	0.39 (0.27, 0.52)[†], 0.27 (0.17, 0.37)[‡], 0.33 (0.22, 0.45)[§]	82[†], 77[‡], 77[§]
Centralization phenomenon				
Kilpikoski et al[14]	Physical therapists who had an MDT diploma	In real time (twice)	0.70	95
Werneke et al[39]	Physical therapists who had received MDT training	In real time (twice)	0.11 (−0.14, 0.27)[†], 0.35 (0.22, 0.46)[‡], 0.39 (0.28, 0.51)[§]	81[†], 79[‡], 72[§]
Other (identify lateral shift)				
Clare et al[2‖]	1. First-year undergraduate physical therapy students with no clinical experience or training in the McKenzie method	Photo	Intrarater: 0.56 (0.53, 0.59); interrater: 0.53 (0.46, 0.61)	...
	2. Graduate physical therapists with some clinical experience but no formal training in the McKenzie method	Photo	Intrarater: 0.48 (0.43, 0.53); interrater: 0.49 (0.42, 0.51);	...
	3. Graduate physical therapists who had clinical experience and had completed a minimum of 70 hours of formal training in the McKenzie method	Photo	Intrarater: 0.59 (0.55, 0.63); interrater: 0.64 (0.57, 0.71)	...
Seymour et al[33]	Physical therapists who had received MDT training (courses A and B)	In real time (twice)	0.56	73

Table continues on page 931.

cording to the multiple criteria used in this study. However, our results have to be interpreted cautiously due to the small number of included studies. Overall, we observed acceptable interrater reliability of the MDT system for identifying main syndromes and subsyndromes in patients with LBP when performed by credentialed MDT therapists and physical therapists who had received an MDT diploma. However, given the large difference in sample size between studies, there is also a possibility that the difference in chance-corrected reliability levels between studies is not only associated with educational level, but also with the representativeness of the sample of therapists and patients. It is also unclear from our data whether the therapists are reliable at various components of the classification (eg, directional preference, centralization, and lateral shift). It was not possible to draw firm conclusions in patients with neck pain and mixed pain locations due to the wide variability between studies.

It is recommended that the time interval between the measures of interrater reliability should be long enough to prevent recall, though short enough to

TABLE 4 Intrarater and Interrater Reliability of the MDT System, Rater Characteristics, and Procedure of Reliability Assessments (continued)

Reliability Studies	Rater Characteristics (Training Level)	Procedure of Assessment	Kappa*	Percentage of Agreement
Neck pain				
Main syndromes classification				
Bybee and Dionne[1]	Students formally trained in MDT	Video recording	0.50 (0.48, 0.53)	85.6
Clare et al[3]	Credentialed MDT therapists and physical therapists who received an MDT diploma	In real time (once)	0.63 (−0.11, 1.00)	92
Dionne et al[6]	Physical therapists who had received MDT training	Video recording	0.55 (0.52, 0.58)	67
Subsyndromes				
Clare et al[3]	Credentialed MDT therapists and physical therapists who received an MDT diploma	In real time (once)	0.84 (0.60, 1.00)	88
Dionne et al[6]	Physical therapists who had received MDT training	Video recording	0.47 (0.44, 0.50)	63
Directional preference				
Dionne et al[6]	Physical therapists who had received MDT training	Video recording	0.46 (0.43, 0.49)	70
Spine pain from mixed locations				
Main syndromes classification				
Clare et al[4]	Credentialed MDT therapists	By mail	0.56 (0.46, 0.66)	91
Clare et al[3]	Credentialed MDT therapists and physical therapists who received an MDT diploma	In real time (once)	0.84 (0.35, 1.00)	96
Werneke et al[38]	Physical therapists who had received MDT training and who had an MDT diploma	In real time (once)	0.96	...
Subsyndromes				
Clare et al[4]	Credentialed MDT therapists	By mail	0.68 (0.67, 0.69)	76
Clare et al[3]	Credentialed MDT therapists and physical therapists who received an MDT diploma	In real time (once)	0.87 (0.71, 1.00)	90

Abbreviation: MDT, Mechanical Diagnosis and Therapy.
**Values in parentheses are 95% confidence interval.*
†Levels A and B.
‡Level C.
§Level D.
‖This study reported reliability using intraclass correlation coefficients.

ensure that clinical change has not occurred. More than half of the studies assessed reliability in real time, and only 3 (25%) assessed patients twice,[14,32,39] once by each rater. However, there is also evidence suggesting that, for the MDT system, patients should be assessed only once, because patients with derangement syndrome can change substantially during examination.[13] Most of the studies assessed patients only once, with both an observer therapist and an assessor therapist in the same room. Two of these studies[13,31] randomized the raters to be observer and assessor. This approach may inflate intertester reliability, as differences in how each therapist performs the assessment are not included.

Findings in the Context of Other Literature

Two previous systematic reviews have investigated the reliability of different classification systems (including but not limited to MDT) for patients with LBP,[8,20] and another systematic review aimed to investigate the reliability of MDT for lower and upper extremity problems.[36] To our knowledge, our review is the first to summarize the available evidence on the reliability of the MDT classification in patients with spine pain (neck pain, LBP, and spine pain from mixed locations). The first 2 mentioned systematic reviews[8,20] reported conflicting evidence regarding interrater reliability of the MDT classification system in patients with LBP, which ranged from acceptable to unacceptable reliability. The 4 studies included in these reviews were also included in our review. However, a large amount of new evidence was published after the publication of these reviews, and therefore was included in our review. This includes 2 new LBP studies,[14,39] 3 neck pain studies,[1,3,6] 2 mixed pain location studies,[4,38] and 2 studies[2,33] that assessed the reliability of identifying lateral shift.

Strengths and Limitations of the Study

The strengths of this review include the use of a sensitive search strategy and that 2 independent authors conducted study screening, data extraction, and assessment of methodological quality, as recommended by the Cochrane Collaboration.[12] We used the QAREL tool,[17,18] which was designed for assessing the quality of reliability studies and for the preparation of systematic reviews, and we also used 5 levels of evidence currently suggested for functional movement screening scores.[30] Unfortunately, due to the large variability among eligible studies, a meta-analysis approach was not possible.

Future Research

Further studies are required to investigate interrater reliability of the MDT classification system for neck and thoracic pain and directional preference and the centralization phenomenon for spine pain, as very little evidence exists in these populations. We also suggest the following for future studies: include a sample size of at least 50 patients to assess reliability,[29] with independent raters (interrater reliability)[29] and an appropriate time interval to keep patients stable in the interim period.[29] The ideal study following reliability principles would include multiple raters independently assessing the same patient at different times.

However, it is challenging to propose an ideal approach and establish a perfect time interval for the MDT system, due to the potential change in a patient's symptoms during the repeated movement test. It is important to determine a design with minimal bias and, at the same time, that is viable for clinical practice. One option would include multiple raters in independent rooms observing someone's assessment of the patient in real time, but with the opportunity to interact with the patient during the assessment (without others being able to listen). Another design suggestion is to include multiple blind and independent raters assessing the same patient at different time points. Each rater might report patients in whom they believe the classification has likely changed post movement test assessment, and the analysis could investigate whether this possible change in symptoms impacted the reliability.

CONCLUSION

This review shows, based on studies of high methodological quality, that the MDT system appears to have acceptable interrater reliability for classifying patients with back pain into main syndromes and subsyndromes when applied by therapists who have completed the MDT credentialing examination, but unacceptable reliability in other therapists. There is moderate evidence of acceptable interrater reliability of the MDT system for identifying subsyndromes in patients with mixed pain locations. However, there was conflicting evidence regarding the reliability of the MDT classification system for identifying directional preference and the centralization phenomenon in patients with LBP, main syndromes in patients with neck pain and mixed pain locations, and subsyndromes in patients with neck pain. There is also limited evidence on interrater reliability of the MDT system to identify directional preference in patients with neck pain. ◉

KEY POINTS

FINDINGS: The Mechanical Diagnosis and Therapy (MDT) system might be considered reliable to classify patients with low back pain into main syndromes and subsyndromes and to identify subsyndromes in patients with mixed pain locations. There is conflicting evidence regarding the interrater reliability of the MDT classification system in patients with neck pain.

IMPLICATIONS: The MDT system is widely used by physical therapists and requires an adequate classification to select a specific intervention. Understanding the reliability of this method is very important for clinical practice. Regarding implications for research, there is a need for further high-quality research to investigate interrater reliability of MDT in patients with neck pain and in patients with spine pain, mainly to identify directional preference and the centralization phenomenon.

CAUTION: Only a small number of studies were included in this review. Therefore, the existing reliability estimates are very likely to be biased.

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APPENDIX

SEARCH STRATEGY

MEDLINE (Ovid)

Part A: Specific Search—Reliability

1. reliabilit$.ab,pt, ti.
2. reproducibilit$. ab,pt, ti.
3. validit$. ab,pt, ti.
4. inter-examiner.ab,ti.
5. inter-observer.ab,ti.
6. test-retest ab,ti.
7. inter-rater.ab,ti.
8. intra-rater.ab,ti.
9. intra-observer.ab,ti.
10. agreement.ab,ti
11. validation.ab,ti.
12. kappa.ab,ti
13. Intra-class$.ab,ti.
14. Internal consistency.ab,ti.
15. measurement error, af.
16. hipoth$ test$.af
17. responsiveness.af
18. interpretability.af
19. response theor$.af
20. generalizabilit$.ab,ti.
21. or/1-20

Part B: Specific Search—Low Back Problems

22. Dorsalgia.af,ab,ti.
23. exp Back Pain/
24. backache.ab,ti.
25. Exp Low Back Pain/
26. Lumbago.ab,ti.
27. Spinal injur$.ab,ti.
28. Spondylosis.ab,ti.
29. or/22-28

Part C: Specific Search—Neck Pain Problems

30. exp Neck Pain/
31. Neck ache.ab,ti.
32. Neckache.ab,ti.
33. Cervical pain.ab,ti.
34. Neck injur$.ab,ti.
35. or/30-34

Part D: Specific Search—McKenzie Method

36. McKenzie.ab,ti.
37. mechanical diagnosis and therapy.ab,ti.
38. directional preference exercise.ab,ti.
39. active range of motion.ab,ti.
40. end- range.ab,ti.
41. centralization.ab,ti.
42. unloaded exercise.ab,ti.
43. extension exercise.ab,ti.
44. Lateral shift
45. or/36-44
46. 21 and 29 and 35 and 45

PEDro

Each term below was searched in the 'Abstract & Title' field, combined with 'clinical trial' in the 'Method' field, using the advanced search option.

1. McKenzie
2. Mechanical diagnosis therapy
3. mechanical diagnosis and therapy
4. directional preference exercise
5. directional preference exercises
6. active range of motion
7. centralization
8. end- range
9. unloaded exercises
10. extension exercise

Embase

Part A: Specific Search—Reliability

1. reliabilit$.ab,pt, ti.
2. reproducibilit$. ab,pt, ti.
3. validit$. ab,pt, ti.
4. inter-examiner.ab,ti.
5. inter-observer.ab,ti.
6. test-retest ab,ti.
7. inter-rater.ab,ti.
8. intra-rater.ab,ti.
9. intra-observer.ab,ti.
10. agreement.ab,ti
11. validation.ab,ti.
12. kappa.ab,ti
13. Intra-class$.ab,ti.
14. Internal consistency.ab,ti.
15. measurement error, af.
16. hipoth$ test$.af
17. responsiveness.af
18. interpretability.af
19. response theor$.af
20. generalizabilit$.ab,ti.
21. or/1-20

Part B: Specific Search—Low Back Problems

22. dorsalgia.ab,kw,ti.
23. back pain.mp.
24. (back pain or backache or back ache). ab,kw,ti.
25. exp LOW BACK PAIN/
26. exp BACKACHE/
27. (lumbar adj pain).ab,kw,ti.
28. coccyx,ab,kw,ti
29. coccydynia.ab,kw,ti.
30. spondylosis.mp.
31. sciatica.ab,kw.ti
32. sciatica/
33. exp ISCHIALGIA
34. back disorder$.ab,kw,ti.
35. lumbago.ab,kw,ti.
36. or/22-35

Part C: Specific Search—Neck Pain Problems

37. exp Neck Pain/
38. Cervical pain.ab,ti.
39. Neck injur$.ab,ti.
40. or/37-39

Part D: Specific Search—McKenzie Method

41. McKenzie.mp
42. Mechanical diagnosis.mp
43. directional preference.mp
44. active range of motion.mp
45. end- range.mp
46. centralization.mp
47. centralization.mp
48. unloaded exercise.mp
49. extension exercise.mp
50. lateral shift
51. or/41-50
52. 21 and 36 and 40 and 51

CINAHL

Part A: Specific Search—Reliability

1. reliabilit*
2. reproducibility*
3. validit*
4. "inter-examiner"
5. "inter-observer"
6. "test-retest"
7. "inter-rater"
8. "intra-rater"
9. "intra-observer"
10. agreement
11. validation
12. kappa
13. "intra-class"
14. "internal consistency"
15. "measurement error"
16. responsiveness
17. interpretability
18. "response theor*"

APPENDIX

19. generalizability*
20. or/1-19

Part B: Specific Search—Low Back Problems

21. "dorsalgia"
22. (MH "Back Pain+")
23. (MH "Low Back Pain+")
24. back pain
25. lumb* W3 pain
26. backache or "back ache"
27. (MH "Coccix)
28. (MH "Sciatica")
29. "Sciatica"
30. "coccix"
31. "cocydynia"
32. (MH "Lumbar Vertebrae")
33. Lumbar N2 Vertebra
34. or/21-35
35. (MH "Thoracic Vertebrae")
36. (MH "Spondylolisthesis")
37. (MH "Spondylolysis")
38. Lumbago
39. or/37-40

Part C: Specific Search—Neck Pain Problems

40. (MH "neck pain"+)
41. Neckache or "neck ache")
42. Cervical pain
43. Neck injur*
44. or/42-45

Part D: Specific Search—McKenzie Method

45. "McKenzie Diagnosis"
46. "end-range"
47. "active range of motion"
48. "unloaded exercise"
49. "directional preference"
50. "extension exercise"
51. "centralization"
52. Lateral shift
53. or/47-53
54. 20 and 36 and 41 and 46 and 55

Scopus

Part A: Specific Search—Reliability

TITLE-ABS-KEY (reliabilit$.) OR
TITLE-ABS-KEY (reproducibilit$.) OR
TITLE-ABS-KEY (validit$.) OR
TITLE-ABS-KEY (validit$.) OR
TITLE-ABS-KEY (inter-examiner) OR
TITLE-ABS-KEY (inter-observer.) OR
TITLE-ABS-KEY (test-retest.) OR
TITLE-ABS-KEY (inter-rater.) OR
TITLE-ABS-KEY (intra-rater.) OR
TITLE-ABS-KEY (intra-observer.) OR
TITLE-ABS-KEY (agreement.) OR
TITLE-ABS-KEY (validation.) OR
TITLE-ABS-KEY (kappa.) OR
TITLE-ABS-KEY (intra-class$.) OR
TITLE-ABS-KEY (internal AND consistency.) OR
TITLE-ABS-KEY (measurement AND error.) OR
TITLE-ABS-KEY (hipoth$ AND test$.) OR
TITLE-ABS-KEY (responsiveness.) OR
TITLE-ABS-KEY (interpretability.) OR
TITLE-ABS-KEY (response AND theor$.) OR
TITLE-ABS-KEY (generalizabilit$.)

Part B: Specific Search—Low Back Problems

AND
TITLE-ABS-KEY (dorsalgia.) OR
TITLE-ABS-KEY (exp AND back AND pain/) OR
TITLE-ABS-KEY (backache.) OR
TITLE-ABS-KEY (exp AND low AND back AND pain/) OR
TITLE-ABS-KEY (lumbago.) OR
TITLE-ABS-KEY (spinal AND injur$.) OR
TITLE-ABS-KEY (spondylosis.)

Part C: Specific Search—Neck Pain Problems

OR
TITLE-ABS-KEY (exp AND neck AND pain/) OR
TITLE-ABS-KEY (neck AND ache.) OR
TITLE-ABS-KEY (neckache.) OR
TITLE-ABS-KEY (cervical AND pain.) OR
TITLE-ABS-KEY (neck AND injur$.)

Part D: Specific Search—McKenzie Method

AND
TITLE-ABS-KEY (mckenzie.) OR
TITLE-ABS-KEY (mechanical AND diagnosis AND therapy.) OR
TITLE-ABS-KEY (directional AND preference AND exercise.) OR
TITLE-ABS-KEY (active AND range AND of AND motion.) OR
TITLE-ABS-KEY (end- AND range.) OR
TITLE-ABS-KEY (centralization.) OR
TITLE-ABS-KEY (unloaded AND exercise.) OR
TITLE-ABS-KEY (extension AND exercise.) OR
TITLE-ABS-KEY (lateral shift.)

[CASE REPORT]

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SUMMER D. OTT, PsyD[2,3] • **ROGELIO A. CORONADO,** PT, PhD[4]

Rehabilitation of an Adolescent Equestrian Athlete With a History of Multiple Concussions: A Case Report Describing an Adapted Return-to-Sport Protocol

A concussion is a brain injury with a complex pathophysiological process that results from trauma to the head, neck, or elsewhere on the body.[3,9,32,33] In the United States, 1.6 to 3.8 million brain injuries, including concussions, occur during competitive sports and recreational activities.[23] Equestrian athletes are at substantial risk of a concussion due to falls or being bucked from a horse.[27,43] Rates of concussion range from 10% to 45% of all equestrian-related injuries.[22,27,38,43,50] These estimates are conservative, as rates of concussion in equestrian sports are likely underreported.[14,27] Typically, individuals experience symptom resolution within 10 to 14 days post concussion[32]; however, 10% to 30% of individuals report persistent symptoms beyond this time frame.[39]

BACKGROUND: Equestrian riding is a sport with a high risk of concussion. Currently, the literature guiding rehabilitation for concussions in equestrian athletes is limited, especially for direct-ing return to sport.

CASE DESCRIPTION: In this case report, a 14-year-old female equestrian athlete presented to physical therapy following her third concussion in 3 years. Her primary complaints were headaches, dizziness, difficulty concentrating, light sensitivity, and neck pain. On examination, the patient demonstrated reproduction of symptoms during testing of the vestibular-ocular reflex, showed a 3-line symptomatic loss on the dynamic visual acuity test, and had impairments in the joint position error test (1/5 correct on the left, 4/5 correct on the right) and a Balance Error Scoring System (BESS) score of 38/60 errors. A return-to-riding protocol was adapted from general return-to-sport guidelines and tailored to meet the unique demands of the patient's equestrian sport. The protocol included phased progression through no activity, light aerobic activity, moderate aerobic activity, sport-specific nonjumping skills, sport-specific jumping skills, full practice, and return to competition. During the protocol, the patient participated in 8 physical therapy sessions over 4 weeks for vestibular training, aerobic conditioning, and cervical and core exercises, as well as equestrian exercises at her stables.

OUTCOMES: At the final evaluation, the patient reported no symptoms at rest, with exercise, or when testing vestibular-ocular reflex. Improvements were noted in the dynamic visual acuity test, joint position error, and BESS, with changes in the BESS exceeding minimal detectable change. The patient completed the full return-to-riding protocol in 8 weeks and was able to return to equestrian competition without complaints.

DISCUSSION: This case report describes the physical therapy management of an adapted return-to-sport protocol for an equestrian athlete with a history of multiple sport-related concussions.

LEVEL OF EVIDENCE: Therapy, level 5.
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KEY WORDS: *athletic injuries, concussion, horses, pediatrics, postconcussion syndrome, return to sport*

Physical therapy can address postconcussion symptoms in order to facilitate symptomatic recovery and progress toward return to sport.[11,36,39,40] Majerske et al[30] reported that adolescent athletes who sustained a concussion during sport participation performed better on neurocognitive tests when allowed to engage in moderate-intensity physical and cognitive activities. Progressive subthreshold aerobic exercise has been shown to be an appropriate strategy for addressing postconcussion symptoms in athletes with persistent symptoms.[25,26] Schneider et al[41] demonstrated that physical therapy provided benefits for returning to sport. A combination of vestibular and cervical spine interventions as part of a physical

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therapy protocol, in addition to range-of-motion exercises and postural education, has resulted in decreased time to return-to-sport clearance in adolescent and young adult athletes with persistent postconcussion symptoms.[41]

General protocols guiding return to sport after concussion have been developed and presented in the literature. In 2010, the American Academy of Pediatrics adopted the International Conference on Concussion in Sport's proposed 6-phase return-to-sport protocol that included periods of no activity, light aerobic activity, sport-specific exercise, noncontact training drills, full-contact practice, and return to sport.[31,33] A similar protocol was recommended in the recent consensus statement on concussion.[32] May et al[31] expanded on these 6-phase protocols by adding a moderate-aerobic-activity phase to bridge light activity and more demanding sport-specific tasks, as well as differentiating limited and full-contact drills. These general concussion guidelines can be used to tailor a sport-specific protocol for patients wanting to return to sport. Familiarity with the demands of each sport is vital, because each sport has unique tasks that require different physical and cognitive skills.

To our knowledge, there are no published cases describing the adaptation of general return-to-sport guidelines for equestrian athletes. Thus, the purpose of this case report was to describe the physical therapy management and adaptation of a return-to-sport protocol for an equestrian athlete with a history of multiple concussions.

CASE DESCRIPTION

History

The patient was a 14-year-old female competitive equestrian rider with a history of 3 concussions within a 3-year span. The patient's first 2 concussions occurred as a result of being thrown from her horse. She reported that she recovered from these episodes and had no residual symptoms or deficits. Three years after the initial concussion, the patient sustained a third concussion when she was struck in the left frontal region of her face with a hockey stick during a floor hockey game in physical education class. The patient was referred to neuropsychology and physical therapy. She experienced postconcussion symptoms for 2 weeks before her physical therapy evaluation was conducted.

Two days prior to her initial physical therapy visit, a neuropsychologist performed a neurocognitive evaluation, which included the computerized administration of Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT; ImPACT Applications, Inc, San Diego, CA).[1,48] Her ImPACT results revealed normal scores on verbal and visual memory, visual motor speed, and reaction time.[49] The patient scored a 27 on the 22-item Post-Concussion Symptom Scale (PCSS) component of ImPACT, which is a "very high" normative score.[29] The PCSS is a reliable and valid measure of postconcussion symptoms.[29] An initial screen was conducted by a physical therapist at the neuropsychology visit to determine whether additional physical therapy was warranted. The quick screen involved assessment of the vestibular-ocular reflex (VOR) and visual motion sensitivity, which were both positive for reproduction of the patient's symptoms.

The patient reported symptoms of headache, dizziness, difficulty with balance, light sensitivity, neck pain, and difficulties in concentration. Her past medical history was significant for myringotomy, tonsillectomy, and adenoidectomy. The patient was in the ninth grade and denied any history of learning disability, attention disorder, or failing grades. The patient's goal for physical therapy was to return to equestrian competition as quickly and safely as possible.

Initial Examination

The initial physical therapy examination included cervical spine screening, vestibular testing, balance assessment, and aerobic capacity (**TABLE 1**). An initial cervical screen included alar ligament, transverse ligament, and vertebrobasilar insufficiency testing due to the traumatic mechanism of injury.[45] The Sharp-Purser, alar ligament, and vertebrobasilar insufficiency tests are commonly used in physical therapy practice and were all negative.[17,18] The patient demonstrated full cervical active range of motion with normal end feel, but reported neck pain during cervical extension. Cervical segmental mobility and scapular mobility were not assessed during the initial evaluation. The patient was able to maintain the deep neck flexor (DNF) endurance test for 4 seconds, indicating weakness in the DNF muscle group. For the DNF endurance test, the established normative time for adolescent females is 31 seconds,[20] and the minimal detectable change (MDC) is 17.8 seconds.[6]

Joint position error (JPE) testing was used to assess proprioceptive awareness in the cervical spine. During JPE testing, a laser was attached to the patient's head and focused toward the center of a target. The patient was asked to close her eyes, turn her head to the side, turn her head back to the center, and open her eyes when she thought she was back at the target center. Correct performance is within 4.5 cm from the center of the target, and a normal result is at least 4 of 5 correct performances per side.[3,46] The patient scored 4 of 5 correct on the right and 1 of 5 correct on the left, indicating impaired cervical proprioception when turning her head to the left. The MDC for JPE has not been established.

Vestibular and oculomotor testing included a series of assessments for smooth pursuit, saccades, near-point convergence, VOR, and visual motion sensitivity. These assessments were performed as described by Mucha et al[35]; however, item scoring was adapted, and only symptomatic response (ie, reproduction of patient symptoms) was recorded. Additional testing included the head impulse test and the dynamic visual acuity test (DVAT).[2,28,37,42] During smooth pursuit, the patient's eye movements were smooth, and she was asymptomatic during horizontal and vertical movements. The saccades test, which examines a patient's ability to focus on a target and quickly move to another, was negative, indicating that her symptoms were not reflective of a central oculomotor disorder. During the near-point convergence test, the patient was able to converge to 5 cm before seeing double, and did not experience any symptoms. Thus, the patient's near-point convergence was negative.

During testing of VOR, the patient was unable to maintain a head speed of 180 bpm and experienced symptoms when the metronome was set to 120 bpm, indicating a symptomatic test. Moderate dizziness during the visual motion sensitivity test was provoked to 4/10 on a numeric rating scale (NRS), with 0 indicating "no dizziness" and 10 the "worst possible dizziness." The head impulse test was used to rule out a unilateral vestibular hypofunction and was negative. Finally, the DVAT was positive, as the patient lost 3 lines and reported symptoms of dizziness and headache. Impairments in VOR and the DVAT with a negative head impulse test indicate that VOR is likely affected by visual sensitivity rather than a true deficit in VOR.

Balance was assessed using the Balance Error Scoring System (BESS). The BESS consists of 6 testing conditions and is scored on the total number of errors during each position.[10,47] The positions are Romberg, tandem, and single leg each performed on firm ground and foam. Each position is held for 20 seconds, with the patient's shoes off, hands placed on hips, and eyes closed. The maximum number of errors for each position is 10, with 60 total errors being the maximum score.[47] The MDC for the BESS is 9.3 errors.[8] The patient scored 38 errors during her initial evaluation, which was above the normative value of 16 errors for healthy children and adolescents between 11 and 14 years of age, indicating impaired balance.[13]

During the patient's initial assessment with the neuropsychologist, it was recommended that the patient perform a graded exertion test during her initial physical therapy visit. A recovery protocol for postconcussion syndrome at the submaximal symptom-limited threshold was administered. The submaximal symptom-limited threshold is determined by using the modified Balke treadmill protocol, in which the patient wore a heart-rate (HR) monitor while walking on a treadmill at a constant speed of 1.6 m/s.[25,26,44] The incline of the treadmill was increased 1% every minute until the patient reported an increase in symptoms. The patient's maximum predicted HR was 206 bpm, and she was able to perform 20 minutes of the modified Balke treadmill protocol with no increase in symptoms when reaching a maximum HR of 180, which is above her 85% maximum HR, indicating no deficit in aerobic function.[44]

TABLE 1 Examination Findings at the Initial Physical Therapy Visit

Examination Test	Result
Cervical screening	
Sharp-Purser	Negative
Alar ligament	Negative
Vertebrobasilar insufficiency	Negative
Cervical range of motion	
Flexion	WNL
Extension	WNL, but with pain
Rotation	WNL
Side flexion	WNL
Deep neck flexor endurance	4 s
Cervical proprioception: joint position error	4/5 correct to right side, 1/5 correct to left side
Vestibular and oculomotor screening	
Smooth pursuit	WNL
Saccades	WNL
Near-point convergence	WNL
VOR	Symptomatic
Visual motion sensitivity	Symptomatic
Head impulse test	WNL
Dynamic visual acuity test	Symptomatic with loss of 3 lines
Balance: Balance Error Scoring System	38 errors
Aerobic: Balke treadmill protocol	Negative

Abbreviations: VOR, vestibular-ocular reflex; WNL, within normal limits.

Guided Physical Therapy Management Within a Return-to-Riding Protocol

Because there were no equestrian-specific return-to-sport guidelines available, a return-to-riding protocol was adapted from guidelines proposed by May et al.[31] **TABLE 2** depicts the 7-phase return-to-riding protocol. Specific physical therapy exercises from each session are outlined in **TABLE 3**. Due to factors such as the patient's younger age, acuity of symptoms, and motivation, the patient was scheduled for physical therapy twice a week. The physical therapist and neuropsychologist collaborated with the patient's equestrian trainer to ensure the protocol included necessary sport-specific skills. As the patient advanced through the return-to-riding protocol, exercises transitioned from the physical therapy clinic to the stables where the patient's horses were maintained and her typical training occurred. The equestrian trainer supervised the stages of the return-to-riding protocol at the stables and maintained communication with the physical therapist and neuropsychologist to ensure proper progression.

Phase 1: No Activity The first phase of the return-to-riding protocol involved a period of no activity to provide physical and mental rest.[33,39] This phase occurs during the acute injury period. In this case, phase 1 occurred during the 2 weeks after the day of injury and prior to the patient starting physical therapy.

Phase 2: Light Aerobic Activity During the second phase, the patient began stationary biking at less than 70% maximum predicted HR for 10 to 15 minutes in the physical therapy clinic.[33] Stationary biking was chosen initially because it has limited visual perturbation compared to other modes of aerobic training and allowed the patient to perform exercise without provoking dizziness. Other in-clinic exercises included seated VOR exercises, progressing to standing and supine chin tucks.[33] The initial VOR exercise performed was a replication of the VOR test. The goal of the exercise was to perform 3 sets of 2 minutes, while achieving moderate-level dizziness of 4-5/10 on the NRS. Reproducing dizziness during this exercise results in adaptation and habituation of the vestibular and visual systems, respectively.[40] The metronome was set between 120 and 240 bpm and was determined by reaching the appropriate level of dizziness. Prior to initiating the subsequent set, dizziness symptoms were monitored for a return to baseline.[3]

The VOR exercise, prescribed as part of the patient's home exercise program, was performed for 3 sets of 2 minutes 3 times per day. Clinical recommendations for unilateral vestibular hypofunction state that VOR exercises should be performed 3 to 5 times per day for a total of 20 minutes.[12] The patient was allowed to progress the intensity by increasing the beats per minute if 4-5/10 dizziness was not achieved. The goal of VOR exercises was to integrate the vestibular and visual systems so that functional stimulation of these systems no longer provoked symptoms.[3,47] Balance was addressed by changing the surface of the VOR exercises.

During an equestrian competition, the athlete must memorize the course design immediately prior to riding the course. Therefore, in order to add a cognitive task to this phase of the protocol, the patient memorized and walked through the course at the stables. The

TABLE 2 Novel Adaptation of a Graded Return-to-Sport Protocol Applied to an Equestrian Athlete

Protocol Phase	Phase Objective	Phase Duration and PT Sessions	Exercises	Progression Criteria
1. No activity	Symptom recovery	2 wk (from injury to initiation of PT)	Complete physical and cognitive rest	Once medical clearance is provided, advance to phase 2 and begin rehabilitation
2. Light aerobic activity	Increase HR and restore connection between rider and horse	1 wk in duration (began on day 15) PT sessions 1-2	PT exercises*: walking or stationary bike, keeping intensity under 70% MPHR for 10-15 min; begin VOR exercises and cervical stabilization; no resistance training Stable exercises: memorize and walk course (rider only); walk (on horse) and focus on objects in the distance	If symptom free for 24 h following completion of phase 2, progress to phase 3
3. Moderate aerobic activity	Increase HR and build cardiovascular endurance Begin conditioning on horse Build core and lower extremity strength	2 wk in duration (began on day 22) PT sessions 3-6	PT exercises*: stationary bike, elliptical, and jogging while keeping intensity under 85% MPHR for 20-30 min; begin light resistance training Stable exercises: trot, riding in 2-point position for 1-2 min without stirrups	If symptom free for 24 h following completion of phase 3, progress to phase 4
4. Sport-specific non-jumping drills	Begin sport-specific drills on horse	1 wk in duration (began on day 36) PT sessions 7-8	PT exercises*: general sport-specific drills, light resistance training Stable exercises: sitting trot, cantering, ground-pole and cavaletti work, complete flat work	If symptom free for 24 h following completion of phase 4, progress to phase 5
5. Sport-specific jumping drills	Advance sport-specific drills to prepare for return to full practice	1 wk in duration (began on day 43)	Stable exercises: progression to multistep training drills, progressive return to normal resistance training, small jumps with measuring lines, progress to larger jumps	If symptom free for 24 h following completion of phase 5, progress to phase 6
6. Full practice	Restore confidence and assess functional skills by equestrian trainer	1 wk in duration (began on day 50)	Stable exercises: participate in normal training activities, but no competing; full course with related distance	If symptom free for 24 h following completion of phase 6, progress to phase 7
7. Return to competition	Return to competition	Patient cleared for full competition 8 wk (day 57) after injury	Normal competition as tolerated; monitor symptoms	...

Abbreviations: HR, heart rate; MPHR, maximum predicted heart rate; PT, physical therapy; VOR, vestibular-ocular reflex.
See* **TABLE 3 *for specific exercises performed during each PT session.*

TABLE 3 DETAILED SUMMARY OF PHYSICAL THERAPY EXERCISES AT EACH SESSION

Protocol Phase/Session	Exercise
Phase 2: light aerobic activity	
1	• Stationary bike for 20 min • VOR performed in sitting, facing a blank wall in a quiet room at 120 bpm for 3 sets × 2 min
2	• Stationary bike for 15 min • Supine chin tucks • VOR performed in standing, facing blank wall in a quiet room at 170 bpm for 2 sets × 2 min • VOR weaving through cones for 2 min
Phase 3: moderate aerobic activity	
3	• Stationary bike for 15 min • Agility ladder drills • Prone planks • Supine chin tucks • VOR performed in standing, facing a busy gym at 150 bpm for 2 sets × 2 min • VOR weaving through cones for 2 min
4	• Stationary bike for 15 min • JPE: tracing an object on wall • VOR performed standing on a BOSU Balance Trainer in a busy gym at 230 bpm for 3 sets × 2 min • VOR weaving through cones at 230 bpm for 2 sets × 2 min
5	• Elliptical for 15 min • Supine chin tucks • Prone planks • Quadruped exercises with a cuff weight on head and opposite-extremity lifting • Agility ladder drills • VOR performed standing on a BOSU Balance Trainer in a busy gym at 230 bpm for 3 sets × 2 min • VOR weaving through cones at 230 bpm for 2 sets × 2 min
6	• Elliptical for 15 min • Supine chin tucks • Prone planks • Quadruped exercises with a cuff weight on head and opposite-extremity lifting • VOR performed standing on a BOSU Balance Trainer in a busy gym at 240 bpm for 3 sets × 2 min • VOR weaving through cones at 240 bpm for 2 sets × 2 min
Phase 4: sport-specific nonjumping drills	
7	• Supine chin tuck and lift • Prone plank with cuff weight on head • VOR performed standing on a BOSU Balance Trainer in a busy gym at 240 bpm for 3 sets × 2 min • VOR weaving through cones at 240 bpm for 2 sets × 2 min • Visual tracking of ball toss, with 180° turn, for 3 sets × 1 min • Elliptical with head movements, on for 1 min and off for 1 min, for 20 min total
8	• VOR performed standing on a BOSU Balance Trainer at 240 bpm for 3 sets × 2 min • VOR weaving through cones at 240 bpm for 2 sets × 2 min • Visual tracking of ball toss, with 180° turn, for 3 sets × 1 min • Agility ladder drills: memorize 5 exercises at once and then complete • Squatting on a BOSU Balance Trainer with perturbations

Abbreviations: JPE, joint position error; VOR, vestibular-ocular reflex.

horse-rider connection is extremely important during equestrian activities and should be restored as quickly and safely as possible. The patient rebuilt this connection by walking and leading her horse through the course. No horseback riding or resistance training was allowed during this phase. During stable sessions, the patient was permitted to ride her horse, beginning with a slow walk. To add gaze stabilization into this phase, the patient focused on an object in the distance while riding. For the remainder of the phases, if the patient was asymptomatic for 24 hours following a phase, she progressed to the next phase.[39] Phase 2 began on day 15 and lasted for 1 week. Phase 2 consisted of 2 physical therapy sessions and 1 session at the stables.

Phase 3: Moderate Aerobic Activity The third phase of the return-to-riding protocol was moderate aerobic activity, which included performing aerobic exercise on a bike, elliptical, and treadmill for 20 to 30 minutes at less than 85% maximum predicted HR.[33] Using an elliptical and treadmill added a visual perturbation to challenge the vestibular system. The VOR exercises were progressed to incorporate a busy background, unstable surface, and walking. Light resistance training began during this phase, including DNF and core stabilization exercises to address the patient's cervical impairments.

During stable sessions, the patient progressed to a slow trot on her horse. Strengthening exercises on the horse included riding in the 2-point position—a position required for jumps—and riding without stirrups for 1 to 2 minutes. The goal of this phase was to increase HR, build up cardiovascular endurance, and improve core and lower extremity strength. Phase 3 began on day 22 and lasted 2 weeks. Phase 3 included 4 physical therapy sessions and 4 sessions at the stables.

Phase 4: Sport-Specific Nonjumping Drills The fourth phase of the return-to-riding protocol was sport-specific nonjumping drills. During physical therapy, the patient continued light resistance training exercises, as well as progressing VOR exercises. The riding position was mimicked in the physical therapy clinic using a BOSU Balance Trainer (BOSU, Ashland, OH), requiring the patient to maintain balance with perturbations.

Nonjumping drills included cantering, complete flat work, and cavaletti work. *Cantering* is a 3-beat horse gait in which both front and rear legs on one side land farther forward than those on the other side, at typical speeds of 4.47 to 7.6 m/s. *Complete flat work* includes drills where the horse is on flat ground performing circles, turns, and transitions from pace to pace. A *cavaletti* is a small jump that is no more than 30.48 cm off the ground, and designed for the horse to step rather than leap. Cavaletti work helps the patient with counting strides for higher jumps. The goal of this phase was to improve control and coordination on the horse, as monitored by the equestrian trainer. Phase 4 began on day 36 and lasted 1 week. Phase 4 consisted of 2 physical therapy sessions and 2 sessions at the stables.

Phase 5: Sport-Specific Jumping Drills The fifth phase of the return-to-riding protocol involved sport-specific jumping drills. At this phase and subsequent phases, all training was conducted at the stables. The patient progressed to multistep training drills, such as small jumps over obstacles and normal resistance training exercises on land as well as on horse. The jumping drills require measuring distance and counting steps to ensure proper takeoff distance.

Progressing to larger jumps began after mastering the small jumps. Mastery, as assessed by the equestrian trainer, was based on consistent counting of steps before the jump and proper takeoff and landing. Cognitive load was increased during this phase by increasing the demand of the jumps and course memorization. The goal of this phase was to provide cognitive load while introducing sport-specific forces related to jumping. This was a crucial step in the protocol and was gradual due to sensitivity of forceful movements after concussion.[33] Phase 5 began on day 43 and was 1 week in duration. To ensure proper progression, the physical therapist was informed of patient performance and response to specific activities.

Phase 6: Full Practice The sixth phase of the return-to-riding protocol was full practice. The athlete participated in normal training activities (eg, full course work), but no competitions. The goal of this phase was to restore confidence and allow the equestrian trainer to assess functional skills. Phase 6 began on day 50 and lasted 1 week.

Phase 7: Return to Competition The last phase of the return-to-riding protocol was return to competition. On postconcussion day 57, the neuropsychologist cleared the athlete for full competition based on symptom-free progression through the full protocol. The athlete competed in normal competition activities while monitoring symptoms.[33]

OUTCOMES

The patient was reassessed 6 weeks after the initial physical therapy evaluation (8 weeks after injury) and at the completion of the return-to-riding protocol. She demonstrated pain-free cervical extension and an increase in DNF endurance from 4 seconds at baseline to 15 seconds, which did not exceed the MDC of 17.8 seconds. However, as this patient did not present with neck pain at the final physical therapy session, DNF endurance was not seen as an impediment for return-to-sport clearance. There was an increase in the number of correct performances on JPE testing, from 4/5 correct on the right and 1/5 correct on the left to 5/5 correct on both sides, indicating an improvement in cervical proprioception.

The VOR test at initial evaluation provoked dizziness symptoms at 120 bpm on the metronome. At the final evaluation, the patient was able to perform the VOR test at 240 bpm without any symptoms present. The visual motion sensitivity test provoked dizziness symptoms of 4/10 on an NRS during the initial evaluation, but did not provoke dizziness at discharge (ie, 0/10 on NRS). The patient improved from a 3-line loss with symptoms during the DVAT at baseline evaluation to a 1-line loss with no symptoms at discharge, which is considered a normal result.

The BESS test improved from 38 errors at baseline evaluation to 12 errors at discharge, which is also considered a normal result and exceeded the MDC of 9.3 errors. The patient did not experience an increase in symptoms during progression of phases in the return-to-riding protocol. The patient scored a 0 on the PCSS, which reflects no symptoms at discharge and is considered a "low-normal" normative score.[29] She progressed through the full protocol in 8 weeks and returned to competition without symptoms.

DISCUSSION

This case report describes the physical therapy management and successful return to sport of an equestrian athlete with a history of multiple concussions. The physical therapy program included an impairment-based approach that involved exercises for the cervical spine, vestibular system, and balance. Because there are no equestrian-specific return-to-sport guidelines, a protocol was adapted to direct the patient's progression back to competition. The return-to-riding protocol was patterned after existing sport-specific guidelines and is an example of how guidelines can inform clinical application.

Concussion recovery timelines vary among individuals. McKeon et al[34] reported that 88.8% of high school athletes return to sport within 3 weeks after concussion. However, prior work has shown that younger high school athletes recover from a concussion slower than do college-aged individuals.[7,19] Additionally, females take longer to recover and are more likely to have symptoms longer than a month in duration.[19]

In this case report, the adolescent female patient had an increased risk for slow recovery and future concussion episodes due to her age, sex, and history of multiple concussions.[19] At the time of the initial evaluation, she was still experiencing symptoms 2 weeks post concussion. Brooks et al[4] showed that adolescents with previous history of concussion present with more baseline symptoms than do those without a history of concussion. Another outcome consideration for patients with prior concussions is the risk of other musculoskeletal injuries. For example, recent preliminary evidence suggests that individuals with a history of previous concussion may be at risk for subsequent lower extremity injury after returning to sport.[5,16,21,24] Although no research has yet demonstrated this, it is plausible that physical therapy may serve as a preventive strategy to reduce risk of future nonconcussion injury during sport participation.

The return-to-riding protocol described in this case report was adapted from other return-to-sport protocols.[33] The novel additions to the protocol included sport-specific tasks for equestrian athletes that were performed in the physical therapy setting and in the equestrian training environment. In the current case, a targeted rehabilitation approach directed interventions to the patient's visual motion sensitivity, tracking deficits (eg, impaired VOR), and cervical impairments, with progression and adaptations to sport-specific tasks at the stables. In contrast to other sports, equestrian athletes not only have to control their own body, but also must control the movements of the horse. A fundamental skill in equestrian athletes is the ability to be able to use their body to communicate with the horse during competition. The rider must be responsive to the horse's character and movements to successfully complete the course.[15] Therefore, restoring the rider-horse connection early in the protocol in a controlled environment was critical to improving rider confidence and ensuring full return to competition. During equestrian competition, the rider must focus on the next jump in the distance. Adding gaze stability on the horse to the protocol helped to maintain the rider-horse connection, as well as to improve VOR in order to decrease symptoms.

There are limitations to consider. This is a single-patient case study and is limited in its generalizability to other patients with potentially complex presentation. Sport-related concussions can involve different clinical subtypes that may require personalized treatment approaches.[3] While the patient was able to return to competition 6 weeks after initiating physical therapy, long-term follow-up data are not available. Additionally, there was a lack of data on the quality of sport performance once the patient returned to riding.

While a validated measure of post-concussion symptoms was included, the pre-to-post administration of the PCSS differed in format. At baseline, the PCSS was administered as part of the ImPACT computerized program, while at follow-up, a written form was used. Additionally, it is common for "healthy" nonconcussed adolescents to report low-level symptoms that range from scores of 1 to 9 on the PCSS.[29] The patient's score of 0 is considered low normal, and it may not be representative of a typical outcome response.

During the initial neuropsychologist visit, a quick screen was administered by a physical therapist to determine whether physical therapy was warranted. The choice of screening tests was based on the judgment and experience of the evaluating physical therapist; however, it is unknown whether the selected screening tests reflect the optimal set of tests for determining whether a patient will benefit from physical therapy. Cognition is commonly affected in concussions; however, cognition was not screened during the physical therapy evaluation but rather was assessed by the neuropsychologist. It is important to note that not all concussed patients have access to a neuropsychologist in a primary care setting. In such cases, the physical therapist may be responsible for screening for cognitive deficits in this patient population.

CONCLUSION

This case report describes the physical therapy management of an adolescent equestrian athlete using an impairment-based approach. Moreover, this case depicts how existing return-to-sport guidelines can be adapted for use with patients with unique sport demands. ◉

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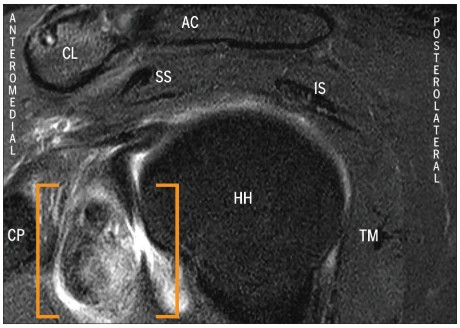

FIGURE 1. This oblique, sagittal T2-weighted magnetic resonance image of the left shoulder, with fat suppression, demonstrates a high-grade tear of the distal subscapularis tendon, with proximal retraction of the torn fibers (brackets). The remaining fibers are indistinct, with heterogeneous T2 hyperintensity indicative of edema. Abbreviations: AC, acromion; CL, distal clavicle; CP, coracoid process; HH, humeral head; IS, infraspinatus; SS, supraspinatus; TM, teres minor.

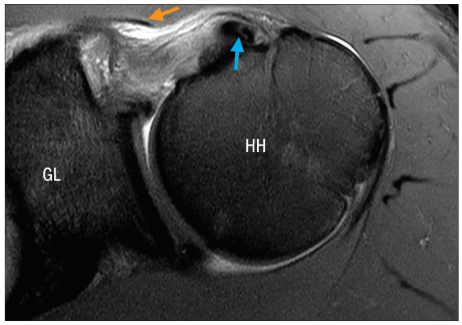

FIGURE 2. Axial, proton density magnetic resonance image of the left shoulder, with fat suppression, shows a near-complete tear of the distal subscapularis tendon, with the remaining fibers demonstrating increased signal and 1 cm of proximal retraction. The tear involves the biceps pulley, with medial subluxation of the long-head biceps tendon (blue arrow). The orange arrow illustrates the coracohumeral ligament. Abbreviations: GL, glenoid; HH, humeral head.

Large Partial-Thickness Tear of the Subscapularis Tendon

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A 27-YEAR-OLD ACTIVE-DUTY MALE sailor directly accessed physical therapy for deep left anterior shoulder pain. The patient sustained his injury the previous day, when he threw a left hook into the body of his sparring partner, creating a sudden high-energy external rotation force. He described immediate anterior shoulder pain and weakness, but denied an audible "pop," bruising, or a palpable defect. Pain limited his ability to reach in his back left pocket and carry loads at work. The primary working diagnosis was a subscapularis tear, followed by a pectoralis major tear, or (less likely) a labral injury.

Examination revealed painful active shoulder elevation and external rotation, and significant internal rotation weakness with pain.[1] Functional behind-the-back internal reach was limited to the posterior superior iliac spine due to pain and weakness. Passive range of motion was full, without apprehension signs and instability signs. The following tests were performed to diagnose subscapularis pathology: internal rotation lag sign, bear hug, and belly-press test. All tests were considered positive due to the patient's inability to maintain the prescribed testing position.[3]

Based on the patient's complaint, mechanism of injury, and internal rotation weakness, the examining physical therapist ordered magnetic resonance imaging.[2] The images revealed a large partial tear, with retraction of the subscapularis tendon at the lesser tuberosity, a labral tear, and an intratendon biceps tendon tear with subluxation (**FIGURES 1** and **2**; **FIGURES 3** and **4**, available at www.jospt.org). The patient was referred to an orthopaedic surgeon for further evaluation. Due to heavy occupational demands and in order to optimize recovery, the patient performed 3 months of treatment prior to undergoing arthroscopic subscapularis repair, labral repair, and biceps tenodesis. The patient regained full motion within 2 months and was cleared to resume job duties at 6 months.

The magnetic resonance imaging assisted in the management and expedited referral to an orthopaedic surgeon. Isolated subscapularis tears without other pathology are uncommon.[1] Physical therapists should be aware that surgical intervention has shown superior outcomes for regaining function with large partial rotator cuff tears versus conservative management alone.[2] ◉ *J Orthop Sports Phys Ther 2018;48(12):983. doi:10.2519/jospt.2018.8221*

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Bilateral Alterations in Running Mechanics and Quadriceps Function Following Unilateral Anterior Cruciate Ligament Reconstruction

Surgical reconstruction is the most common treatment option for individuals following anterior cruciate ligament (ACL) injury.[17] Following anterior cruciate ligament reconstruction (ACLR), individuals commonly seek to return to preinjury levels of physical activity.[6] However, many individuals who have undergone ACLR exhibit diminished neuromuscular function despite being cleared for return to physical activity.[38] In particular, persistent neuromuscular impairment of the quadriceps muscles can have a detrimental effect on activities of daily living and sport participation and may elevate the risk of reinjury as well as the development of posttraumatic knee osteoarthritis (OA).[10,25,35]

BACKGROUND: Following anterior cruciate ligament reconstruction (ACLR), individuals have quadriceps muscle impairments that influence gait mechanics and may contribute to an elevated risk of knee osteoarthritis.

OBJECTIVES: To compare running mechanics and quadriceps function between individuals who have undergone ACLR and those in a control group, and to evaluate the association between quadriceps function and running mechanics.

METHODS: In this controlled, cross-sectional laboratory study, 38 individuals who previously underwent primary unilateral ACLR (mean ± SD time since reconstruction, 48.0 ± 25.0 months) were matched to 38 control participants based on age, sex, and body mass index, and underwent assessments of quadriceps muscle performance and running biomechanics. Quadriceps muscle performance was assessed via isokinetic and isometric knee extension peak torque and rate of torque development (RTD) over 2 time frames: 0 to 100 milliseconds (RTD100) and 0 to 200 milliseconds (RTD200). Running evaluation included assessment of the knee flexion angle (KFA), knee extension moment (KEM), rate of knee extension moment (RKEM), vertical instantaneous loading rate, and vertical impact peak.

RESULTS: On average, there was a smaller KFA (P = .016) in the involved limb compared to the uninvolved limb in the ACLR group. Compared to limbs in the control group, involved limbs in the ACLR group had lower RTD100 (P = .015), lower peak torque at 60°/s (P = .007), lower peak torque at 180°/s (P = .016), smaller KFA (P<.001), lower KEM (P = .001), lower RKEM (P = .004), and higher vertical instantaneous loading rate (P = .016). Compared to limbs in the control group, uninvolved limbs in the ACLR group had lower RTD100 (P = .003), lower peak torque at 60°/s (P = .017), and smaller KFA (P = .01). For the involved limbs in the ACLR group, there was a low correlation between isokinetic peak torque at 180°/s and RKEM (r = 0.38, P = .01), and a negligible correlation between RTD100 and RKEM (r = 0.26, P<.05). No differences were found in isometric strength for any comparison.

CONCLUSION: Individuals who have undergone ACLR have bilateral alterations in running mechanics that are weakly associated with diminished quadriceps muscle performance. *J Orthop Sports Phys Ther 2018;48(12):960-967. Epub 22 Jul 2018. doi:10.2519/jospt.2018.8170*

KEY WORDS: *ACL, gait, jogging, kinetics, knee, osteoarthritis*

Knee OA following ACLR has been attributed to mechanical and metabolic processes.[23] Many studies have suggested that alterations in lower-limb biomechanics following ACLR during walking and running may contribute to knee OA.[4,5,14] For example, individuals who have undergone ACLR have lower knee flexion angles (KFAs) and knee internal extension moments (KEMs) during walking and running,[26,28,30] which may contribute to cartilage pathology. The KEM is indicative of the quadriceps' contribution to force applied across the knee joint,[47] and individuals who have undergone ACLR commonly exhibit quadriceps muscle deficits for many years following the completion of rehabilitation.[35,38]

The quadriceps muscle group functions eccentrically for shock attenuation during the stance phase of gait, and diminished quadriceps rate of torque devel-

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opment (RTD) is associated with greater vertical instantaneous loading rate (VILR) during walking.[10] Compared to maximum strength, RTD reflects the ability of a muscle to generate torque rapidly and is of major importance to power-generating activities (ie, running or jumping).[1,3] Furthermore, individuals who have undergone ACLR also exhibit a higher VILR during gait in their injured limb compared to the uninjured limb.[9] A higher VILR contributes to accelerated cartilage breakdown in animal models[18] and overuse conditions in runners.[16] Similarly, the vertical impact peak (VIP) of the vertical ground reaction force (GRF) waveform observed in heel-strike runners is associated with overuse injuries such as stress fracture,[32] and is indicative of a higher VILR. Evidence suggests that individuals who have undergone ACLR have deficits in quadriceps RTD and the rate of knee extension moment development (RKEM) during running,[26] yet the relationship between these impairments remains unclear.

Despite an abundance of evidence demonstrating gait impairments following ACLR,[9,26,28,30,39] many studies have used the uninvolved limb as a reference for comparison. Achieving symmetry in quadriceps strength is a common goal during rehabilitation. However, bilateral deficits in quadriceps function that may influence gait are common,[21,22,48] and previous research has found impaired dynamic balance in the uninvolved limb of patients with unilateral ACL injury.[48] As running requires dynamic balance and postural control,[43] it is possible that both limbs may exhibit altered running mechanics,[48] and a control limb from an uninjured individual may provide a more appropriate reference for comparison.

The purpose of the current study was to compare sagittal plane knee mechanics and vertical GRF characteristics during running between the involved and uninvolved limbs of individuals who have undergone ACLR, and to the limbs of healthy individuals in a control group. The authors hypothesized that the involved limb of persons in the ACLR group would exhibit diminished KFA and KEM, lower RKEM, and higher VILR and VIP when compared to the uninvolved limb and the limbs of individuals in the control group. They further hypothesized that the uninvolved limb of persons in the ACLR group would exhibit diminished KFA and KEM, lower RKEM, and higher VILR and VIP compared to the limbs of those in the control group. A secondary purpose was to evaluate the association between quadriceps muscle performance (isometric peak torque and RTD) and the aforementioned running mechanics in the involved limb of persons who have undergone ACLR. The researchers hypothesized that higher quadriceps function would be associated with larger KFA and KEM, but smaller VILR and VIP.

METHODS

THE DATA REPORTED HERE ARE FROM a larger interventional study (ClinicalTrials.gov; NCT02851316) investigating the influence of vibratory stimuli on running mechanics in individuals who have undergone ACLR. The data presented in this paper were obtained in a single session prior to any intervention procedures.

Study Participants

Thirty-eight participants with primary unilateral ACLR volunteered to participate, and were matched to 38 control participants (**TABLE 1**) based on sex, age (±1 year), and body mass index (±1 kg/m^2). Participants' Tegner activity scale score[46] and International Knee Documentation Committee Subjective Knee Evaluation Form score[24] were recorded to characterize physical activity level and self-reported disability, respectively. All participants were recreationally active (reported exercising for 30 minutes at least 3 times per week).

Participants who had undergone ACLR were required to be cleared by a physician for return to physical activity,

TABLE 1 Group Demographics*

	ACLR Group (n = 38)	Control Group (n = 38)
Age, y	21.9 ± 2.4	21.9 ± 1.3
Height, m	1.70 ± 0.09	1.69 ± 0.09
Mass, kg	69.6 ± 14.1	66.2 ± 11.7
Body mass index, kg/m^2	23.9 ± 3.8	23.2 ± 2.8
Sex (female), %	76	76
IKDC (0-100)†	85.8 ± 9.4	99.4 ± 1.1
Tegner score (0-10)	7.0 ± 1.7	6.8 ± 1.1
Time since ACLR, mo	48.0 ± 25.0	...
Concomitant meniscal injury, n		...
Medial meniscus repair	10	
Lateral meniscus repair	6	
Medial meniscectomy	2	
Lateral meniscectomy	1	
Graft type, n		...
Patellar tendon autograft	21	
Hamstrings autograft	9	
Allograft	8	

Abbreviations: ACLR, anterior cruciate ligament reconstruction; IKDC, International Knee Documentation Committee Subjective Knee Evaluation Form.
**Values are mean ± SD unless otherwise indicated.*
†*$P<.05$.*

and were excluded if they presented with bilateral ACL injury, graft rupture, or revision surgery. Participants were also excluded if they reported any lower extremity injury within 6 months prior to participation, lower extremity surgery (other than ACLR or concomitant meniscal repair/resection), or neurological disorder. All participants provided written informed consent prior to participation, and methods were approved by California State University, Fullerton's Institutional Review Board.

A priori power analyses using previously published data related to walking and running gaits indicated that 28 participants would be needed to provide a power of 0.80 (α = .05) to identify differences between limbs for the variables of interest.[9,10,30]

Quadriceps Muscle Performance

Participants were tested bilaterally for maximal isometric and isokinetic knee extensor strength at 60°/s, 180°/s, and 240°/s in a block-randomized order. Participants were seated on a dynamometer (HUMAC NORM; Computer Sports Medicine, Inc, Stoughton, MA), with straps secured over the leg, thigh, and torso. The axis of rotation of the lever arm was aligned with the knee joint center, and the ankle pad was positioned 2 cm above the medial malleolus. Participants completed submaximal isometric knee extensions at 25%, 50%, and 75% and at 100% of perceived maximum for warm-up and acclimatization.

During the isometric testing, the knee and hip were positioned in 45° and 85° of flexion, respectively, and participants' arms were crossed over their chest. Three maximal trials were completed, with 60 seconds of rest provided between trials. This knee position was selected because individuals who have undergone ACLR demonstrate greater quadriceps strength impairments at 45° compared to other positions.[27]

For isokinetic testing, participants performed 5 consecutive knee extension/flexion efforts from 90° of knee flexion to full knee extension. For all assessments, participants were instructed to extend their knee "as hard and fast as possible," and verbal encouragement was provided while a monitor displayed visual feedback of the torque signal. During the isokinetic trials, participants also were instructed to pull back as hard and fast as possible to simultaneously evaluate knee flexor strength. However, as this study was concerned with quadriceps muscle performance and associated gait impairments that may contribute to posttraumatic knee OA,[8,10,30,38] only the data for knee extensor torque are reported here.

Running Biomechanics

Following a 5-minute jogging warm-up on a treadmill, 3-D running biomechanics were obtained as participants ran along a 20-m runway with a force plate (Advanced Mechanical Technology, Inc, Watertown, MA) located at the midpoint of the runway. Marker trajectories were obtained using a 9-camera motion-capture system (Qualisys AB, Gothenburg, Sweden) sampling at 240 Hz, and force-plate data were sampled at 2400 Hz. Participants ran at a self-selected speed while wearing laboratory-standard neutral-cushion footwear (Pegasus 32; Nike, Inc, Beaverton, OR) and compression/spandex shorts. Retroreflective markers were placed bilaterally on the iliac crests, greater trochanters, medial and lateral femoral epicondyles, medial and lateral malleoli, heel counters, and first and fifth metatarsals. Clusters of 4 markers were secured to the sacrum and bilaterally on the thighs, shanks, and feet. Individual anatomical markers were removed following a standing calibration trial.

Five practice trials were performed to determine the average preferred running speed, and to ensure that participants could strike the force plate without altering their gait. Participants were instructed to continue running after making contact with the force plate while looking forward toward a target. Speed was monitored using infrared timing gates 2 m apart (model TF100; TracTronix, Belton, MO). Participants performed 5 trials on each limb in a block-randomized order, and trials were accepted when the participants' foot made full contact with the force plate without visibly altering their stride, and when their speed was within ±5% of the speed obtained from practice trials.

Data Reduction

Knee extensor torque data were sampled at 2000 Hz and processed using a custom LabVIEW program (National Instruments, Austin, TX). For the isometric trials, the slopes of the torque-time curve from 0 to 100 milliseconds and from 0 to 200 milliseconds following contraction onset were used to define early RTD (RTD100) and late RTD (RTD200), respectively. Contraction onset was determined as the point when the torque signal exceeded 3 standard deviations above the resting value. These intervals were selected because RTD100 is influenced by neural contributors (ie, motor unit firing frequency) to torque development, whereas RTD200 is influenced by muscle cross-sectional area.[31] The isometric trial with the highest peak torque value and the peak value from the middle 3 of the 5 isokinetic knee extension trials were used for analysis. Torque data were normalized to body mass (Newton meters per kilogram).

Marker position and force-plate data were combined using Track Manager software (Qualisys AB) and exported to Visual3D (C-Motion, Inc, Germantown, MD) for model construction. Raw marker position data and GRF data were low-pass filtered at 12 Hz and 75 Hz, respectively (fourth-order, zero-phase-lag recursive Butterworth).[11,20] The ankle and knee joint centers were estimated as the midpoints between the medial and lateral malleoli and femoral epicondyles, respectively. The hip joint center was estimated as 25% of the intertrochanteric distance. Three-dimensional knee joint angles were calculated as motion of the shank relative to the thigh using a joint coordinate system, and joint moments were calculated using standard inverse dynamics equations.

All dependent variables of interest were identified during the stance phase, which was defined as when the vertical GRF exceeded 20 N and subsequently fell below 20 N, and included peak KFA, peak internal KEM, RKEM, VIP, and VILR. The RKEM was defined as the change in KEM divided by the time representing 10% to 30% of the stance phase.[26,39] This interval was selected because it is the most linear phase of the KEM. The VILR was calculated as the peak of the first derivative during the first 13% of the stance phase.[40,41] This method was selected to allow inclusion of participants regardless of foot-strike pattern.

Ground reaction force and loading rate data were normalized to body weight, while joint moments were normalized to a product of body weight and height.[33] Analysis of the VIP was limited to rearfoot-strike runners only (ACLR group, 32; control group, 30). Foot-strike pattern was determined using the strike index.[13] The average of 5 trials for each limb was used for analysis, and the comparison limb from the control group was selected based on limb dominance of the ACLR limb for each matched pair (defined as the preferred limb to kick a ball).

Statistical Analysis

Data were assessed for normality using the Shapiro-Wilk test and screened for outliers using box plots. All data were found to be normally distributed and treated as such, and no outliers were identified. Paired-samples *t* tests (involved versus uninvolved limb) and independent-samples *t* tests (involved and uninvolved limbs versus control limb) were used to compare running biomechanics (VIP, VILR, KFA, KEM, and RKEM) and quadriceps muscle performance variables (isometric peak torque; RTD100 and RTD200; and isokinetic peak torque at 60°/s, 180°/s, and 240°/s).

A Bonferroni adjustment was applied for each dependent variable to account for multiple comparisons of the involved, uninvolved, and control limbs (α = .017). Preliminary analyses indicated a relationship between running speed and several biomechanical variables. Therefore, partial correlation (α = .05) was used to assess the association between quadriceps muscle performance and running variables after controlling for running speed. Correlation coefficients were interpreted as negligible (0.0-0.3), low (0.31-0.50), moderate (0.51-0.70), and high (0.71-1.00).

RESULTS

Participant demographics are summarized in **TABLE 1**. No between-group differences were found for age, sex, height, mass, body mass index, or Tegner activity scale score.[46] The International Knee Documentation Committee Subjective Knee Evaluation Form score[24] was lower in the ACLR group than in the control group (P<.01).

Running Kinematics and Kinetics

The average ± SD self-selected running speed did not differ between the ACLR group and the control group (3.10 ± 0.36 m/s versus 3.19 ± 0.37 m/s, P = .18). There was a smaller KFA (t_{37} = 2.23, P = .016) (**FIGURE 1**, **TABLE 2**) in the involved limb compared to the uninvolved limb in the ACLR group. No differences were found between the involved and uninvolved limbs of the ACLR group for KEM, RKEM, VILR, or VIP (**TABLE 2**).

There was a smaller KFA (t_{74} = 3.92, P<.001) (**FIGURE 1**), smaller KEM (t_{74} = 3.27, P = .001) (**FIGURE 2**), lower RKEM (t_{74} = 2.72, P = .004) (**FIGURE 2**), and higher VILR (t_{74} = 2.19, P = .016) (**FIGURE 3**) in the involved limbs of the ACLR group compared to control limbs of the control group (**TABLE 2**). No difference was found between the involved limbs in the ACLR group and control limbs for VIP (**TABLE 2**).

There was a smaller KFA in the uninvolved limbs in the ACLR group compared to the control limbs in the control group (t_{74} = 2.19, P = .01) (**FIGURE 1**). No differences were found between the uninvolved limb in the ACLR group and the limbs of those in the control group for KEM, RKEM, VILR, or VIP (**TABLE 2**).

TABLE 2 Summary of Limb Comparisons*

Variable	Involved Limb	Uninvolved Limb	Control Limb
Quadriceps function			
Isometric PT, Nm/kg	2.31 (2.13, 2.48)	2.32 (2.15, 2.49)	2.57 (2.34, 2.80)
RTD100, Nm/s/kg	11.90 (9.90, 13.91)†	11.03 (9.39, 12.67)†	15.27 (13.07, 17.47)
RTD200, Nm/s/kg	6.27 (5.44, 7.09)	5.70 (4.94, 6.46)	6.60 (5.72, 7.49)
PT at 60°/s, Nm/kg	2.51 (2.29, 2.72)†	2.52 (2.31, 2.73)†	2.87 (2.68, 3.06)
PT at 180°/s, Nm/kg	1.68 (1.53, 1.83)†	1.75 (1.62, 1.88)	1.89 (1.75, 2.05)
PT at 240°/s, Nm/kg	1.59 (1.43, 1.74)	1.59 (1.45, 1.71)	1.69 (1.56, 1.81)
Running biomechanics			
VILR, BW/s	99.4 (89.5, 109.5)†	98.8 (88.9, 109.9)	86.8 (81.7, 91.8)
VIP, BW	1.60 (1.45, 1.75)	1.61 (1.48, 1.74)	1.54 (1.44, 1.64)
KFA, deg	49.6 (47.5, 51.5)†‡	52.2 (49.9, 54.5)†	55.4 (53.4, 57.5)
KEM, % BW × height	0.17 (0.16, 0.18)†	0.19 (0.17, 0.20)	0.20 (0.19, 0.21)
RKEM, % BW × height/s	2.37 (2.17, 2.57)†	2.54 (2.33, 2.75)	2.75 (2.57, 2.95)

Abbreviations: BW, body weight; KEM, internal knee extension moment; KFA, knee flexion angle; PT, peak torque; RKEM, rate of knee extension moment development; RTD100, rate of torque development from 0 to 100 milliseconds; RTD200, rate of torque development from 0 to 200 milliseconds; VILR, vertical instantaneous loading rate; VIP, vertical impact peak.
**Values are mean (95% confidence interval). Involved and uninvolved limbs were compared via paired-samples t tests, and involved and uninvolved limbs were compared to the control limbs via independent-samples t tests (α = .017).*
†Different from control limb.
‡Different from uninvolved limb.

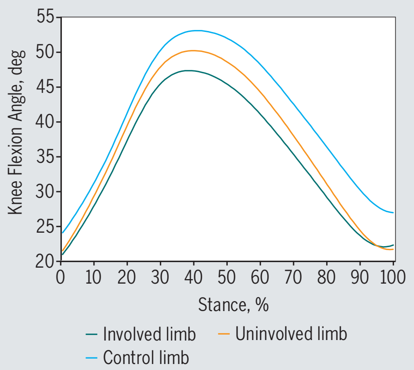

FIGURE 1. Ensemble average of the knee flexion angle of the involved, uninvolved, and control limbs.

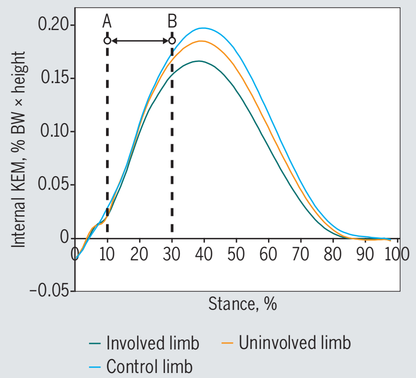

FIGURE 2. Ensemble average of the internal KEM between the involved, uninvolved, and control limbs. The region between A and B represents 10% to 30% of the stance phase, from which the rate of KEM development was derived. Abbreviations: BW, body weight; KEM, knee extension moment.

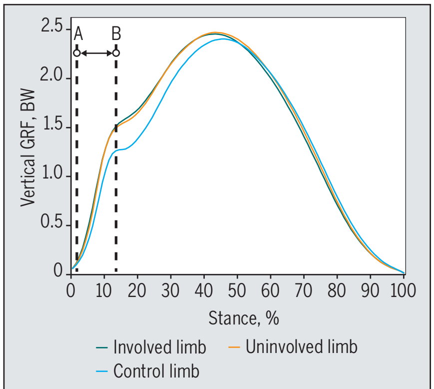

FIGURE 3. Ensemble average of the vertical GRF waveforms between the involved, uninvolved, and control limbs. The region between A and B represents 0% to 13% of the stance phase, from which the peak vertical instantaneous loading rate was derived. Abbreviations: BW, body weight; GRF, ground reaction force.

Quadriceps Muscle Performance

No differences were found between the involved and uninvolved limbs in the ACLR group for isometric peak torque, RTD100, RTD200, peak torque at 60°/s, peak torque at 180°/s, or peak torque at 240°/s (**TABLE 2**). There was a significantly lower RTD100 (t_{74} = 2.54, P = .015), lower peak torque at 60°/s (t_{74} = 2.79, P = .007), and lower peak torque at 180°/s (t_{74} = 2.54, P = .016) in the involved limbs of individuals in the ACLR group compared to the limbs of those in the control group (**TABLE 2**). No differences were found for isometric peak torque, RTD200, or peak torque at 240°/s (**TABLE 2**). There was lower RTD100 (t_{74} = 3.06, P = .003) and lower peak torque at 60°/s (t_{74} = 2.53, P = .017) in the uninvolved limbs of individuals in the ACLR group compared to the limbs of those in the control group (**TABLE 2**). There were no differences between the uninvolved limbs of individuals in the ACLR group compared to the limbs of those in the control group for isometric peak torque, RTD200, peak torque at 180°/s, or peak torque at 240°/s (**TABLE 2**).

Association Between Quadriceps Muscle Performance and Running Biomechanics

Weak associations were observed between isokinetic peak torque at 180°/s and RKEM (r = 0.38, P = .01) and between RTD100 and RKEM (r = 0.26, P<.05) for the involved limbs of participants in the ACLR group. No relationships were found between indices of quadriceps muscle performance and running mechanics in the uninvolved limbs of those in the ACLR group or the limbs of those in the control group (**TABLE 3**).

DISCUSSION

The purpose of the current study was to compare sagittal plane knee kinematics and kinetics and vertical GRF characteristics during running between the involved and uninvolved limbs of individuals who have undergone unilateral ACLR, and to the limbs of healthy individuals in a control group. A secondary purpose was to evaluate the association between measures of quadriceps muscle performance and running mechanics. The primary findings of the study were that both the involved and uninvolved limbs exhibited smaller KFAs during stance compared to control limbs. Furthermore, the involved limb of individuals in the ACLR group had higher VILR, lower KEM, and lower RKEM compared to the limbs of those in the control group. Weak associations were found between RTD100 and RKEM and between isokinetic peak torque at 180°/s and RKEM.

Similar to previous studies,[28,30] the present study found alterations in sagittal plane running mechanics (lower KFA and KEM) in involved limbs in the ACLR group compared to control limbs. Although previous studies have reported a number of asymmetries during running following ACLR,[26,30] the only observed difference between the involved and uninvolved limbs in the current study was in KFA. However, the researchers did find a smaller KFA in both limbs of participants in the ACLR group when compared to the limbs of those in the control group, which is suggestive of a bilateral impairment in this sample.

A previous meta-analysis suggests that bilateral neuromuscular impairments are common following ACLR,[22] despite achieving limb symmetry. Unilateral ACL injury may contribute to impaired dynamic balance of the involved and uninvolved limbs following ACLR.[48] It has been previously suggested that bilateral performance deficits are only found in tests that greatly stress the knee joint.[19] As running is a dynamic unilateral activity, it is possible that reductions in dynamic balance and postural control contribute to bilateral changes in running mechanics. The findings in the current study are supported by previous studies that reported bilateral reductions in single-leg hop performance[15,29] and the Star Excursion Balance Test score.[48] Collectively, the findings of this study emphasize the need for bilateral assessment of the involved and uninvolved limb in individuals following ACLR relative to a healthy control.

The authors also found a higher VILR in the involved limb of the ACLR group compared to the control limb. However, the difference in VILR between the uninvolved and control limbs did not reach statistical significance. Previously, the VILR in persons who have undergone ACLR has been reported during walking only,[9,34] and was higher in the involved limb compared to the uninvolved limb[9] and in the involved limb compared to control limbs.[34] Future research is needed to determine the importance of activity modifications or gait retraining to limit exposure to a higher VILR when returning to physical activity following ACLR.

Lower KFA and KEM are often attributed to a quadriceps-avoidance gait pattern.[8] The individuals post ACLR in the current study did exhibit lower knee extensor strength in the involved and uninvolved limbs compared to the control limbs. Interestingly, the authors only observed deficits in RTD and isokinetic measures of peak torque. These findings suggest that rapid and dynamic knee extensor muscle performance, rather than isometric strength, may be more indicative of muscular impairment following ACLR.

In the current study, the researchers found weak correlations between RKEM and isometric RTD100 and peak torque at 180°/s in the involved limb of the ACLR group, which corroborates a previously established relationship between quadriceps weakness and altered knee mechanics.[35] During running, rapid force generation is required prior to heel contact and in the early stance phase to stabilize the knee joint.[30] Typically, the quadriceps require greater than 300 milliseconds to reach peak force-producing capacity,[31] yet the stance phase of running is shorter than 300 milliseconds. The RTD100 is a measure of the quadriceps' ability to produce force quickly, and peak torque at 180°/s may provide a better indication of quadriceps function under dynamic settings.

Similarly, RKEM provides an indication of speed of torque development during early stance.[26] The reduction in RKEM is indicative of the inability of the quadriceps to quickly generate the moment required to decelerate the limb and absorb impact forces. This study's findings suggest that improving quadriceps RTD and isokinetic peak torque may be more useful in changing loading characteristics during running, as opposed to improving maximum isometric strength.

The authors did not observe a difference in RTD200 between the involved and uninvolved limbs of participants in the ACLR group and the limbs of those in the control group. Previous research indicates that arthrogenic muscle inhibition following ACLR contributes to reductions in voluntary quadriceps activation.[22,38] RTD100 is associated with neural contributors to muscle force production, such as motor unit recruitment and firing frequency. However, RTD200 is associated with morphologic characteristics, such as cross-sectional area,[31] which may explain the discrepancy in findings.

These data suggest that improving RTD100 rather than RTD200 should be a focus during rehabilitation. Previous studies indicate that therapeutic modalities, such as transient skin cooling[42] and whole-body vibration,[37] may be useful for targeting RTD100, while whole-body vibration also influences the KFA and VILR following ACLR.[36]

Despite reaching significance, the associations between quadriceps function and RKEM in the involved limb of individuals in the ACLR group were relatively weak, leaving a substantial proportion of unexplained variance (approximately 85%). A previous investigation suggests that individuals who have undergone ACLR adopt a compensatory strategy at the hip joint (greater hip flexion angle and external moment during stance) during running.[28] Furthermore, individuals who have undergone ACLR and exhibit quadriceps muscle performance deficits also have greater hip extension strength.[7] As such, a shift to a running pattern that requires greater use of the hip extensors may reflect a compensatory action in response to quadriceps weakness and a different strategy for load attenuation at the knee.[28] Future studies should concurrently evaluate the contribution of the hip and knee extensors to knee mechanics and joint loading characteristics during running in individuals who have undergone ACLR.

No relationships were found between any measure of quadriceps function and VILR or peak KFA. It previously has been reported that higher quadriceps RTD is associated with lower VILR.[10] However, this previous study evaluated walking gait under barefoot conditions.[10] As such, there are other factors that may contribute to high VILR following ACLR, such as footfall patterns

TABLE 3 PARTIAL CORRELATION ANALYSES, ADJUSTED FOR RUNNING SPEED*

	RTD100	PT at 60°/s	PT at 180°/s
VILR	0.14	0.05	0.15
VIP	–0.20	–0.03	0.04
KFA	0.03	0.23	0.07
KEM	0.16	0.16	0.05
RKEM	0.26†	0.12	0.38†

Abbreviations: KEM, internal knee extension moment; KFA, knee flexion angle; PT, peak torque; RKEM, rate of knee extension moment development; RTD100, rate of torque development from 0 to 100 milliseconds; VILR, vertical instantaneous loading rate; VIP, vertical impact peak.
**Values are r.*
†P<.05.

and ankle mechanics.[2,12,44] The current study's sample primarily consisted of rearfoot-strike runners. As such, it was not possible to conduct a subanalysis between footfall patterns.

There are limitations to consider when interpreting the results of this study. This sample was heterogeneous in terms of graft type and meniscal injury status, which may have influenced the magnitude of quadriceps muscle impairment. Currently, there is no evidence to suggest that posttraumatic knee OA incidence differs by graft type; however, concomitant meniscal injury elevates the risk for posttraumatic knee OA,[45] and future studies should consider the influence of concomitant meniscal injury on gait mechanics.

Further, this study's sample exhibited a wide range in time since ACLR (mean ± SD, 48.0 ± 25.0 months), which may influence the magnitude of gait and muscle performance symmetry between limbs.[10] Preliminary exploratory analysis indicated no relationship between time since ACLR and any outcome variable. It is important to note that on average, this sample had quadriceps weakness, compared to control limbs, for approximately 4 years following ACLR. The expected time course of quadriceps impairment is unknown; however, these findings highlight the need for ongoing intervention beyond the current standard of care.

Finally, participants in the current study did not report running as their primary means of exercise, and, as such, their running biomechanics may not be reflective of habitual movements. However, the majority of the sample did report participation in recreational sports that require running, as indicated by the Tegner activity scale score (**TABLE 1**).[46]

CONCLUSION

The current study found that sagittal plane running mechanics of the involved and uninvolved limbs of individuals after unilateral ACLR are different from those in the limbs of healthy control participants, suggesting bilateral impairment. These differences are weakly associated with RTD100 and isokinetic strength of the quadriceps. Future studies are needed to examine the longitudinal effect of chronic quadriceps impairment on gait mechanics and knee OA development. ◉

KEY POINTS

FINDINGS: Individuals who have undergone unilateral anterior cruciate ligament reconstruction exhibit bilateral alterations in running biomechanics. Quadriceps muscle performance is weakly associated with some measures of running biomechanics.

IMPLICATIONS: Improving bilateral quadriceps muscle performance and running biomechanics is necessary following unilateral anterior cruciate ligament reconstruction.

CAUTION: This study used a sample of mixed graft types, which may have influenced the magnitude of quadriceps impairment and running mechanics.

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[RESEARCH REPORT]

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Clinimetric Testing of the Lumbar Spine Instability Questionnaire

Low back pain (LBP) is a condition commonly associated with disability and high costs for patients and health care systems.[34] Although most patients with this condition are classified as having "nonspecific" LBP (ie, LBP not attributed to a recognizable or specific pathology), some researchers suggest that nonspecific LBP may represent a heterogeneous group of conditions and advocate classifying patients with nonspecific LBP into subgroups that may better respond to one treatment than another.[5,7,15,17,26]

One proposed subgroup has been argued to be patients with lumbar spine instability.[22,24,25] Lumbar spine instability has been considered in 2 categories: (1) radiological instability, usually diagnosed by radiographic measurements; and (2) clinical instability. Clinical instability has been

BACKGROUND: The Lumbar Spine Instability Questionnaire (LSIQ) is a self-report measure of 15 items. Previous studies have used the LSIQ as a measure of clinical instability; however, a comprehensive evaluation of its clinimetric properties has not been conducted.

OBJECTIVES: The aim of this study was to evaluate the clinimetric properties of the LSIQ in patients with chronic nonspecific low back pain (LBP).

METHODS: In this clinical measurement study, the authors included patients with nonspecific LBP presenting to primary care clinicians in Australia. Rasch analysis was conducted to assess item hierarchy, targeting, unidimensionality, person fit, internal consistency, and differential item functioning. The researchers assessed test-retest reliability of total scores and individual item scores, as well as convergent and divergent validity.

RESULTS: A total of 107 participants with LBP (60 men and 47 women) were recruited. The results were variable. The LSIQ appeared to constitute a unidimensional measure, targeted the sample well, and showed adequate test-retest reliability. However, the scale had poor internal consistency, did not appear to function as an interval-level measure, and had unclear construct validity. Although no items appeared to be redundant, several items were biased by factors other than the proposed construct of the measure.

CONCLUSION: The LSIQ does not seem to be ready to be implemented in clinical practice and may require theoretical reconsideration. Although the LSIQ provided satisfactory estimates for some clinimetric features, the authors do not consider the instrument to be useful as an interval-level measure but rather as an index. Future studies are needed to investigate whether the LSIQ could measure clinical instability or some other construct.
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defined as the loss of the spine's ability to maintain its patterns of movement under physiologic loads.[23] The diagnosis of clinical instability is controversial, and most clinical tests to detect clinical instability have not undergone validation studies.[11]

Cook et al[6] established a consensus list of clinical features associated with clinical instability of the spine by using a Delphi study, in which expert practitioners agreed on common features of lumbar clinical instability. Based on this consensus list, the 15-item Lumbar Spine Instability Questionnaire (LSIQ) for self-reported clinical instability was developed.[19,20] Although a theoretical justification has not been presented, the LSIQ has been previously used in a manner that suggests that it constitutes a unidimensional, interval-level measure of perceived clinical instability.[3,20]

The LSIQ has undergone preliminary testing in a planned subgroup analysis of a trial comparing motor control exercise to graded activity in 172 patients with chronic LBP.[20] The questionnaire showed promise in predicting patients who respond to motor control exercise or graded activity (although the study was unable to consider whether the mechanism underlying this difference was the presence or absence of clinical instability) and acceptable internal consistency (Cronbach

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α = .69; 95% confidence interval: .62, .76). A comprehensive evaluation of the questionnaire as a measure is required before the LSIQ can be recommended. The aim of this study was to evaluate the measurement properties of the LSIQ in a sample of patients with nonspecific LBP in Australia. Specifically, the researchers considered construct validity, reliability, agreement, internal consistency, and ceiling and floor effects.

METHODS

The authors included patients with nonspecific LBP presenting to primary care clinicians (general medical practitioners, physical therapists, and chiropractors) for treatment in Australia. They sought to recruit 100 participants for this study. The sample size was based on guidelines for clinimetric studies, which suggest that a sample of 100 participants is necessary to investigate relevant clinimetric properties.[8,32]

The inclusion criteria were nonspecific LBP, defined as LBP not attributed to a recognizable or specific pathology (eg, nerve root compromise indicated by pain in dermatomal distribution or by loss of sensation, reflex, or power) or to serious spinal pathology (eg, fracture, cancer, and inflammatory diseases),[1,33] with symptoms of any duration, and being between 18 and 80 years of age. Exclusion criteria were previous spinal surgery, major identified spinal pathology (eg, tumor, infection, fracture), pregnancy, or nerve root compromise (eg, sciatic pain).

Clinicians identified potential participants who met the inclusion criteria, explained the study to them, and asked if they would like to participate. Those patients who were interested in finding out more about the study were directed to the research team and invited to participate. Study information and consent forms were provided to the participants by e-mail. Potential participants who agreed to participate were directed to the survey. Data were collected at baseline and after 24 hours in a follow-up online survey to assess test-retest reliability.

The researchers collected demographic information (age, sex, body mass index [BMI]), smoking status, educational level, employment status, duration of symptoms, use of analgesics or painkillers, pain intensity over the past week, the LSIQ, and symptoms of neuropathic pain (painDETECT questionnaire [PD-Q]). At the follow-up survey, participants only completed the LSIQ.

Measures

Lumbar Spine Instability Questionnaire The LSIQ comprises 15 dichotomous (yes/no) items, each relating to specific clinical features considered by clinical experts to be associated with clinical instability. The sum of the features, ranging from 0 to 15 points, is supposed to provide a measure of perceived clinical instability, where higher scores are purported to imply greater instability.[20]

painDETECT Questionnaire The PD-Q is a self-reported questionnaire developed to screen for neuropathic pain components in patients with LBP.[14] The questionnaire includes 7 items, and is scored from −1 to 38, according to the likelihood of a neuropathic pain component. A score equal to or less than 12 indicates that pain is unlikely to have a neuropathic component, a score between 13 and 18 indicates that the result is uncertain and a more detailed examination is required, and a score of 19 or higher indicates pain with a neuropathic component.[14] The questionnaire has good internal consistency, excellent test-retest reliability, and high criterion validity (high sensitivity, specificity, and positive predictive value).[14,21]

Data Analysis

Rasch Analysis To assess the psychometric properties of the LSIQ, Rasch analysis was conducted using Winsteps Version 3.73.0 software (John Linacre/Winsteps.com, Beaverton, OR). The authors considered the following components: item hierarchy, targeting, unidimensionality, person fit, internal consistency, and differential item functioning. Item hierarchy provides evidence of construct validity. The LSIQ was formulated to assess perceived (self-reported) clinical instability with items based on a consensus list of clinical features that experts considered to be associated with a clinical diagnosis of instability. To be considered a measure of perceived clinical instability, the LSIQ should have an item hierarchy ordered in a logical manner, from comparatively mild perceived clinical instability to more severe presentation. The researchers considered an item reliability of greater than 0.9 to be sufficient in a sample large enough to confirm the item hierarchy.

Targeting (ie, how well the items are targeted for people in the sample) was assessed by visual inspection of the distribution of persons and item threshold averages and comparison of the summary statistics. The average item endorsability was anchored at zero logits by default. Positive average person agreeability suggests that the sample experienced greater perceived clinical instability than the average of the scale. Negative average person values indicate the opposite.[31] Visual inspection of the distribution of persons and items also provides a means of assessing whether the scale has interval-level measurement qualities. Evidence that the items form a continuous scale that measures the range of person abilities evenly suggests that there are no redundancies or deficiencies in the scale.

For the LSIQ to be validly summated as a measure, the 15 items must collectively assess only the construct in question (unidimensionality). Each LSIQ item should thus share in common an aspect of perceived clinical instability, yet be sufficiently different so as not to be redundant. An analysis of item-fit statistics and a principal-component analysis (PCA) of residuals were conducted to identify items or clusters of items that may assess a secondary dimension, thus threatening the assumption of unidimensionality. Item-fit statistics are chi-square based and are reported as mean-squares (in logits). They have an expected value of 1 logit, hence fit was considered excessive if greater than 1.4 or less than 0.6 logits.[35]

Both information-weighted fit statistics (infit) and outlier-sensitive fit statistics (outfit) were analyzed. The item characteristic curves of misfitting items were visually inspected to assess item performance across the person agreeability range. The PCA residual correlation matrix was inspected visually to identify clusters of items with substantial positive or negative loadings. An eigenvalue greater than 2 was considered to be indicative of a second dimension.[29] Included in the PCA was a test of local independence. High correlations (greater than 0.5) were considered to be indicative of local dependence, indicating that the response to one item relies on the response to another.

Assessment of person fit identifies people who responded in an unexpected manner. Person fit was considered excessive if the outfit statistics were greater than 2 logits.[31] Misfitting persons were compared across variables to those who fit the model using a chi-square test of significance, or an independent-samples *t* test if greater than 10% of persons demonstrated misfit.

Two measures of internal consistency were considered: the Rasch-specific "person reliability index" and the more widely recognized Cronbach alpha.[13] Acceptable internal consistency is greater than .70 in both instances.[28,31]

Differential item functioning (or item bias) identifies whether characteristics other than the latent construct alter the functioning of the item. The authors assessed whether age, sex, pain intensity, and pain duration biased the functioning of the scale by splitting the sample, according to median, and comparing the 2 subgroups. Body mass index was split according to underweight/healthy weight (less than 25 kg/m^2) and overweight/obese (25 kg/m^2 or greater). The PD-Q score was split into nonneuropathic (12 points or less), uncertain (13-18 points), and neuropathic (19 points or greater) categories. Items with statistically significant (P<.05) contrasts greater than 0.5 logits were further explored.

Test-Retest Reliability *Reliability* is defined as the degree to which the measure is free from measurement error.[8,32] *Test-retest reliability* refers to the degree to which the measure results are consistent with repeat testing, and it is usually tested by giving the same measure to the same respondents on 2 separate occasions.[8,32] Test-retest reliability for the total score of the measure was assessed with the intraclass correlation coefficient (ICC) using a 2-way random model and absolute agreement. Reliability for ICC values of less than 0.40 was interpreted as poor, 0.40 to 0.75 as moderate, greater than 0.75 to 0.90 as substantial, and greater than 0.90 as excellent.[8,32] To quantify the reliability of each item of the measure, the researchers used the prevalence and bias-adjusted kappa (PABAK) coefficient. A PABAK coefficient of less than 0 was interpreted as poor, 0.00 to 0.20 as slight, 0.21 to 0.40 as fair, 0.41 to 0.60 as moderate, 0.61 to 0.80 as substantial, and 0.81 to 1.00 as almost perfect.[18]

Construct Validity In addition to hierarchy of items, evidence of construct validity can be established through an assessment of convergent and divergent validity. *Construct validity* refers to the degree to which the scores of a measure are consistent with hypotheses, which in this study is when the measure can be related to other measures.[8,32] If the hypothesis supports the idea that the items of the measure are positively correlated with another measure (ie, they measure a similar construct), then construct validity refers to convergent validity. However, when items are supposed to measure dissimilar constructs and are hypothesized to have low correlation coefficients, construct validity refers to divergent validity.[8,32] The authors assessed construct validity by correlating the LSIQ items with the PD-Q items using a Pearson product-moment correlation coefficient. The PD-Q was selected because it aims to identify a group of patients with LBP with a different clinical profile (ie, neuropathic pain). A correlation coefficient with an absolute value of 0.70 or above is interpreted as strong convergence, 0.50 to 0.69 as moderate convergence, 0.20 to 0.49 as moderate divergence, and less than 0.20 as strong divergence.[12,30] As there is no accepted measure of clinical instability that could be used in this study, it was impossible to evaluate whether the score measured clinical instability. Instead, the authors chose to confirm that the score did not measure another construct. In this case, the researchers used the PD-Q, which is a measure to identify signs of neuropathic pain that could be reasonably considered to represent a different clinical profile. The authors hypothesized that the LSIQ would not correlate highly with the PD-Q, thus supporting divergent validity.

RESULTS

Descriptive Analysis

The researchers included 107 participants (60 men and 47 women) with nonspecific LBP, of whom 100 answered the second questionnaire for the reliability analysis. The mean age of the participants was 50 years, and the reported median duration of symptoms was 36 months (interquartile range, 9-180 months). The mean pain intensity reported was 51 points on a 0-to-100 scale. The full description of the characteristics of the participants is detailed in **TABLE 1**, and the frequency of the response to each item of the LSIQ is presented in **TABLE 2**.

Rasch Analysis

Rasch analysis was performed on the data from 107 participants. No persons registered a minimum score or maximum score, suggesting that there were no ceiling or floor effects. **TABLE 3** shows the items in hierarchical order, where higher measures indicate items that were harder to endorse. Item 9 ("My pain is usually worse with prolonged or static positions") was the easiest to endorse, and item 12

("I get temporary pain relief with a back brace or corset") was the most difficult to endorse. The item order appeared to progress in a logical manner, from comparatively generic back pain–related items to items perhaps associated with perceived clinical instability, suggestive of construct validity. An item reliability of 0.95 suggested that the size of the sample was sufficient to confirm the reproducibility of the item hierarchy.

The person-item distribution map highlights the targeting of the LSIQ to the sample. The average person agreeability of 0.42 ± 1.09 logits (range, –1.75 to 3.17 logits) was comparable to the default average item endorsability of 0 ± 1.15 logits (range, –1.75 to 2.45 logits), but the items were distributed evenly across the range.

The LSIQ items constituted a unidimensional scale. **TABLE 3** also summarizes the fit statistics for the 15 items. Item 2 ("I feel the need to frequently pop my back") showed slightly excessive positive outfit (1.38 logits), and item 11 ("I have had this problem a long time") showed excessive positive outfit (2.85 logits). Visual analysis of the item characteristic curve of item 11 suggested that the misfit was due to respondents with higher scores overall scoring low on this item. Overall fit to the model was satisfactory, but the variations in interval-level item and person locations suggest that the LSIQ does not function as an interval-level measure. Visual inspection of the PCA correlation matrix did not identify clusters of items indicative of a second dimension, and an eigenvalue of 1.8 indicated that the scale appears to be unidimensional.[29] Assessment of local dependence revealed no meaningful relationships between the LSIQ item residuals, suggesting that none of the items are redundant.

Seven persons (7%) displayed excessive outfit (ie, endorsed most items in the scale). A person reliability index of 0.60 and Cronbach alpha of .63 suggest that the LSIQ has poor internal consistency.[31]

Analysis of the differential item functioning (item bias) identified several items that were significantly ($P<.05$) and meaningfully (greater than 0.5 logits) biased by factors other than instability. Item 10 ("It seems like my condition is getting worse over time") was harder to endorse by people who were comparatively overweight or in less pain. Item 11 ("I have had this problem a long time") was harder to endorse by people who were comparatively younger or less chronic. Men found it significantly harder to endorse item 2 ("I feel the need to frequently pop my back") than women. In addition, people with lower levels of perceived clinical instability found it harder to endorse items 1 ("I feel like my back is going to 'give way' or 'give out' on me") and 4 ("In the past, my back catches or locks when I twist or bend my spine"), whereas those with higher levels of perceived clinical instability found it harder to endorse item 2.

TABLE 1 CHARACTERISTICS OF THE PARTICIPANTS (N = 107)

Characteristic	Value
Age, y*	49.5 ± 16.6
Sex (female), n (%)	47 (44)
Body mass index, kg/m²*	28.5 ± 5.5
Smoking status (yes), n (%)	15 (14)
Educational level, n (%)	
School certificate	20 (19)
Higher school certificate	12 (11)
Trade certificate	25 (23)
Diploma	13 (12)
Advanced diploma	5 (5)
Bachelor's degree	14 (13)
Postgraduate degree	13 (12)
Other	5 (5)
Employment status, n (%)	
Full-time	46 (43)
Part-time	18 (17)
Not working	43 (40)
Duration of low back pain, mo†	36 (9-180)
Pain beyond the buttocks, thighs, or knees, n (%)	61 (57)
Current use of analgesics, n (%)	52 (49)
Pain intensity (VAS, 0-100)*	51.3 ± 22.8
Lumbar instability (LSIQ, 0-15)*	8.6 ± 2.7
Neuropathic pain (PD-Q, –1-38)*	10.4 ± 6.3

Abbreviations: LSIQ, Lumbar Spine Instability Questionnaire; PD-Q, painDETECT questionnaire; VAS, visual analog scale.
**Values are mean ± SD.*
†Values are median (interquartile range).

Test-Retest Reliability

The test-retest reliability (ICC) for the total score of the measure was 0.84, representing substantial agreement. The reliability for each item (PABAK coefficients) was considered moderate to substantial, ranging from 0.57 to 0.78. **TABLE 4** describes the percentages of agreement and reliability testing for each item of the LSIQ.

Construct Validity

The additional analysis for construct validity showed a moderate correlation between the LSIQ and the PD-Q (r = 0.57, $P<.001$), which challenges the hypothesis of divergent validity. This observation was unexpected and led the authors to undertake additional exploratory analysis to understand the relationship between the LSIQ and PD-Q. Of the participant group, 13 were considered to be in the "likely" neuropathic pain category based on the PD-Q (ie, score of 19 or more). The researchers considered which items of the LSIQ were more likely to be endorsed by this group than by those with scores in the "unlikely" and "uncertain" neuropathic pain categories. Items were compared with independent t tests. The items more likely to be endorsed by those with than by those without neuropathic pain were item 1 ("I feel like my back is going to 'give way' or 'give out' on me"; 77% versus 35%, $P = .004$), item 7 ("My pain increases with quick, unexpected, or mild movements"; 92% versus 65%, $P = .047$), item 10 ("It seems like my condition is getting worse over time"; 77% versus 47%, $P = .042$), and item 12 ("I get temporary pain relief with a back brace or corset"; 39% versus 13%, $P = .017$). Other items that were selected by all or nearly all of those with neuropathic pain, but narrowly missed significance, were item 3 ("I have frequent bouts or episodes of symptoms"; 100% versus 79%, $P = .066$) and item 8 ("I have difficulty sitting without a back support"; 92% versus 70%, $P = .095$).

The authors also considered the opposite analysis: features of the PD-Q more commonly endorsed by participants with higher LSIQ scores. Unlike the PD-Q,

TABLE 2 Description of Each Item and Response Frequency of the LSIQ (n = 107)

Item	Response, n (%) 0 (No)	1 (Yes)
1. I feel like my back is going to "give way" or "give out" on me	64 (60)	43 (40)
2. I feel the need to frequently pop my back	68 (64)	39 (36)
3. I have frequent bouts or episodes of symptoms	20 (19)	87 (81)
4. In the past, my back catches or locks when I twist or bend my spine	62 (58)	45 (42)
5. I experience pain when I change positions (eg, sit-to-stand or stand-to-sit)	19 (18)	88 (82)
6. When I bend forward it hurts, but returning to standing is usually worse	54 (50)	53 (50)
7. My pain increases with quick, unexpected, or mild movements	34 (32)	73 (68)
8. I have difficulty sitting without a back support (such as a chair) and feel better with a supportive back rest	29 (27)	78 (73)
9. My pain is usually worse with prolonged or static positions	15 (14)	92 (86)
10. It seems like my condition is getting worse over time (eg, shorter intervals between bouts)	53 (50)	54 (50)
11. I have had this problem a long time	18 (17)	89 (83)
12. I get temporary pain relief with a back brace or corset	90 (84)	17 (16)
13. I have many occasions when I get muscle spasms in the back	63 (59)	44 (41)
14. I am sometimes fearful to move because of my pain	51 (48)	56 (52)
15. I have had a back injury OR trauma in the past	50 (47)	57 (53)

Abbreviation: LSIQ, Lumbar Spine Instability Questionnaire.

TABLE 3 Average Item Endorsability Thresholds Shown in Hierarchical Order and Fit Statistics for the LSIQ Scores of Respondents (n = 107)

Item	Measure*	Score†	Infit MSQ	Outfit MSQ
12. I get temporary pain relief with a back brace or corset	2.45	17	1.00	1.06
2. I feel the need to frequently pop my back	1.09	39	1.24	1.38
1. I feel like my back is going to "give way" or "give out" on me	0.89	43	0.82	0.78
13. I have many occasions when I get muscle spasms in the back	0.85	44	0.92	0.99
4. In the past, my back catches or locks when I twist or bend my spine	0.80	45	0.79	0.73
6. When I bend forward it hurts, but returning to standing is usually worse	0.42	53	1.02	0.95
10. It seems like my condition is getting worse over time (eg, shorter intervals between bouts)	0.38	54	1.04	1.09
14. I am sometimes fearful to move because of my pain	0.28	56	0.86	0.80
15. I have had a back injury OR trauma in the past	0.24	57	1.17	1.23
7. My pain increases with quick, unexpected, or mild movements	−0.53	73	0.94	0.91
8. I have difficulty sitting without a back support (such as a chair) and feel better with a supportive back rest	−0.80	78	1.00	0.85
3. I have frequent bouts or episodes of symptoms	−1.36	87	1.10	1.12
5. I experience pain when I change positions (eg, sit-to-stand or stand-to-sit)	−1.44	88	0.91	0.82
11. I have had this problem a long time	−1.51	89	1.07	2.85‡
9. My pain is usually worse with prolonged or static positions	−1.75	92	1.01	1.10

Abbreviations: LSIQ, Lumbar Spine Instability Questionnaire; MSQ, mean-square.
**Higher measures indicate items that were harder to endorse, and lower measures indicate items that were easier to endorse.*
†Raw score out of 107.
‡Misfit item.

there is no accepted cutoff score to dichotomize the LSIQ. As a surrogate, the researchers used the cutoff score (9 or more) on the LSIQ identified by Macedo et al[20] that predicted a favorable response to motor control exercise. The authors compared the scores for the individual items of the PD-Q between groups with independent *t* tests. All PD-Q items were higher for the high LSIQ group. Those with a mean rating of 2 or more (ie, "slightly") were item 1 ("Do you suffer from a burning sensation in the area of your pain?"; 2.01 versus 1.17, $P = .006$), item 4 ("Do you have sudden pain attacks in the area of your pain, like electric shocks?"; 2.32 versus 1.27, $P<.001$), and item 7 ("Does slight pressure in this area trigger pain?"; 2.35 versus 1.46, $P = .001$).

DISCUSSION

The aim of this study was to evaluate the measurement properties of the LSIQ in a sample of patients with nonspecific LBP. The results were variable. The LSIQ appeared to constitute a unidimensional measure, targeted the sample well, and showed adequate test-retest reliability. However, the scale had poor internal consistency, did not appear to function as an interval-level measure, and had unclear construct validity. Although no items appeared to be redundant, several items were biased by factors other than the proposed construct of the measure.

Careful interpretation of the study results is required, as it remains unclear exactly which construct is being measured by the LSIQ, and whether it measures this as a single construct. In the present study, the internal consistency of the LSIQ was found to be poor, with a person reliability index of 0.60 and Cronbach alpha of .63. A previous validation of the LSIQ that evaluated internal consistency reported a Cronbach alpha of .69, which is borderline acceptable (.70).[8] Item hierarchy showed that the LSIQ items range from generic back-pain items (eg, "I have had this problem a long time"; "My pain is usually worse with prolonged or static positions") to items perhaps more related to clinical instability (eg, "I get temporary pain relief with a back brace or corset"; "I feel the need to frequently pop my back"). Although the LSIQ shows a logical set of items, it is impossible to determine whether the questionnaire is able to identify levels of instability.

TABLE 4 PERCENTAGES OF AGREEMENT AND PABAK COEFFICIENTS FOR EACH ITEM OF THE LSIQ IN THE TEST-RETEST RELIABILITY ANALYSIS (N = 100)

Item	Agreement, %	PABAK
1. I feel like my back is going to "give way" or "give out" on me	85.3	0.71
2. I feel the need to frequently pop my back	87.3	0.75
3. I have frequent bouts or episodes of symptoms	82.4	0.65
4. In the past, my back catches or locks when I twist or bend my spine	78.4	0.57
5. I experience pain when I change positions (eg, sit-to-stand or stand-to-sit)	79.4	0.59
6. When I bend forward it hurts, but returning to standing is usually worse	88.2	0.77
7. My pain increases with quick, unexpected, or mild movements	83.3	0.67
8. I have difficulty sitting without a back support (such as a chair) and feel better with a supportive back rest	83.3	0.67
9. My pain is usually worse with prolonged or static positions	89.2	0.78
10. It seems like my condition is getting worse over time (eg, shorter intervals between bouts)	79.4	0.59
11. I have had this problem a long time	89.2	0.78
12. I get temporary pain relief with a back brace or corset	87.3	0.75
13. I have many occasions when I get muscle spasms in the back	82.4	0.65
14. I am sometimes fearful to move because of my pain	86.3	0.73
15. I have had a back injury OR trauma in the past	88.2	0.77

Abbreviations: LSIQ, Lumbar Spine Instability Questionnaire; PABAK, prevalence and bias-adjusted kappa.

The authors found a moderate correlation with the PD-Q ($r = 0.57$). As only high scores on the PD-Q relate to neuropathic pain signs, the authors undertook additional analysis to identify which LSIQ items were more commonly endorsed by this group. This analysis revealed that people with probable neuropathic pain frequently selected items such as experiencing pain on quick movements, relief with support, feeling of giving way, and having pain that is frequent and worsening. Those with LSIQ scores of 9 or more reported higher scores on the PD-Q items of burning sensation, sudden attacks, and pain on slight pressure. Most of these features could be nonspecific signs of more severe LBP. On this basis, the authors propose that the significant correlation is possibly explained by the nonspecific nature of both questionnaires and the likely more frequent selection of items related to the severity of LBP in those with a higher score on either scale. This study population included a high proportion (57%) of people with pain below the buttocks. It is possible that the correlation between LSIQ and PD-Q scores would be lower in a population with a lower proportion of pain below the buttocks.

Previous use of the LSIQ involved dichotomizing the scale based on a median split, which would be most appropriate if it is an interval-level measure of clinical instability[3,20]; however, this may be premature to conclude. These findings suggest that the LSIQ may not be a "measure" (ie, an interval-level scale) but rather an "index" (ie, a checklist of features that may be related to clinical instability that has ordinal data qualities). This concurs with what the Delphi process of the LSIQ development aimed to achieve—to find features that therapists consider to be related to clinical instability, instead of being used as an interval-level scale. This has implications for how the LSIQ can be used. For example, inferential statistics are based on assumptions that the data to be analyzed are interval data that are normally distributed, with variance that is consistent across the levels of the scale. If these assumptions are not met, researchers and clinicians should usually treat these data as ordinal level.[16]

Measurement models can be classified as reflective or formative, depending on the direction of causality between the construct and the items; these are theoretical considerations that should be decided before construction of a scale.[10] This is an important distinction, as it indicates how the LSIQ should be used. In this study, the authors used Rasch analysis, which may assume (although it cannot determine) that the model is reflective, in that the causality flows from the construct (perceived clinical instability, in this case) to the items. Each item assesses an aspect of the latent trait but is interchangeable, as it is the construct that defines the item. In formative models, the causality flows from the items to the construct. That is, the construct measured is formed by the items, and removal or replacement of an item would fundamentally change the construct being assessed.[10] Formative models are multidimensional by nature, and whether they constitute measurement is controversial and beyond the scope of this discussion.[9]

Although the Rasch analysis assumes unidimensionality, there are several reasons to suggest that the LSIQ be considered a multidimensional ordinal index of clinical instability. First, the LSIQ presented unclear construct validity, and several items functioned poorly. The LSIQ was constructed from clinical features identified by experts in a Delphi study (ie, features that usually present in patients with clinical instability). Although these features together may be indicative of clinical instability, individually, many of them are characteristics of LBP in general. For example, item 11, a poorly functioning item, relates to the duration of the condition; there is no reason to suspect duration to be characteristic of clinical instability. Second, the LSIQ has poor internal consistency. As a multidimensional formative measure, internal consistency is not necessarily expected as it is with unidimensional models. Each of the items contribute to this composite variable, but are not necessarily related because the causality flows from the item to the construct. Finally, hierarchical evidence of construct validity would not be expected as it would in a unidimensional measure.

This study has some limitations. The authors recruited a care-seeking population with LBP in the city of Sydney and were successful in recruiting participants primarily with chronic LBP, which may limit the generalizability of the data to other settings or people with acute and subacute LBP.

Further, the authors did not test the association of the LSIQ with an objective instability measurement. They were unable to find a gold standard measure for lumbar clinical instability, as most objective tests show limited ability to diagnose lumbar instability.[2] For example, the aberrant movement sign, instability catch sign, painful catch sign, and the apprehension sign have demonstrated sensitivity rates of 18%, 26%, 37%, and 18%, respectively.[4,11]

The limitations of the current tests also represent the complexity and challenge of detecting clinical lumbar instability.[27] The PD-Q was used for divergent validity, as it would represent a different clinical profile, but the researchers understand that the choice of a different measure could have led to different results, and not testing for convergent validity is a limitation of this study. A potential limitation of the LSIQ at the development stage is that it did not include patients' perspectives on clinical instability, and, because this is a self-reported measure, this may be useful for future studies investigating the questionnaire.

Finally, it remains unclear whether the LSIQ measures clinical instability or some other construct in nonspecific LBP. A previous secondary analysis of a trial found some evidence that the LSIQ provides clinically useful information in relation to effect modification.[20] However, the data from the present study imply that the questionnaire may identify some other element of pain. For instance, many of the questions relate to the relationship between pain and postures or movement, which may explain why people who score high do well with motor control exercise. Thus, if the LSIQ does measure some other pain construct, then it may perform better as an index with some questions removed. At this stage, a theoretical reconsideration of this questionnaire is necessary.

CONCLUSION

The findings from this study suggest that a theoretical reconsideration of the LSIQ is necessary, but do not alter its potential usefulness. The findings enable a better understanding of the questionnaire for future studies. For example, as an index, the cutoff of 9 points can still be used in future studies validating the predictive ability of the LSIQ to identify patients who would benefit most from motor control exercise or graded activity. Further, it still has acceptable test-retest reliability and targets the sample well. Before implementation in clinical practice, future studies are needed to elucidate the dimensionality of the LSIQ and clarify the underlying construct of this questionnaire. ◉

KEY POINTS

FINDINGS: The Lumbar Spine Instability Questionnaire appeared to constitute a unidimensional measure, targeted the sample well, and showed adequate test-retest reliability. However, it does not appear to function as an interval-level measure, had poor internal consistency, and presented unclear construct validity.
IMPLICATIONS: A theoretical rethink of the Lumbar Spine Instability Questionnaire is necessary before implementing the questionnaire in clinical practice.

CAUTION: This study presented data from a care-seeking population with chronic low back pain in Sydney, which may limit the generalizability of the data.

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Changes in Measures of Cervical Spine Function, Vestibulo-ocular Reflex, Dynamic Balance, and Divided Attention Following Sport-Related Concussion in Elite Youth Ice Hockey Players

Concussion, defined as "traumatic brain injury induced by biomechanical forces,"[25] is one of the most common injuries in youth sport and recreation.[15] Risk of concussion is reportedly the highest among individuals participating in contact and collision sports.[12,26,27,33] Though the majority of adults recover in the initial 2 weeks following injury,[24] children and youth may need up to 4 weeks to recover following a concussion.[9,41,46]

BACKGROUND: Concussion is a commonly occurring injury. The extent to which the cervical spine, vestibulo-ocular reflex (VOR), dynamic balance, and divided attention are affected following concussion is not well understood.

OBJECTIVES: To evaluate acute changes in measures of (1) cervical spine function, (2) VOR function, (3) dynamic balance, and (4) tasks of divided attention in elite youth ice hockey players following a sport-related concussion.

METHODS: In this prospective cohort study, elite 13- to 17-year-old ice hockey players completed cervical spine measures (cervical flexor endurance test, head perturbation test, anterolateral strength, cervical flexion rotation test, joint position error), VOR function tests (head thrust test, dynamic visual acuity [clinical and computerized]), dynamic balance tests (Functional Gait Assessment), and divided-attention tasks (walking-while-talking test) both in the preseason and following concussion.

RESULTS: At least 1 test was completed by 69 of 97 (71%) players (a maximum of 55 for any 1 test) at both preseason and immediately following concussion (median, 4 days post concussion). After Bonferroni corrections (α = .00625), using Wilcoxon signed-rank tests, cervical spine measures were significantly worse following concussion compared to baseline (cervical flexor endurance test: z = –5.20, P<.001; anterolateral neck strength: z_{left} = –5.36, P<.001 and z_{right} = –5.45, P<.001; and head perturbation test: z = –4.36, P<.001). Time taken to complete a complex task of divided attention relative to normal walking speed was faster (improved) compared to the preseason (z = –2.59, P<.01). There was no change in VOR or dynamic balance following concussion.

CONCLUSION: Measures of cervical spine function and divided attention were altered following concussion. However, tests of VOR and dynamic balance were not significantly different from baseline. Future research to evaluate the mechanism underlying these changes is warranted. *J Orthop Sports Phys Ther 2018;48(12):974-981. Epub 27 Jul 2018. doi:10.2519/jospt.2018.8258*

KEY WORDS: *cervical spine, concussion, dynamic visual acuity, ice hockey, vestibular, youth*

The diagnosis of sport-related concussion is challenging due to the subjective nature of self-reported symptoms. Consistently, the most commonly reported symptom following a concussion is headache.[3,21] Dizziness, nausea, and neck pain are also among the most commonly occurring symptoms after a concussion.[3] Persistent symptoms of dizziness may be secondary to persisting alterations in the function of afferent systems—including vestibular, visual, and proprioceptive systems—involved in sensory input concerning position in space.[37,40] The cervical spine may be a source of ongoing neck pain and headache following concussion.[37] It has also been reported that the vestibular system and/or the cervical spine may be injured at the time of concussion.[11,40] However, little is currently known about how clinical measures change following concussion compared to preseason values in a sport population.

Rehabilitation with techniques aimed at targeting the cervical spine and vestib-

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ular/balance systems has demonstrated positive effects in individuals with ongoing symptoms following concussion.[38,40] However, acute changes in cervical spine function, vestibulo-ocular function, dynamic balance, and tasks of divided attention have received little attention in the literature to date. A greater understanding of how these systems may be affected following concussion using objective tests would inform detection, clinical management, and rehabilitation after a sport-related concussion.

The objective of the present study was to evaluate the acute changes in measures of (1) cervical spine function, (2) vestibulo-ocular function, (3) dynamic balance, and (4) tasks of divided attention in elite youth ice hockey players who have suffered a sport-related concussion. An exploratory objective was to describe changes in these measures in individuals with and without a history of concussion.

METHODS

Participants

This study is part of a larger cohort study of youth ice hockey players. Youth ice hockey teams (male and female, aged 13-17 years) in Calgary and Edmonton, Alberta, Canada were asked to participate in a prospective cohort study.[41] These players competed at the highest level of play (top 20%) for youth ice hockey players (AA and AAA leagues). Individuals were included in this substudy if they participated in Calgary, because preseason measures of cervical function, vestibulo-ocular function, dynamic balance, and divided attention were only collected in this portion of the sample. Participants were included in this study if they had completed the measures described below at the preseason assessment as well as at the initial physician appointment following a sport-related concussion.

Individuals who had sustained an injury or had a chronic illness that prevented full participation in ice hockey prior to the beginning of the season were excluded from the study. All participants provided written informed assent prior to participation in the study. Ethics approval was granted through the Conjoint Health Research Ethics Board at the University of Calgary (ethics ID 24026).

Procedures

A previously validated injury surveillance system was used to prospectively collect injury and exposure data throughout the season of play.[13,14,16,28] Details of the prospective surveillance portion of this study have been previously described.[41] Preseason questionnaires, including demographic information (eg, sex, age, weight, height, position, year of play) and injury history, were collected before the start of the season and included reports of previous concussion. Athletes were categorized as having a history of concussion if they answered "yes" to the question, "Have you ever had a concussion or been 'knocked out' or 'had your bell rung'?" on the preseason baseline questionnaire.[14] The number of previous concussions was also self-reported on the preseason baseline questionnaire.

Participants attended a 2-hour preseason testing session with their teams. Preseason measures were collected in a series of stations with a registered physical therapist. All therapists who participated in the testing sessions underwent a training session with the lead physical therapist that lasted approximately 1 hour and included (1) an evidence-informed review of the rationale for each of the measures, (2) review of the standardized testing protocol, (3) a practice session, and (4) discussion regarding scoring procedures. A standardized script was used for each measure.

To improve efficiency of the testing protocol for the participants, between 2 and 4 physical therapists participated in each preseason testing session. One physical therapist completed the postinjury assessments. Participants rotated through multiple stations of testing, thus precluding implementation of a standard test order.

Measures included in the test protocol were symptom reports (ie, neck pain, dizziness, headaches on a numeric pain or dizziness rating scale [0-10]),[5,6] cervical spine function (cervical spine range of motion, cervical flexor endurance [CFE] test,[10,23,32] cervical flexion rotation test,[31] anterolateral cervical spine strength test,[29] joint position error [left rotation, right rotation, and extension][34]), vestibulo-ocular function (clinical dynamic visual acuity [DVA],[7,8] head thrust test,[43] computerized DVA[19]), dynamic balance (Functional Gait Assessment[45]), and divided attention (walking-while-talking test[18,20]).

These measures were selected because they evaluate a variety of domains in each subcategory, are clinically useful and relevant, and are the most psychometrically sound measures currently available.[6,10,18,19,22,31,32,35,43,45] A newly developed test (the head perturbation test [HPT], where the clinician applies an unexpected force and watches for a "bobble" in the patient's position) was also included; however, reliability and validity of this test have not yet been published. A description of each clinical measure can be found in **TABLE 1**, and a detailed description of the HPT is available in the **APPENDIX** (available at www.jospt.org).

Statistical Analysis

Participant characteristics at preseason, including age, history of concussion, height, weight, position, and year of play, were summarized by sex, using medians and ranges for numeric variables and frequencies and percentages for categorical variables. Measures were subclassified, based on domains of interest, as cervical spine, vestibulo-ocular, dynamic balance, and divided attention. Symptoms were measured on a scale from 0 to 10, and participants were considered to have a symptom when they reported a score of 1 or greater. The proportion of participants who had an increase in symptoms was calculated by subtracting the preseason score from the postseason score on the numeric pain or dizziness rating scale (0-10). The mean score with standard deviation or, depending on the distribution of the data, the median score with first and third quartiles, frequencies, and proportions were calculated for all preseason and postseason clinical measures.

Confidence intervals with Bonferroni correction were calculated for preseason-postseason differences. The Wilcoxon signed-rank test was used to compare numeric variables, the McNemar test to compare dichotomous variables, and the Stuart-Maxwell test to compare variables with 3 levels. Alpha was set a priori at .05. Bonferroni correction was used for each of the domains with multiple measures (symptoms: α = .017, .05/3; cervical spine: α = .006, .05/8; vestibulo-ocular: α = .013, .05/4). The exploratory analysis was conducted by stratifying changes in measures by previous history of concussion and presented descriptively as medians (interquartile range [IQR]) or frequencies (proportions), as appropriate.

RESULTS

A total of 97 of 559 (17.4%) participants sustained a sport-related concussion during the season of play and were eligible to participate in this study. Of these, 69 (71%) completed acute postconcussion measures of cervical

TABLE 1 Description of Measures

Name of Test	Description
Numeric pain or dizziness rating scale	An 11-point numeric pain or dizziness rating scale was used to rate the participant's perceived level of pain/dizziness, with 0 representing no pain/dizziness and 10 representing the worst pain/dizziness imaginable
Head thrust test	The head thrust test is a clinical test that assesses the angular vestibulo-ocular reflex.[43] The participant was asked to fixate on a target, and a high-acceleration, small-amplitude (approximately 5°-10°) motion was applied in rotation. A positive test was indicated by an inability of the eyes to maintain fixation with head motion (ie, a corrective saccade after the head thrust)
Dynamic visual acuity	Dynamic visual acuity is a measure that has been used to quantify an individual's ability to see clearly with predictable or unpredictable head motion.[36] This can be tested clinically[2] and with computer-generated programs.[19] To perform the test here, visual acuity was tested statically (head still) and then dynamically while the head was moving at high speeds. The difference between static and dynamic visual acuity scoring yields a dynamic visual acuity score
Clinical	The clinical test of dynamic visual acuity was measured on an Early Treatment Diabetic Retinopathy Study eye chart, with the head still and during active assisted head rotation (timed with a metronome set at 2 Hz). A line was considered recited correctly if 1 or fewer errors in recitation of letters occurred on the eye chart. The difference between the number of lines correctly recited with head motion and the number with the head still was recorded
Computerized	Computerized dynamic visual acuity was measured using a NeuroCom inVision system (Natus Medical Inc, Pleasanton, CA). Computerized dynamic visual acuity was measured at 120°/s in a random order for each participant, who was seated 2 m from the screen
Walking-while-talking test	The walking-while-talking test involved a timed walk and various cognitive tasks. Participants walked a 12.2-m (walk 6.1 m, turn around, and return) course.[18] The initial time was taken while walking at a normal walking pace. The walking-while-talking simple task involved reciting the letters of the alphabet out loud and walking the same course. The walking-while-talking complex task involved individuals reciting alternating letters of the alphabet (starting with either A or B).[18] For the purposes of this study, the walking-while-talking simple, walking-while-talking complex, and walking-while-talking word (in this case, as many words as possible beginning with a letter of the alphabet) tests were used to minimize practice effects
Functional Gait Assessment	The Functional Gait Assessment was used to assess dynamic balance.[45] This 10-item gait assessment is based on the Dynamic Gait Index and includes 10 different walking tasks with varied balance tasks, including head movement, changes in speed, turning, walking backward, and walking with eyes closed[45]
Joint position error	Joint position error was measured using a laser helmet and a bull's eye. The participant was fitted with a laser helmet and focused on a target with a bull's eye 90 cm ahead. The participant was asked to close his or her eyes and then maximally rotate or extend his or her head and return to where center was perceived to be. The distance between zero point (center) and the point on which the laser stopped was measured in inches.[35] An average of 3 trials in each direction (extension and right and left rotation) was taken
Cervical flexor endurance test	The cervical flexor endurance test is a timed test (seconds), performed with the participant in a crook-lying position, holding his or her head against gravity to fatigue.[23] The testing was done per the methods described by Olson et al,[32] with the chin "tucked" and head lifted 2 finger widths
Cervical flexion rotation test	The cervical flexion rotation test has been described as a measure to assess the mobility of the C1-2 segment and presence of cervicogenic headache.[31] The participant's neck was placed into a position of maximal flexion (to minimize movement at levels of the cervical spine other than the C1-2 level), followed by rotation. The therapist reported a restriction in motion (defined as a firm end feel with a minimum perceived limitation of a 10° reduction in expected range of motion) and presence of pain
Anterolateral cervical spine strength	The cervical rotation side-flexion test has been reported to assess the strength of the anterolateral cervical flexor muscles.[29] The participant was supine, with his or her head maximally rotated in 1 direction. The neck was then laterally flexed off the plinth, and the subject was asked to "hold your head still and do not let me move you."[29] A Lafayette Manual Muscle Tester (model 01163; Lafayette Instrument Co, Lafayette, IN) was placed superior to the ear on the temporal region of the head. The direction of pressure was toward the floor until the subject could no longer maintain the testing position. The subject was then asked if the test was limited by weakness or pain. This test was performed 3 times on each side, and the mean of 3 trials was calculated
Head perturbation test	The participant sat in an upright position, with arms crossed on the shoulders, and was given instructions to maintain the head as still as possible and keep the eyes closed. The examiner stood behind the subject and applied a gentle force in an unpredictable order and direction to the front, back, right side, left side, front right side, front left side, back right side, and back left side of the head. Initially, a practice session (2 times in each direction) was performed. Following this, the examiner applied a mild force randomly in each of the 8 directions for 3 times each. The examiner watched for a "bobble" in the head when the force was initially applied (see the **APPENDIX** for test description details)

function, vestibulo-ocular function, dynamic balance, and divided attention for their first concussion. Eighty percent of these individuals (n = 55) had also completed preseason measurements and were included in the analyses. In some cases, not all players completed all tests at both time points; however, any tests that were completed were included in these study results. Preseason demographics are summarized in **TABLE 2**.

The median time from concussion (n = 55) to initial assessment by the study sport medicine physician was 4 days (IQR, 2-6 days). Only 1 participant was assessed more than 10 days after injury (18 days post injury). Preseason and acute postinjury values for each of the clinical tests are summarized in **TABLE 3**. Following concussion, symptom complaints were reported to increase for neck pain in 42% (23/55), headache in 56% (31/55), and dizziness in 40% (19/48) of participants (**TABLE 3**). Of these, new onset of neck pain was reported in 33% (18/55), headache in 44% (24/55), and dizziness in 29% (14/48) of participants.

At preseason assessment, all players completed clinician assessment, including cervical range of motion. Following concussion, 9 of 46 (19.6%) individuals were reported to have less than full range of motion in at least 1 direction. The cervical flexion rotation test was positive in 1 participant (1/52, 1.9%) at the preseason evaluation and was positive in 9 of 52 (17.3%) players in the acute period following concussion. At preseason assessment, 6 of 48 (12.5%) participants reported pain during the CFE test, and 18 of 48 (37.5%) reported pain during this test following concussion. At preseason assessment, 36 of 53 (68%) participants scored perfectly (8/8), and 1 of 53 (2%) scored 0/8, on the HPT. On the same test postinjury, 16 of 53 (30%) participants scored perfectly, and 12 (23%) scored 0/8. Cervical spine measures were significantly worse following concussion compared to baseline (CFE test: $z = -5.20$, $P<.001$; anterolateral neck strength in left- and right-rotated positions: $z_{left} = -5.36$, $P<.001$ and $z_{right} = -5.45$, $P<.001$; HPT: $z = -4.36$, $P<.001$).

Time to complete a complex task of divided attention (walking-while-talking test) relative to normal walking speed was faster (improved) than in the preseason ($z = -2.59$, $P<.01$). On the Functional Gait Assessment, 69% (24/35) of participants scored perfectly (30/30) at the preseason assessment, and 74% (26/35) scored perfectly following injury. There were no changes observed in measures of vestibulo-ocular function (ie, clinical DVA, computerized DVA, head thrust test) or Functional Gait Assessment scores following concussion.

TABLE 4 summarizes scores on each measure by history of concussion using either proportions or medians (IQRs), as appropriate. For neck pain, 52% of individuals with a history of concussion reported an increase in neck pain, compared to 31% of individuals without a history of concussion. Similarly, 50% of individuals with a history of concussion reported an increase in dizziness, compared to 29% of individuals without a history of concussion. Clinical measures of cervical spine function, vestibulo-ocular function, dynamic balance, and divided attention all appeared to be similar, with overlapping IQRs for all measures.

TABLE 2 PARTICIPANT CHARACTERISTICS

	Female (n = 9)	Male (n = 46)	Total (n = 55)
Age group, n (%)			
Bantam	4 (44)	9 (20)	13 (24)
Midget	5 (56)	37 (80)	42 (76)
Previous history of concussion, n (%)			
Yes	4 (44)	25 (54)	29 (53)
No	5 (56)	21 (46)	26 (47)
Height, cm*	167.6 (147.3-172.7)	176.5 (160.0-193.0)	175.3 (147.3-193.0)
Weight, kg*	56.8 (46.4-63.6)	70.5 (50.0-96.8)	68.2 (46.4-96.8)
Position, n (%)			
Forward	4 (44)	29 (63)	33 (60)
Defense	3 (33)	16 (35)	19 (34)
Goalie	1 (11)	1 (2)	2 (4)
Missing	1 (11)	0	1 (2)
Year of play, n (%)			
First	2 (22)	17 (37)	19 (34)
Second	6 (67)	24 (52)	30 (55)
Third (Midget only)	1 (11)	5 (11)	6 (11)

*Values are median (range).

DISCUSSION

THE PRESENT STUDY IDENTIFIED ALterations in measures of cervical spine function (ie, CFE, anterolateral strength, the flexion rotation test, and the HPT) following concussion when compared to preseason scores in elite youth ice hockey players. The clinical tests employed in this study were used to evaluate a variety of components of cervical spine function, including endurance (CFE test), strength, head-on-neck control (HPT), flexion rotation (cervical flexion rotation test), and joint position error. All measures, except for 2 of 3 of the joint position error tests, decreased significantly following concussion.

These findings are of interest, as neck pain is one of the most commonly occurring symptoms following concussion.[3] However, the source of this neck pain after concussion has received minimal evaluation in the literature to date and is not well understood. The neck may also be a source of headache following concussion. The neck has been reported to be injured concurrently at the time of concussion, but the underlying physiological mechanisms for this injury and for ongoing pain are not well understood.[17]

Some individuals may have ongoing neck pain and headaches secondary to trauma of the cervical spine itself.[4,44] In such cases, the cervical spine should be treated to alleviate symptoms and restore function prior to returning to sport.[37] Changes in control of head-on-neck motion may also occur secondary to altered processing of sensory input from the central nervous system. In this case, it may be that a more conservative approach to care is appropriate, and allowing adequate time for recovery from physiological dysfunctions prior to returning to play is imperative. Thus, further evaluation of alterations in cervical spine function from a neurophysiological standpoint is needed.

Of interest is the significantly greater proportion of participants who reported symptoms of dizziness following concussion but showed no differences in measures of vestibulo-ocular or dynamic balance function. Vestibular-type symptoms (including symptom provocation with testing) and functional alterations have been reported following concussion.[11,30] However, these studies have not made comparisons with preinjury measures. In the present study, the IQRs for individuals who did and did not report a history of concussion were overlapping, and test scores appeared similar. However, 50% of participants who reported a history of concussion had an increase in dizziness, compared to 29% of individuals who did not report a concussion history.

It may be that there are pre-existing alterations in sensorimotor control in some individuals.[22,39] Due to the interaction and combined processing of cervical spine, vestibular, and visual stimuli, it may be that the symptoms that are reported following concussion are secondary to alterations in sensorimotor processing rather than specific vestibular dysfunction.[1] This study evaluated differences in behavioral measures of vestibulo-ocular function, and specific vestibular diagnoses were not made. Thus, further research is needed to comprehensively evaluate the function of the vestibular system following injury, while considering the potential pre-existing vestibular and balance diagnoses.

Following concussion, time to complete a task of complex divided attention relative to normal walking speed improved. This may reflect a learning or developmental effect of this test in youth

TABLE 3 PRESEASON AND POSTINJURY VALUES AND CHANGE IN MEASURES FOLLOWING SPORT-RELATED CONCUSSION

Category/Variable	n	Preseason Values	Postinjury Values	Test Statistic
Symptoms*				
Neck pain	55	29% (n = 16)	47% (n = 26)	NA
Headache	55	31% (n = 17)	64% (n = 35)	NA
Dizziness	48	21% (n = 10)	48% (n = 23)	NA
Cervical spine†				
CFE test, s	55	39 (26-59)	20 (12.66-33)	$z = -5.20, P<.001$
CFRT	52			$z = -2.54, P = .01$
Unilateral positive test		1.9% (n = 1)	13.5% (n = 7)	
Bilateral positive test		0	3.9% (n = 2)	
Anterolateral cervical spine strength, kg				
Left rotation	50	4.60 (3.63-5.34)	2.58 (2.10-3.55)	$z = -5.36, P<.001$
Right rotation	51	4.42 (3.48-5.14)	2.60 (2.04-3.69)	$z = -5.45, P<.001$
HPT (0-8)	53	8 (7-8)	6 (1-8)	$z = -4.36, P<.001$
JPE, cm				
Extension	37	5.43 (3.32-8.0)	6.68 (4.17-8.33)	$z = 1.19, P = .24$
Right	37	4.18 (3.33-6.68)	6.68 (4.17-8.33)	$z = 2.16, P = .031$
Left	38	4.18 (2.92-5.83)	6.68 (4.17-9.18)	$z = 2.96, P = .003$
Dynamic balance†				
FGA (0-30)	35	30 (29-30)	30 (29-30)	$z = 0.14, P = .89$
Divided attention†				
WWT test, s‡	39	3.47 (2.0-6.5)	3.0 (1.71-4.32)	$z = -2.59, P<.01$
Vestibulo-ocular†				
Computerized DVA at 120°/s, logMAR				
Left	38	0.3 (0.2-0.41)	0.2 (0.11-0.3)	$z = -2.17, P = .030$
Right	38	0.3 (0.2-0.34)	0.2 (0.12-0.3)	$z = -0.58, P = .56$
Head thrust test total§	54			$\chi^2 = 2.60, P = .27$
Unilateral positive test		5.6% (n = 3)	13% (n = 7)	
Bilateral positive test		0	1.9% (n = 1)	
Clinical DVA, logMAR	52	0.2 (0.1-0.4)	0.2 (0.1-0.3)	$z = -0.64, P = .52$

Abbreviations: CFE, cervical flexor endurance; CFRT, cervical flexion rotation test; DVA, dynamic visual acuity; FGA, Functional Gait Assessment; HPT, head perturbation test; IQR, interquartile range; JPE, joint position error; NA, not applicable; WWT, walking while talking.

**Reported as an increase in symptoms. Proportions calculated as "yes" for reporting symptom are stated values of 1 or greater.*

†Values are median (IQR) unless otherwise indicated.

‡Difference between complex and normal walking.

§Chi-square calculated based on 0, no positive tests; 1, unilateral positive; and 2, bilateral positive tests. Eighty percent of participants had no change.

athletes.[42] Thus, further evaluation of the changes that may occur with growth and development, as well as with practice, in this population is warranted.

Concussion is a heterogeneous injury, with multiple systems that may be affected following injury.[17,24] An ongoing challenge with concussion is the lack of objective measures to quantify injury. As concussion presents with a variety of different symptoms and clinical findings, quantification of specific clinical subdomains will assist in informing both detection and management of concussion.[26]

TABLE 4 CHANGES IN MEASURES FOLLOWING CONCUSSION, STRATIFIED BY CONCUSSION HISTORY

		Change in Score Following Concussion	
Category/Variable	n	No Previous Concussion	Previous Concussion
Symptoms*			
Neck pain	55	31% (8/26)	52% (15/29)
Headache	55	58% (15/26)	59% (17/29)
Dizziness	48	29% (7/24)	50% (12/24)
Cervical spine			
CFE test, s	55	–23.31 (–32 to –12)†	–14 (–20.99 to –5.31)†
CFRT	52		
Unilateral positive test		4/26	3/26
Bilateral positive test		1/26	1/26
Anterolateral cervical spine strength, kg			
Left rotation	50	–1.47 (–2.38 to –1.01)†	–2.01 (–2.95 to –0.53)†
Right rotation	51	–1.29 (–1.61 to –0.36)†	–2.17 (–3.01 to –0.56)†
HPT (0-8)	53	1 (0-6)†	2 (0-6)†
JPE, cm			
Extension	37	–2.5 (–5.0 to 0.0)†	1.65 (–1.68 to 2.93)†
Right	37	–2.5 (–4.18 to 0.0)†	0.43 (–4.17 to 1.68)†
Left	38	–1.68 (–3.75 to 0.0)†	–2.5 (–5.0 to 0.83)†
Dynamic balance			
FGA (0-30)	35	0 (–1.0 to 0.0)†	0 (–1.0 to 1.0)†
Divided attention			
WWT test, s‡	39	–2.79 (–4.74 to –1.73)†	–1.29 (–3.39 to 0.81)†
Vestibulo-ocular			
Computerized DVA at 120°/s, logMAR			
Left	38	0.02 (–0.02 to 0.2)†	0.03 (–0.1 to 0.18)†
Right	38	0.04 (–0.03 to 0.22)†	–0.09 (–0.18 to 0.14)†
Head thrust test total§	54		
Unilateral positive test		19% (5/26)	7% (2/28)
Bilateral positive test		4% (1/26)	0% (0/28)
Clinical DVA, logMAR	52	–0.1 (–0.2 to 0.1)†	0.1 (–0.1 to 0.3)†

Abbreviations: CFE, cervical flexor endurance; CFRT, cervical flexion rotation test; DVA, dynamic visual acuity; FGA, Functional Gait Assessment; HPT, head perturbation test; IQR, interquartile range; JPE, joint position error; WWT, walking while talking.
**Reported as an increase in symptoms. Proportions calculated as "yes" for reporting symptom are stated values of 1 or greater.*
†Values are median (IQR).
‡Difference between complex and normal walking.
§Chi-square calculated based on 0, no positive tests; 1, unilateral positive; and 2, bilateral positive tests. Eighty percent of participants had no change.

While not all individuals may have clinical findings of alterations in cervical spine function, vestibulo-ocular function, dynamic balance, and divided attention, this study identified significant changes in cervical spine measures following injury. The measures evaluated here provide additional insight into alterations in function that occur following concussion. These typical standardized clinical tests of cervical spine function, vestibulo-ocular function, dynamic balance, and divided attention could ultimately identify clinical subtypes that present following injury and be used to inform management strategies. Future research to combine these measures with additional objective measures that evaluate additional domains that may be affected by concussion will ultimately assist in a greater understanding of the multifaceted effects of concussion.

Limitations

Though this study provides new insight into potential sources of symptoms following concussion, it is not without limitations. In the sample of elite youth ice hockey players who completed both preseason and postinjury measures , there were some participants with missing data. Thus, it is possible that, due to selection bias, only the more severely injured or at-risk participants had complete data and were included in the analysis, which might have resulted in overestimation of the alterations in function that occur following concussion. A strength of this study is that its participants were part of a prospective cohort study rather than a select clinical sample, and thus are expected to be more representative of youth ice hockey players than individuals presenting to specialist clinics.

This study was not powered to evaluate the effect of additional covariates such as age, sex, and history of concussion. Thus, there might have been unmeasured confounding or effect-measure modification, and additional study is required to further evaluate the effect of these variables on the outcomes following concussion. The test order was not standardized due to multiple participants attending the sessions concurrently, and there could have been variability in test scores from preinjury to postinjury due to the order of testing.

One participant presented 18 days following injury. On review, scores were similar to the summary measures for all except the clinical test of DVA. Repeating the analysis without this participant did not change the results of the study.

Only 9 female participants were included in this study, thus limiting the authors' ability to evaluate the effect of sex on outcomes. While the authors hypothesize that female and male participants would be similarly affected by concussion, values on the various measures may differ at preseason and postinjury in female participants. Thus, identification of potential differences in test scores, both at preseason and following injury, by sex is an important area for future research. When stratifying based on concussion history, the difference values for each of the measures appeared to be similar.

This study used a battery of the best currently available measures that could be completed on a large sample of elite youth ice hockey players during preseason and postinjury assessments. To optimize the standardization of these tests, a training session was held for all physical therapists, and a standardized script was used during test administration. A specific diagnosis related to the cervical spine, balance, and vestibular dysfunction was not included in this study. Thus, there may be additional subclassifications/diagnoses that exist in this population that the authors were unable to identify. Future research should include assessment of concomitant diagnoses to better understand the nature of the injuries that occur following concussion.

CONCLUSION

A unique battery of cervical spine, vestibulo-ocular, dynamic balance, and divided-attention tests was performed on youth ice hockey players. Measures of cervical spine function were worse following concussion. Tests of vestibulo-ocular function and dynamic balance were not significantly different following concussion compared to preseason values. Future research to evaluate the mechanisms underlying these changes is warranted to better understand the acute injury characteristics that define concussion. ◉

KEY POINTS

FINDINGS: Symptoms of dizziness, neck pain, and headaches were reported to increase following concussion in 40%, 42%, and 56% of participants, respectively. Decreased performance on cervical spine measures was noted in the early days following concussion, while vestibulo-ocular function and dynamic balance did not change following concussion.

IMPLICATIONS: Assessment of cervical spine function, vestibulo-ocular function, dynamic balance, and divided attention may add to the multifaceted differential diagnosis of concussion. Despite the lack of change seen in vestibulo-ocular function and dynamic balance measures and the heterogeneous clinical presentation of concussion, further study to better understand the clinical utility of these tests after concussion is needed. Further study to better understand the underlying mechanism for the changes seen in cervical spine function is also warranted.

CAUTION: Further evaluation to understand the effect of relevant covariates, such as sex, age, and history of concussion, is necessary.

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APPENDIX

HEAD PERTURBATION TEST

Description

The head perturbation test is a newly developed clinical test to look at the ability of an individual to maintain a stationary head position with eyes closed in sitting while external perturbations are applied to the head. To perform the test, the participant sits in an upright postural position, with arms crossed on the shoulders, and is given instructions to maintain the head as still as possible and keep the eyes closed.

The examiner stands behind the participant and applies a gentle force in an unpredictable order and direction to the front, back, right side, left side, front right side, front left side, back right side, and back left side of the head. Initially, 2 practice sessions in each direction are performed to allow for learning to occur.

Following this, the examiner applies a mild force randomly in each of the 8 directions for 3 times each. After 1 trial in each direction, the score is written down before proceeding to the next set of 8. If the participant fails to maintain a static head position for 2 of the 3 trials, no point is awarded for that direction. The maximal score on the test is 8.

This is a newly developed test that appears to have clinical utility, but has not yet been formally evaluated. Prior to each testing session, the examiner practiced the application of 2.27 kg of force to a handheld dynamometer until he or she was consistently able to apply this force while blinded to the measure of force. The rationale for this is to remind examiners of the predetermined force to maximize the consistency of force they apply.

Script

"Please sit in a tall but comfortable posture with your arms crossed and eyes closed [if necessary, a blindfold or blackout goggles can be used to obstruct vision]. I will gently apply a force to some part of your head, and I would like you to try and maintain the position that you are sitting in without allowing your head to 'bobble' [you can use the analogy of a bobblehead doll]. I will repeat in each direction 3 times in an unpredictable order. Please let me know if you have pain or need to stop the test."

[VIEWPOINT]

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Is There a Postworkout Anabolic Window of Opportunity for Nutrient Consumption? Clearing up Controversies

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Nutrient timing is a popular strategy for enhancing muscular adaptations and athletic performance. From the standpoint of muscle hypertrophy, the concept of a "postworkout anabolic window of opportunity" has been proposed, whereby a limited time exists after training to optimize accretion of muscle proteins—generally believed to be less than an hour after completion of an exercise bout.[1,8,10] According to nutrient timing theory, ingesting the proper nutrients during this time frame promotes an additive anabolic response to the exercise bout that maximizes hypertrophic adaptations; delaying protein intake by a matter of minutes after this period is suspected to compromise muscular gains. Some researchers have gone so far as to claim that the timing of nutritional consumption is even more critical to muscle development than the absolute daily consumption of nutrients.[1] Thus, the purpose of this paper is to review the current literature as to the relevance of the anabolic window of opportunity, and draw evidence-based conclusions for application into practice.

Origin of the Concept

The concept of nutrient timing was originally based on short-term studies showing superior increases in muscle protein synthesis (MPS) when amino acids were consumed in the immediate postworkout period versus delaying ingestion. Early work in canines has demonstrated that immediate infusion of an amino acid and glucose solution following 150 minutes of treadmill running significantly increased MPS compared to infusion 2 hours post exercise.[17] Levenhagen et al[13] found similar results in human participants with either early (immediately after 60 minutes of moderate-intensity cycling) or late (3 hours post exercise) consumption of a supplement containing 10 g of protein, 8 g of carbohydrates, and 3 g of fat. Whereas MPS spiked 3-fold in the early condition, the response was attenuated to only 12% with late provision. Although these findings suggest that the timing of protein ingestion after a workout is critical to maximizing MPS, it should be noted that these studies involved long-duration cardiorespiratory exercise. Given the aerobic nature of the exercise bouts, it can be speculated that the increased protein synthetic rate from immediate provision was due to greater mitochondrial and/or sarcoplasmic fractions as opposed to contractile elements.[11]

In contrast to studies employing aerobic exercise, acute resistance training studies have shown mixed results as to the effects of postworkout nutrient timing

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on the MPS response. Rasmussen et al[19] randomized participants to receive a supplement containing 6 g of essential amino acids and 35 g of sucrose, either 1 hour or 3 hours following a high-volume bout of leg-press and leg-extension exercise. Muscle protein synthesis levels were elevated by approximately 400% in both conditions, indicating that timing was not a factor in the postexercise response. Intriguingly, Tipton and colleagues[24] found that consuming an essential amino acid-carbohydrate solution preworkout produced a significantly more pronounced elevation of MPS versus the immediate postworkout intake of the same supplement. These findings seemingly refute the anabolic window hypothesis. However, follow-up work from the same lab demonstrated similar increases in MPS when 20 g of whey was consumed immediately prior to a resistance training bout versus 1 hour post exercise.[23] Further confounding matters, Fujita et al[3] reported that consumption of an essential amino acid-carbohydrate supplement 1 hour prior to multiset leg-extension training did not elevate MPS to a greater extent than in those exercising in a fasted state. At the very least, the conflicting nature of these findings raises skepticism as to the existence of a narrow postexercise window for protein consumption.

Long-Term Findings

While the aforementioned studies provide interesting insights into the acute response to nutrient timing, it is important to note that isolated measures of MPS do not necessarily correlate with long-term exercise-induced hypertrophy.[15] Thus, the practical implications of these findings must be taken with circumspection; scrutiny of longitudinal studies using direct measures of muscle growth is required to draw relevant inferences on the topic.

An early nutrient-timing study appeared to lend support to the claims of an anabolic window of opportunity. Esmarck et al[2] randomly assigned untrained, older men (mean ± SD age, 74 ± 1 years) to a supervised resistance training protocol whereby the participants consumed a combination of skim milk and soy protein either immediately following or 2 hours after each exercise bout. Training was carried out 3 days a week for 12 weeks. At study's end, muscle cross-sectional area and mean fiber area of the quadriceps femoris increased, respectively, by 7% and 22% in the group that consumed protein immediately post workout, while the group that delayed protein ingestion did not show significant growth. On the surface, this study provides strong evidence of a benefit for early provision of postworkout nutrients to promote muscular adaptations. However, the study had several notable limitations and inconsistencies worthy of consideration. For one, the sample size encompassed just 13 participants, 7 in the group that received immediate protein supplementation and 6 in the group that delayed supplementation. This compromises the ability to draw valid statistical inferences. In addition, the protein dose was a mere 10 g—well below the estimated 40 g needed to maximize MPS in older individuals.[25] It also is highly curious that those delaying consumption by 2 hours showed no hypertrophy after 12 weeks of consistent resistance training. Considering that significant increases in hypertrophy are routinely seen in the elderly with regimented resistance training that does not involve immediate protein supplementation,[14] and that the immediate postworkout consumption group achieved increases in cross-sectional area similar to those experienced in such studies, these results must be viewed with a high degree of skepticism.

Extensive research subsequently has been conducted on the long-term hypertrophic effects of nutrient timing, and the body of literature as a whole is highly equivocal: some studies show a benefit, while others do not. In an effort to achieve clarity on the topic, our lab conducted a meta-analysis of all randomized controlled trials where one group received protein within 1 hour post workout and the other group delayed consumption by at least 2 hours after completion of the exercise bout.[21] A total of 23 studies comprising 525 participants met inclusion criteria. A simple pooled analysis showed that nutrient timing, within 1 hour of workout, conferred a small but statistically significant benefit to muscle hypertrophy. This finding supports the contention that the window of opportunity for maximizing muscular adaptations following an exercise bout is fairly narrow. However, subsequent regression analysis that controlled for all covariates indicated that virtually the entire effect was explained by greater protein consumption in the nutrient-timed condition. At issue is the fact that the majority of studies gave a placebo, generally in the form of carbohydrate, to participants in the control (ie, nontimed) group. This resulted in a discrepancy of approximately 1.7 g/kg versus only 1.3 g/kg consumed in the experimental and control conditions, respectively. Given research showing that a daily protein intake of 1.6 to 2.2 g/kg is required to maximize muscular adaptations,[16] participants who received timed protein provision were necessarily at an advantage from a hypertrophy standpoint.

The meta-analysis had several limitations that must be taken into account when attempting to draw evidence-based conclusions. Specifically, only 5 studies matched protein intake; 2 showed a timing-related benefit, 3 did not. Moreover, only 2 studies that matched protein intake employed resistance-trained individuals; one showed an effect, the other did not. These issues cloud the ability to fully understand the nuances of the topic and speak to the need for additional research on the topic.

Recent Work

Recently, our laboratory endeavored to fill important gaps in the literature by conducting a study that compared pre-exercise versus postexercise nutrient timing in resistance-trained men.[20] Participants were randomized to receive a supplement containing 25 g of whey protein either immediately before or immediately after total body–resistance training. The group receiving protein immediately before exercise was instructed to refrain from eating for at least 3 hours after training to ensure that postexercise nutrition did not confound results. Similarly, the group receiving protein immediately after exercise was instructed to refrain from eating for at least 3 hours prior to training to avoid confounding from pre-exercise nutrition. Results showed no differences in measures of hypertrophy between groups over the 10-week study period. These findings indicate that any benefits of immediate postworkout nutrition are nullified when protein is consumed prior to the exercise bout.

Although protein is undeniably the most important nutrient for muscle building, some nutrient timing proponents have claimed that immediate postworkout carbohydrate consumption enhances anabolism. This is based on the premise that a postexercise "spike" in nutrient-mediated insulin levels expedites glycogen resynthesis and also has the potential to augment the MPS response by inhibiting protein breakdown. However, Greenhaff et al[5] observed a plateau in net MPS at insulin concentrations raised to 15 to 30 mU/L during a sustained elevation of amino acid availability. This degree of insulinemia is 3 to 4 times that of normal fasting levels, and is easily achieved with a typical mixed meal. Using 45 g of whey protein alone, Power et al[18] saw a 5-fold rise in insulin beyond fasting concentrations. Importantly, the proposed necessity of postexercise carbohydrate for optimizing the anabolic response has been challenged by a consistent replication of negative findings. Several acute studies have compared the effect of a robust protein dose (20-25 g) versus the coingestion of protein and carbohydrate, and all of them failed to see the additional carbohydrate augment net muscle protein accretion.[4,6,9,22] Corroborating these acute findings, a 12-week trial by Hulmi et al[7] found no difference in muscle size and strength gains via postexercise protein alone (30 g of whey) compared to coingestion with carbohydrate (34.5 g of maltodextrin).

Conclusion

Based on current evidence, it appears clear that any effect of protein timing on muscle hypertrophy, if in fact there is one, is relatively small. Total daily protein intake is by far the most important factor in promoting exercise-induced muscle development. Research indicates that consumption of 1.6 to 2.2 g/kg per day is needed to optimize results.[16] While nutrient timing potentially can be a beneficial strategy for enhancing muscular gains, the "window of opportunity" is not as narrow as often purported. Rather, the window exists on a fairly wide continuum, and its effects on muscle growth ultimately depend on when nutrients were consumed prior to the training bout. Research shows that the anabolic effects of an individual mixed meal last up to 6 hours.[12] Thus, provided that such a meal is consumed within about 3 to 4 hours prior to a workout (or possibly even longer, depending on the size of the meal), the need for immediate postexercise nutrient consumption is abated. For those who train partially or fully fasted, on the other hand, consuming protein immediately postworkout becomes increasingly more important to elicit anabolism. If one's primary training goal is to maximize muscle growth, it seems prudent to consume high-quality protein (at a dose of approximately 0.4-0.5 g/kg of lean body mass) both pre-exercise and postexercise within about 4 to 6 hours of each other, depending on meal size.

Key Points

1. Consuming protein postexercise is important for muscular adaptations, but the "window of opportunity" is not as narrow as previously proposed, as muscles are sensitized to protein intake for at least 24 hours after a training bout.
2. The immediacy for postexercise protein consumption will depend on the timing of the preworkout meal. The closer the proximity of the meal to the training bout, the less the need for immediate postworkout protein intake; if training fasted, expeditious refueling with high-quality protein is beneficial to enhance muscular adaptations.
3. To maximize muscle hypertrophy, consume high-quality protein (at a dose of approximately 0.4-0.5 g/kg of lean body mass) both pre-exercise and postexercise within about 4 to 6 hours of each other, depending on meal size.

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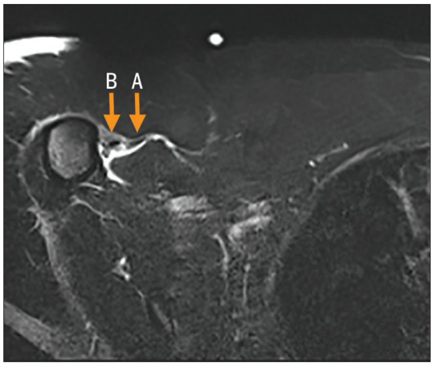

FIGURE 1. T2-weighted, fat-saturated axial magnetic resonance image of the right chest and proximal humerus, identifying a complete detachment of the right pectoralis major tendon from the humerus, with 2.5 cm of medial retraction (arrow A). Edema, highlighted by the T2 hyperintense signal, surrounds the biceps and pectoralis major tendons (arrow B).

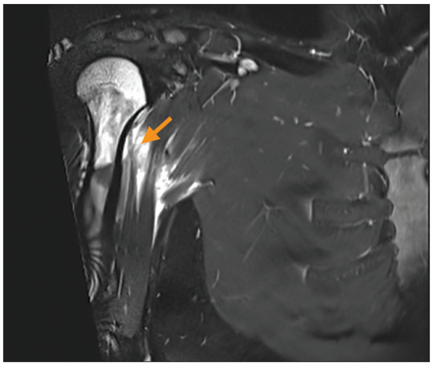

FIGURE 2. T2-weighted, fat-saturated coronal magnetic resonance image of the right chest and proximal humerus, demonstrating hemorrhage and edema in the clavicular head of the pectoralis major muscle (arrow).

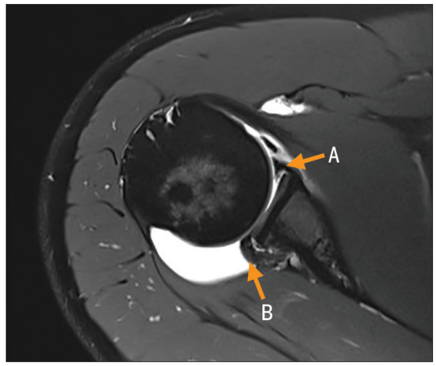

FIGURE 3. T1-weighted, fat-saturated axial magnetic resonance arthrogram of the right shoulder, demonstrating the anterior and posterior components of the near-circumferential labral tear. Arrow A represents an anterior labral tear with increased signal within the labrum. Arrow B represents a reverse Bankart fracture with periosteal stripping.

Pectoralis Major Tear and Extensive Capsulolabral Injury After Military Combatives Class

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A 26-YEAR-OLD MAN PRESENTED TO A direct-access physical therapy clinic with right shoulder pain. The pain began 1 week prior, after forceful abduction and external rotation during combatives training. The patient had 4 years of combatives experience, and reported 1 previous subluxation event in his right shoulder 2 years prior.

He presented with mild ecchymosis in his proximal bicep, mild hollowing of the axillary fold,[1] 4/5 strength with shoulder horizontal adduction and internal rotation limited by pain, and pain at end range of active horizontal abduction and external rotation. Radiographs were noncontributory. Due to suspicion of a pectoralis major tear, the patient was referred to an orthopaedic surgeon and was seen 3 days later.

The orthopaedic surgeon confirmed suspicion of a pectoralis major tear and, due to positive posterior load shift and jerk tests, clinical signs of instability. Magnetic resonance images were ordered for assessment of the pectoralis musculature, and a magnetic resonance arthrogram for the right shoulder. The magnetic resonance images confirmed complete pectoralis major tendon detachment from the humerus, with 2.5 cm of medial retraction (**FIGURES 1** and **2**). The magnetic resonance arthrogram confirmed an extensive, near-circumferential labral tear with a reverse Bankart fracture (**FIGURE 3**).

The patient underwent pectoralis reconstruction and posterior labral repair 3 weeks later. A combination of a pectoralis major reconstruction protocol and a posterior labral repair protocol was utilized for rehabilitation. The patient was placed in an immobilizer for 6 weeks, followed by a gradual progression of range of motion and strength. The patient returned to full duty 7 months after surgery.

It is important to identify pectoralis major injury, because surgical repair is recommended within the first 6 weeks after injury in the active population.[1] Key signs are swelling; hematoma to the anterior chest, axilla, and/or arm; visual change of the axillary fold; and pain and weakness with shoulder horizontal adduction and internal rotation.[1] ◉ *J Orthop Sports Phys Ther 2018;48(12):982. doi:10.2519/jospt.2018.7808*

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Psychological Readiness to Return to Sport Is Associated With Knee Kinematic Asymmetry During Gait Following Anterior Cruciate Ligament Reconstruction

Gait asymmetries following anterior cruciate ligament reconstruction (ACLR) are evident at 6 months after surgery[9] and can persist for years.[1,5,22] Quadriceps femoris strength deficits also continue after ACLR and are associated with gait deviations observed following ACLR.[19,25] Participants who have undergone ACLR demonstrate a "stiffened knee" gait pattern, characterized by reduced peak knee flexion (PKF) angles and smaller PKF moments during the stance phase of gait.[9,13]

Participants who are more successful at restoring quadriceps strength demonstrate more normal gait patterns than do participants with greater quadriceps deficits.[19,25] However, gait asymmetries can exist despite the restoration of symmetrical quadriceps strength 6 months following ACLR.[22] Therefore, other factors related to neuromuscular control, such as psychological factors, may be contributing to gait asymmetry after ACLR.

BACKGROUND: Gait asymmetry is frequently observed following anterior cruciate ligament reconstruction (ACLR). Psychological readiness to return to sport is associated with functional and activity-related outcomes after ACLR. However, the association between gait asymmetry and psychological readiness to return to sport is unknown.

OBJECTIVES: To determine the relationship between kinematic and kinetic measures of knee symmetry during gait and psychological readiness to return to sport following ACLR.

METHODS: In this controlled laboratory, cross-sectional study, 79 athletes (39 women) underwent gait analysis following impairment resolution after ACLR (ie, full range of motion, minimal or no effusion, quadriceps strength index of 80% or greater). Interlimb differences during gait were calculated for sagittal plane knee angles at initial contact, peak knee flexion, and peak knee extension, as well as for peak knee flexion moment and peak knee adduction moment. Athletes completed the Anterior Cruciate Ligament-Return to Sport after Injury scale (ACL-RSI) to assess psychological readiness to return to sport. Pearson correlations were used to examine the association between ACL-RSI score and each gait symmetry variable.

RESULTS: Significant negative correlations were observed between the ACL-RSI and 2 kinematic variables: knee flexion angle at initial contact (r = −0.281, P = .012) and peak knee flexion (r = −0.248, P = .027). In general, lower scores on the ACL-RSI were associated with greater interlimb asymmetry.

CONCLUSION: There was a weak association between psychological readiness to return to sport and knee kinematic asymmetry during gait.
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KEY WORDS: *anterior cruciate ligament reconstruction, gait biomechanics, psychological factors*

Psychological factors are related to functional and activity-related outcomes following ACLR.[3,4,16] Studies have examined multiple psychological factors, such as fear of reinjury, fear of movement, self-efficacy, confidence, and psychological readiness to return to sport.[4,6,16,17,23,27] Fear of movement and fear of reinjury decrease during the course of postoperative rehabilitation and are associated with function at the time when athletes return to sport.[6] In addition, changes in fear of movement/reinjury and self-efficacy in rehabilitation tasks predict change in function during the course of postoperative rehabilitation.[7]

From an activity-related outcomes perspective, fear of reinjury is one of the most commonly cited reasons for

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not returning to sport.[3,7] Psychological readiness to return to sport (a construct that encompasses emotions, confidence, and risk appraisal) prior to surgery and 4 months following ACLR predicts preinjury sport-level status 1 year after surgery.[4] Furthermore, athletes who return to their preinjury level of sports 1 year following ACLR have lower levels of fear of reinjury and movement.[18]

Even though kinematic and/or kinetic asymmetries persist following ACLR and psychological factors affect ACLR outcomes, no published studies have examined the association between biomechanical asymmetry and various psychological factors. The Anterior Cruciate Ligament-Return to Sport after Injury scale (ACL-RSI) measures psychological readiness to return to sport with questions regarding emotions, confidence, and risk appraisal. The purpose of this study was to determine whether a relationship exists between the ACL-RSI and kinematic and kinetic measures of knee symmetry during gait in patients who have undergone ACLR. The researchers hypothesized that lower scores on the ACL-RSI would be associated with greater kinematic and kinetic asymmetry at the knee during overground walking.

METHODS

Participants

Seventy-nine athletes between 13 and 55 years of age, who regularly participated in cutting, pivoting, and jumping sports (greater than 50 hours per year), were included in this secondary analysis of a prospective clinical trial (parent study registered at CinicalTrials.gov as NCT01773317). All athletes underwent primary ACLR, completed postoperative rehabilitation, and met the following criteria prior to enrollment: full knee range of motion, minimal or no effusion, quadriceps strength index of 80% or greater, and initiation of a running progression without increased symptoms. Exclusion criteria included grade 3 concomitant ligament injury, full-thickness articular cartilage lesions greater than 1 cm^2, prior anterior cruciate ligament injury, or significant previous lower extremity injury. At enrollment, all participants completed gait analysis and the ACL-RSI. This study was approved by the Institutional Review Board at the University of Delaware, and written informed consent was acquired prior to inclusion.

Gait Analysis

Kinematic and kinetic data were collected during overground walking. Eight infrared cameras (Vicon; Oxford Metrics Ltd, Yarnton, UK) were used to detect retroreflective markers attached to the base of the first and fifth metatarsals, the medial and lateral malleoli, superior and inferior heels, medial and lateral epicondyles of the femurs, greater trochanters, and the midline of the iliac crests. Rigid thermoplastic shells with retroreflective markers were attached to the thigh, shank, and pelvis. Excellent intersession reliability has been established using this marker set.[8] Kinetic data were collected using an embedded force plate within the walkway (Bertec Corporation, Columbus, OH). Kinematic and kinetic data were sampled at 120 and 1080 Hz, respectively.

Participants walked at a self-selected speed, maintained to within ±5% of the first usable trial, along a 6-m walkway over the force plate. Five trials for each limb were collected. Stance-phase joint angles and moments were calculated using rigid-body analysis and inverse dynamics equations, respectively (Visual3D; C-Motion, Inc, Germantown, MD). Kinematic and kinetic data were low-pass filtered (6 Hz and 40 Hz, respectively). Initial contact (IC) and toe-off were defined by a 50-N threshold, as determined from the force plate. All trials were normalized to 100% of stance. Moment data were normalized by mass (kilograms) and height (meters).

Kinematic variables of interest included sagittal plane knee joint angles at IC, PKF during weight acceptance, and peak knee extension during stance. Kinetic variables of interest included peak knee adduction moment and PKF moment during stance. Interlimb differences for each kinematic and kinetic variable were calculated for analysis by subtracting the value of the surgical limb from that of the nonsurgical limb, so that a positive difference would be indicative of a lower value for the surgical limb.

Self-reported Psychological Measure

The ACL-RSI includes 12 questions and measures an athlete's psychological readiness to return to sport, which encompasses emotions (including fear of reinjury), confidence, and risk appraisal.[15,28] The ACL-RSI is scored on a scale from 0 to 100, with a score of 0 indicating an extremely negative psychological response (ie, more fear of reinjury, less confidence).[28] The ACL-RSI has good face validity, good internal consistency, high construct validity, and high test-retest reliability.[15]

Statistical Analysis

Pearson product-moment correlations were used to evaluate the association between ACL-RSI score and each symmetry variable of interest. When significant correlations were found, a secondary analysis was performed to provide greater clinical context. For this secondary analysis, participants were split into 3 groups by their respective ACL-RSI scores. Based on the median ACL-RSI score, the lowest 25% of scores were allocated to the low ACL-RSI score group, the middle 50% to the middle ACL-RSI score group, and the highest 25% to the high ACL-RSI score group. A 2-by-3 (limb by group) mixed-model analysis of variance was used to compare limb differences among the 3 groups. Raw kinematic and kinetic values were used for this analysis, rather than interlimb differences. When significant interactions were found, post hoc *t* tests with Bonferroni correction were used to examine limb differences within each group. Statistical significance was set at $P \leq .05$.

RESULTS

Correlation Analyses

Significant associations were found between ACL-RSI score and 2 kinematic symmetry variables: knee flexion angle at IC (r = −0.281, P = .012) (**FIGURE** part **A**) and PKF (r = −0.248, P = .027) (**FIGURE** part **B**). There were no associations between ACL-RSI score and peak knee extension (r = −0.096, P = .398), PKF moment (r = 0.114, P = .318), or peak knee adduction moment (r = 0.109, P = .340).

Group Analysis

The median ACL-RSI score was 61. Nineteen participants made up the low ACL-RSI group (ACL-RSI score of 47 or less; mean ± SD, 34 ± 11), 40 the middle ACL-RSI group (ACL-RSI score between 48 and 78; mean ± SD, 62 ± 9.0), and 20 the high ACL-RSI group (ACL-RSI score of 79 or greater; mean ± SD, 90 ± 6.0). There were no group differences in age (P = .745), sex (P = .538), body mass index (P = .844), or weeks from surgery to enrollment (P = .923) (**TABLE 1**).

Significant limb-by-group interactions were found for knee flexion angle at IC (P = .009) and PKF (P = .002) (**TABLE 2**). Post hoc analysis revealed that at IC, the low group displayed significantly less knee flexion in the surgical limb compared to the nonsurgical limb (2.4°), while the middle and high groups did not display interlimb differences. At PKF, low, middle, and high groups all displayed significantly less PKF in the surgical limb compared to the nonsurgical limb (7.1°, 2.4°, and 3.3°, respectively).

DISCUSSION

The purpose of this study was to examine the relationship between psychological readiness to return to sport and kinematic and kinetic measures of knee symmetry during gait in patients who have undergone ACLR. A weak but significant relationship was found between ACL-RSI score and 2 of the 3 knee kinematic variables evaluated. Less than 10% of the variance in both knee flexion angle at IC and PKF was explained by the ACL-RSI scores (knee flexion angle at IC, R^2 = 0.079; PKF, R^2 = 0.062). No relationships were found for the knee kinetic variables of interest. Additionally, patients with the lowest ACL-RSI scores (low group) exhibited the greatest side-to-side sagittal plane kinematic differences when compared to athletes in the middle and high groups.

The athletes in the low ACL-RSI group exhibited greater side-to-side differences in knee kinematics, as characterized by less knee flexion in the surgical limb at both IC and PKF compared to the nonsurgical limb. By contrast, the middle and high groups were relatively symmetrical. While the low group's between-limb differences for knee flexion at IC and PKF were statistically significant, only its interlimb difference at PKF exceeded the minimal clinically important difference (MCID) of 3°.[10]

As such, the clinical relevance of these findings could be questioned. However, 2 previous studies found similar results when analyzing group differences in knee angle at IC.[9,24] Di Stasi and colleagues[9] compared knee angles at IC between athletes who passed return-to-sport functional testing and athletes who failed return-to-sport testing. The athletes who failed return-to-sport testing at 6 months following ACLR displayed less knee flexion at IC (mean interlimb difference, 2.2°) in the surgical limb compared to the nonsurgical limb. In contrast, the group that passed return-to-sport testing was symmetrical.

Rudolph and colleagues[23] compared knee flexion angles at IC between anterior cruciate ligament–deficient athletes classified as copers and athletes classified as noncopers. The copers from this cohort successfully returned to sport, while the noncopers did not return to sport and reported instability with activities of daily living. Noncopers demonstrated less knee flexion in the surgical limb at IC

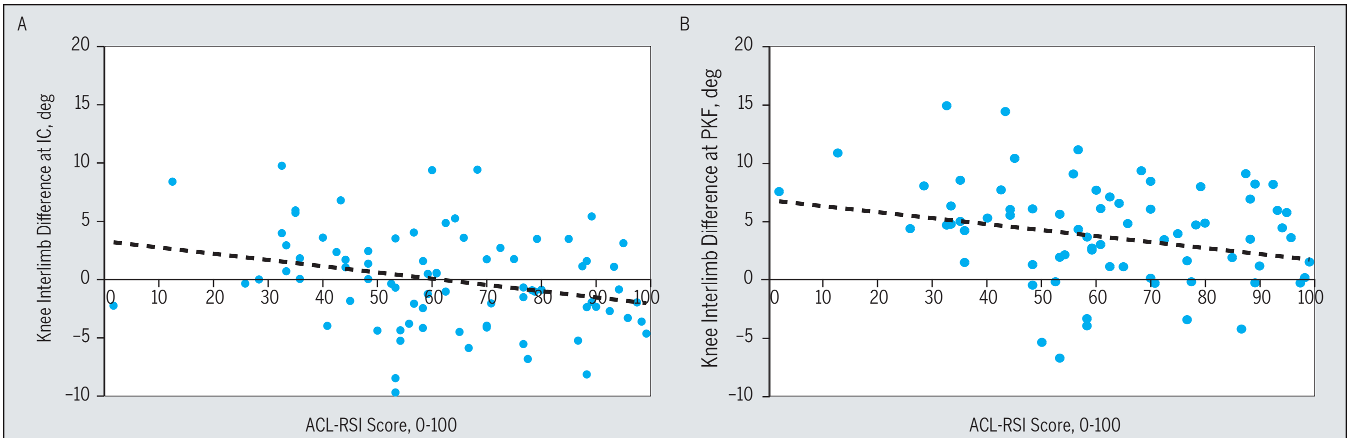

FIGURE. (A) Relationship between ACL-RSI score and PKF angle at IC symmetry. Positive values on the y-axis indicate less knee flexion in the surgical limb. (B) Relationship between ACL-RSI score and PKF angle at PKF symmetry. Positive values on the y-axis indicate less knee flexion in the surgical limb. Abbreviations: ACL-RSI, Anterior Cruciate Ligament-Return to Sport after Injury scale; IC, initial contact; PKF, peak knee flexion.

compared to the nonsurgical limb during walking and jogging. Copers were symmetrical at IC. At PKF, the low group's interlimb difference (7° less in the surgical limb) in knee flexion angle exceeded the MCID. The middle group's interlimb difference at PKF did not exceed the MCID, while the high group's was approximately at the MCID. Reduced PKF also was found in athletes who failed return-to-sport testing 6 months after ACLR,[21] and in noncopers after ACL injury.[24] Therefore, the low group's sagittal plane knee kinematics from the present study are similar to those of athletes who fail return-to-sport testing as well as noncopers.

From an individual perspective, interlimb differences beyond the MCID were present in both directions at IC and PKF, as evident in the **FIGURE**. At IC, approximately half of the cohort (n = 37) displayed an interlimb difference that exceeded the MCID, while the remainder did not (n = 42). Of the 37 participants who demonstrated interlimb differences at IC, 18 patients had less knee flexion in the surgical (versus nonsurgical) limb, while 19 had more knee flexion in the surgical limb. At PKF, 53 patients demonstrated an interlimb difference that exceeded the MCID, with the majority of these patients (n = 46, 87%) demonstrating less knee flexion in the surgical limb. The low ACL-RSI group had the highest percentage of patients who demonstrated less knee flexion in the surgical limb at both IC (37%) and PKF (89%), compared to the middle group (IC, 18%; PKF, 45%) and high group (IC, 20%; PKF, 55%).

No relationships were found between the kinetic symmetry variables of interest and psychological readiness to return to sport. A recent systematic review and meta-analysis found strong evidence that PKF moments are reduced following ACLR compared to the contralateral limb and healthy controls, and remain lower for up to 6 years.[13] Additionally, athletes with quadriceps strength deficits demonstrate lower external knee flexion moments in the surgical limb during gait and a drop vertical jump.[19,24] All athletes in the present study had adequate quadriceps strength (ie, quadriceps strength index of 80% or greater). The present cohort's homogeneity in quadriceps strength may have contributed to the lack of group differences in the kinetic symmetry variables.

The prevalence of knee osteoarthritis (OA) after ACLR is high, with a recent systematic review indicating that 44% of patients develop OA following ACLR.[20] Altered biomechanics have been implicated as a factor contributing to the increased risk of OA.[2,12] A recent study found that asymmetrical loading (ie, underloading the surgical limb) during gait early after anterior cruciate ligament injury and 6 months after ACLR was associated with radiographic signs of OA 5 years after surgery.[29] Additionally, altered kinematics with normal loads may contribute to OA risk development by loading structures that are not conditioned to withstand forces.[14] A reduction of knee flexion during weight acceptance shifts loads to the anterior surface of the medial compartment of the knee.[30] The change in contact location may contribute to degenerative changes in cartilage.[14] The group with low ACL-RSI scores from the present study demonstrated less knee

TABLE 1 PARTICIPANT DEMOGRAPHICS FOR SUBGROUP ANALYSIS*

Variable	Group: Low ACL-RSI Score (n = 19)	Middle ACL-RSI Score (n = 40)	High ACL-RSI Score (n = 20)	*P* Value
Age, y	22.3 ± 6.5	20.7 ± 7.7	21.0 ± 8.7	.745
Sex, n				.538
Women	9	22	8	
Men	10	18	12	
Body mass index, kg/m²	25.9 ± 4.0	26.3 ± 3.3	25.9 ± 3.0	.844
Time from surgery to enrollment, wk	24.1 ± 8.8	23.3 ± 7.1	23.3 ± 9.2	.923

Values are mean ± SD unless otherwise indicated.

TABLE 2 LIMB-BY-GROUP INTERACTIONS*

Biomechanical Variable/Group	Surgical Limb	Nonsurgical Limb	Interlimb Difference	*P* Value†
Knee flexion angle at IC, deg‡				
Low ACL-RSI (n = 19)	6.1 (4.4, 7.7)	8.5 (6.8, 10.3)	2.4 (0.7, 4.2)	.008
Middle ACL-RSI (n = 40)	7.3 (6.2, 8.5)	6.6 (5.4, 7.8)	−0.7 (−2.0, 0.5)	.225
High ACL-RSI (n = 20)	7.4 (5.8, 9.0)	6.3 (4.7, 8.2)	−1.1 (−2.7, 0.8)	.263
Knee flexion angle at PKF, deg§				
Low ACL-RSI (n = 19)	18.9 (16.4, 21.6)	26.0 (24.0, 27.9)	7.1 (4.9, 9.2)	<.001‖
Middle ACL-RSI (n = 40)	20.5 (18.7, 22.3)	22.9 (21.4, 24.4)	2.4 (1.0, 3.7)	.001
High ACL-RSI (n = 20)	21.3 (18.8, 23.9)	24.6 (22.5, 26.7)	3.3 (1.4, 5.2)	.001‖

Abbreviations: ACL-RSI, Anterior Cruciate Ligament-Return to Sport after Injury scale; IC, initial contact; PKF, peak knee flexion.
**Values are mean (95% confidence interval).*
†Post hoc t tests with Bonferroni correction to examine interlimb differences in each group.
‡Significant limb-by-group interaction (P = .009).
§Significant limb-by-group interaction (P = .002).
‖Interlimb difference exceeded minimal clinically important difference of 3°.

flexion in the surgical limb and, therefore, may be at greater risk for knee OA. However, future research is needed to support this premise.

Quadriceps femoris muscle weakness is common after ACLR.[11,21] Studies have examined the relationship between quadriceps strength and gait biomechanics, with mixed findings. Two studies found a relationship between quadriceps strength and gait symmetry, indicating that better quadriceps strength contributes to better symmetry.[19,25] Conversely, Gokeler et al[11] found no correlation between quadriceps strength and gait analysis parameters. Roewer et al[22] found that gait asymmetries were present during weight acceptance, despite restoration of quadriceps strength. As noted above, this cohort had to demonstrate adequate (80% or greater on the quadriceps strength index) quadriceps strength prior to enrollment. These findings, therefore, suggest that gait asymmetries are present in athletes with low ACL-RSI scores, even among athletes with adequate quadriceps strength.

There are limitations to this study. The study design was cross-sectional in nature; thus, the authors are unable to determine cause and effect. Future research should determine whether specific interventions directed at psychological factors lead to improvements in gait asymmetry after ACLR, or vice versa. A second limitation is that the researchers formed groups based on quartiles of the subjects' ACL-RSI scores. Using a different method to divide the cohort into groups could affect the findings. However, the group analysis allowed the researchers to provide greater context to these findings.

CONCLUSION

The results of this study indicate that there is a weak relationship between psychological readiness to return to sport and sagittal knee kinematics during gait in athletes attempting to return to sport after ACLR. Lower ACL-RSI scores were associated with greater interlimb knee kinematic differences at IC and PKF. However, less than 10% of the variance in interlimb knee kinematic differences could be explained by the ACL-RSI score. Future research should determine whether other psychological factors contribute to asymmetrical gait following ACLR, including kinesiophobia, self-efficacy, and motivation. Future research also should elucidate the relationship between psychological factors and movement to determine whether addressing psychological factors leads to improved symmetry, or whether addressing gait asymmetries leads to changes in psychological factors. ◉

KEY POINTS

FINDINGS: A weak relationship was found between psychological readiness to return to sport and interlimb knee kinematic differences during gait. Lower scores on the Anterior Cruciate Ligament-Return to Sport after Injury scale (ACL-RSI) were associated with greater knee interlimb differences.

IMPLICATIONS: The ACL-RSI, a tool to evaluate psychological readiness to return to sport, may provide insight into asymmetrical movement following anterior cruciate ligament reconstruction.

CAUTION: This was a cross-sectional study. The authors, therefore, are unable to determine cause and effect between psychological readiness to return to sport and kinematic gait asymmetry.

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